IWGO

International Working Group on Ostrinia and other maize pests

27th IWGO Conference

14 to 17 October 2019

Hotel Bellevue Terminus

Engelberg, Switzerland

The International Working Group on *Ostrinia* and other Maize Pests (IWGO)
is a Working Group of the International Organization of Biological Control – Global (IOBC - Global)

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Dr Ulrich Kuhlmann (Convenor)
CABI
Rue des Grillons 1, 2800 Delémont, Switzerland
u.kuhlmann@cabi.org

Dr Zhenying Wang (Co-Convenor)
Institute of Plant Protection, Chinese Academy of Agricultural Sciences
No.2 West Yuan Ming Yuan Road, Beijing 100193, P.R. China
zywang@ippcaas.cn

Dr Tom Sappington (Co-Convenor)
USDA-ARS, Corn Insects & Crop Genetics Research Unit Genetics Laboratory, ISU
Ames, Iowa, U.S.A.
Tom.Sappington@ars.usda.gov

SCIENTIFIC SESSION ORGANIZERS

Dr Tom Sappington, USDA-ARS, Ames, Iowa, U.S.A.
Dr Sally Taylor, Virginia Tech University, Blacksburg, Virginia, U.S.A.
Dr William Hutchison, University of Minnesota, St. Paul, Minnesota, U.S.A.
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SCIENTIFIC PROGRAMME*

27th IWGO Conference

*Please note that only the name of the presenting author is provided in the IOBC Global IWGO scientific programme

SCIENTIFIC PROGRAMME

Sunday, 13 October 2019

17:00 ***Registration, Lobby, Hotel Bellevue Terminus***

- *Provision of PowerPoint Oral Presentations on USB stick*

19:00 ***Welcome Reception & Dinner, Hotel Bellevue Terminus***

- *Welcome Remarks, Ulli Kuhlmann, IWGO-IOBC-Global Convenor*

Monday, 14 October 2019

07:45 ***Registration & Drop-off Point Posters, Hotel Bellevue Terminus***

08:30 ***Welcome Addresses – Hotel Bellevue Terminus***

- *Welcome Address, IWGO-IOBC-Global Convenors*

09:00 ***Scientific Session 1***

Scientific Session 1: Neonicotinoid seed treatments in maize: how important to seedling pest management?

Session Organizers: Tom Sappington, USDA-ARS, Ames, Iowa, U.S.A. & Sally Taylor, Virginia Tech University, Blacksburg, Virginia, U.S.A.

09:00	Tom Sappington & Sally Taylor	Introduction
09:05	Lars Straub	Neonicotinoids in maize: bee health and the EU moratorium
09:25	Jocelyn Smith	The role of neonicotinoid seed treatments to manage early season corn pests in Ontario, Canada
09:45	Keri Carstens *presented by Clinton Pilcher*	Insecticide seed treatments – a tool to meet farmers' needs
10:05	Anders Huseth	Insecticide resistance implications of widespread neonicotinoid use in field crops
10:25	Sally Taylor	Neonicotinoid insecticides on *Bt* seed – balancing contributions to crop protection, resistance management, and environmental residues

10:45 ***Coffee/Tea Break & Posters***

11:15 *Scientific Session 2a*

Scientific Session 2a: *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Session Organizers: William Hutchison, University of Minnesota, St. Paul, Minnesota, U.S.A. & Michael Meissle, Agroscope, Zurich, Switzerland

11:15	William Hutchison & Michael Meissle	Introduction
11:20	Michael Meissle	*Bt* maize within a changing IPM paradigm
11:40	Gema P. Farinós	Success with *Bt* maize for corn borers in Spain: farmer views, 20 years of resistance monitoring and challenges
12:00	Johnnie van den Berg	Factors that contribute to management of resistance evolution in pests of *Bt* maize in African small holder farming systems
12:20	William Hutchison	Success with *Bt* maize for European corn borer in the U.S.: benefits of areawide pest suppression in maize and surrounding non-*Bt* crops
12:40	Galen Dively	Sweet corn sentinel network for monitoring lepidopteran resistance to *Bt* traits

13:00 *Lunch Break*

14:00 *Scientific Session 2b*

Scientific Session 2b: *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Session Organizers: William Hutchison, University of Minnesota, St. Paul, Minnesota, U.S.A. & Michael Meissle, Agroscope, Zurich, Switzerland

14:00	William Hutchison & Michael Meissle	Introduction
14:05	Francis Reay-Jones	Challenges for managing *Helicoverpa zea* with *Bt* maize in the southeastern United States
14:25	Art Schaafsma	The first case of field failure of *Bt* corn to control European corn borer *Ostrinia nubilalis* (Lepidoptera: Crambidae) discovered in Nova Scotia, Canada
14:45	Amit Sethi	First report of European corn borer resistance against Cry1F in Nova Scotia, Canada
15:05	Hongqiang Feng	Evaluation of susceptibility in multiple lepidopteran pests to major toxins expressed by *Bt* corn

15:25 *Coffee/Tea Break & Posters*

16:00 ***Scientific Session 3***

Scientific Session 3: Emerging lepidopteran challenges in the maize agro-ecosystem

Session Organizers: Silvana Paula-Moraes, University of Florida, Jay, Florida, U.S.A.; Zhenying Wang, Chinese Academy of Agricultural Sciences, Beijing, China & Richard Hellmich, USDA-ARS, Ames, Iowa, U.S.A.

16:00	Silvana Paula-Moraes, Zhenying Wang & Richard Hellmich	Introduction
16:05	Richard Hellmich	Challenges with landscapes dominated with genetically engineered crops
16:25	Matilde Eizaguirre	Development of caterpillars with low susceptibility to *Bt* on diets enriched with vitamins
16:45	Zhenying Wang	Fall armyworm, *Spodoptera frugiperda*, spread quickly northward threaten the corn production in China
17:05	Eliseu Pereira	Challenges and management efforts of fall armyworm in Brazil
17:25	Silvana V. Paula-Moraes	Noctuids associated with maize in tropical and temperate areas: updates and what we still need to learn
17:45	Inoussa Sanané	Plant-insect relationship: trade-off between growth and defence

18:05 ***End of Day 1***

19:30 ***Social Event Proposal (booking in hotel required)***

Tuesday, 15 October 2019

08:00 ***Scientific Session 4***

Scientific Session 4: Environmentally friendly management of rootworms, wireworms and other soil pests in maize

Session Organizers: Renata Bazok, University of Zagreb, Zagreb, Croatia; Mario Schumann, KWS Saat SE, Einbeck, Germany & Stefan Toepfer, CABI, Hodmezovasarhely, Hungary

08:00	Renata Bazok, Mario Schumann & Stefan Toepfer	Introduction
08:05	Jaka Razinger	*Pleurotus aegerolysin* proteins are selectively toxic to western corn rootworm (*Diabrotica v. virgifera*) and Colorado potato beetle (*Leptinotarsa decemlineata*)
08:25	Špela Modic	Field efficacy evaluation of *Heterorhabditis bacteriophora* Poinar (Rhabditida: Heterorhabditidae) and synthetic insecticides for control of western corn rootworm larvae
08:45	Antoine Pasquier	From proof of concept to optimization: the use of soil-dwelling predatory mites to control western corn rootworm population
09:05	Szabolcs Toth	Factors influencing the efficacy of soil insecticides and entomopathogenic nematodes at reducing the maize pest *Diabrotica v. virgifera* (Coleoptera: Chrysomelidae) under field conditions

09:25 ***Coffee/Tea Break***

10:00 ***Scientific Session 5***

Scientific Session 5: Sustainable non-chemical methods for fall armyworm control

Session Organizers: Dirk Babendreier, CABI, Delémont, Switzerland & Malick Ba, ICRISAT, Niamey, Niger

10:00	Dirk Babendreier & Malick Ba	Introduction
10:05	Melanie Bateman	Assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa
10:25	Felix Dubach	Controlling fall armyworm with the use of baculoviruses and fungi
10:45	Anani Bruce	Native genetic resistance to fall armyworm in Africa: breeding progress by CIMMYT and prospects
11:05	Dirk Babendreier	Prospects for biopesticides and local farmer's methods to achieve sustainable control of fall armyworm
11:25	Sevgan Subramanian *presented by Girma Hailu*	Development of entomopathogenic fungi-based biopesticides for the management of the invasive fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), in Africa
11:45	Lapko Koku Agboyi *presented by Marc Kenis*	Parasitism of *Spodoptera frugiperda* in Ghana, West Africa
12:05	Shachi Gurumayum	Evaluation and registration trials of Fawligen, a baculovirus-based biological control for fall armyworm, in Africa and South Asia

12:25 ***Lunch Break***

13:30 ***Scientific Session 6***

Scientific Session 6: Advances in the development of biological control solutions for the management of fall armyworm

Session Organizers: Komi Kouma Mokpokpo Fiaboe, IITA, Yaoundé, Cameroon & Girma Hailu, ICEPE, Nairobi, Kenya

13:30	Komi Kouma Mokpokpo Fiaboe & Girma Hailu	Introduction
13:35	Malik Ba	Effectiveness of locally recruited egg parasitoids for biological control of the fall armyworm in the Sahel
13.55	Léna Durocher-Granger	Natural enemy complex of the fall armyworm on maize in South-Eastern Zambia
14:15	Patrick Fallet	Novel approaches to control the fall armyworm with entomopathogenic nematodes
14:35	Jincheng Zhou	Biological control characteristics of the egg parasitoid *Trichogramma pretiosum* (Hymenoptera, Trichogrammatidae) against the new invasive pest, fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), in China
14:55	Marc Kenis	Prospects for the classical biological control of *Spodoptera frugiperda* in Africa and Asia using parasitoids from the Americas
15:15	Samira A. Mohamed *presented by Girma Hailu*	Alien invasive *Spodoptera frugiperda* in Africa encounter indigenous natural enemies: new parasitoid host association

15:35 ***Coffee/Tea Break***

16:05 ***Scientific Session 7***

Scientific Session 7: Addressing a significant food security threat: *Spodoptera frugiperda* invading new geographies

Session Organizers: Clinton D. Pilcher, Corteva Agriscience, Johnston, Iowa, U.S.A.; Analiza Piovesan Alves, Corteva Agriscience, Johnston, Iowa, U.S.A. & Marlin Rice, Corteva Agriscience, Johnston, Iowa, U.S.A.

16:05	Clinton D. Pilcher, Analiza P. Alves & Marlin Rice	Introduction
16:10	Clinton D. Pilcher	Industry's role in collaborating with key stakeholders to manage food security threats like *Spodoptera frugiperda*
16:30	Nicholas Miller	MIPs for moths
16:50	Li Xijie	The crop resources in China and ecological consequences of fall armyworm invasion
17:10	Analiza Piovesan Alves	*Spodoptera frugiperda* management in South America – past, present and future
17:30	Fangneng Huang	Resistance of insect pests to *Bt* crops: implications for fall armyworm management in Asia and Africa
17:50	Marlin Rice	Fall armyworm management through educational training: an industry perspective

18:10 ***End of Day 2***

19:30 ***Social Event Proposal (booking in hotel required)***

Wednesday, 16 October 2019

08:30 ***Scientific Session 8***

Scientific Session 8: Field-evolved insecticide resistance in maize pests

Session Organizers: Julie Peterson, University of Nebraska, North Platte, Nebraska, U.S.A. & Brad Coates, USDA-ARS, Ames, Iowa, U.S.A.

08:30	Julie Peterson & Brad Coates	Introduction
08:40	Marcé D. Lorenzen	Can CRISPR mutations mimic field-evolved resistance?
09:00	Juan Luis Jurat-Fuentes	Mechanisms, frequency and dispersal of resistance to transgenic corn in fall armyworm (*Spodoptera frugiperda*)
09:20	Julie A. Peterson	*Bacillus thuringiensis* resistance in western bean cutworm populations and the influence of refuge structure and larval movement
09:40	Dominic Reisig	The interwoven impacts of *Bt* maize, *Bt* cotton, and soybean on *Helicoverpa zea* in the United States

10:00 ***Coffee/Tea Break***

10:30 ***Scientific Session 9***

Scientific Session 9: The use of emerging technologies in maize pest surveillance, reporting and forecasting

Session Organizers: Katarina Mikac, University of Wollongong, New South Wales, Australia; Renata Bazok, University of Zagreb, Zagreb, Croatia & Darija Lemic, University of Zagreb, Zagreb, Croatia

10:30	Katarina Mikac, Renata Bazok & Darija Lemic	Introduction
10:35	James Bell	Smart Armyworm Surveillance
10:55	Michael Caprio	Studying the behavioral ecology of insects in the field using multiple video cameras to produce 3-d tracks for quantification of flight behavior
11:15	Fruzsina Enikő Sári-Barnácz	Use of spectral remote-sensing methods for *H. armigera* detection in maize

11:35 ***Poster Session***

12:30 ***Lunch Break***

13:30 ***Scientific Session 10***

Scientific Session 10: Free topics

Session Organizers: Benedikt Kurtz, Syngenta Crop Protection Münchwilen AG, Stein, Switzerland & Hongmei Li, CABI, Beijing, China

13:30	Benedikt Kurtz & Hongmei Li	Introduction
13:35	Yueqin Wang	Development of resistance to *Bt* toxins in *Ostrinia furnacalis* under spatiotemporal alternation scenery of multiple single-gene events
13:55	Kanglai He	Development of resistance to *Bt* toxins in Oriental armyworm
14:15	Guoping Li	Baselines susceptibility establishment and development of diagnostic concentrations of Asian corn borer (Lepidoptera: Crambidae) populations to Cry1 from Huanghuaihai summer corn region in China
14:35	Yutao Xiao	Molecular identification of invasive fall armyworm *Spodoptera frugiperda* in Yunnan province
14:55	Baoping Zhai	Migration processes and patterns of fall armyworm in China: comparative perspectives on migration arena in the New World and East Asia

15:15 ***Coffee/Tea Break***

15:45 ***IWGO Business Meeting***

16:30 ***End of Day 3***

17:00 ***Farewell Dinner Restaurant Ristis (optional booking required)***

Thursday, 17 October 2019

10:00 ***Excursion (optional booking required; description of excursion please refer to www.iwgo.org)***

10:00 Meeting in the lobby of the Hotel Bellevue Terminus

18:00 Arrival Hotel

18:00 ***End Excursion***

POSTER PRESENTATIONS

Poster 01	James Bell	Corn borer cycles, the response of farmers to outbreaks and the adoption of transgenic crops
Poster 02	Renata Bažok	Factors influencing first generation European corn borer abundance and damages
Poster 03	Xue Chang	Newly found maize insect pest *Amphipoea burrowsi* Chapman, in Jilin, the northeast province of China
Poster 04	Stefan Toepfer	How to use entomopathogenic nematodes against the root-damaging *Diabrotica* larvae in maize?
Poster 05	Fruzsina Enikő Sári-Barnácz	Do we need to worry about WCR adult silk clipping in sweet maize?
Poster 06	Hongmei Li	110 years research on the fall armyworm: where we are?
Poster 07	Zhenying Wang	Integrated deciphering of *Ostrinia furnacalis*-induced maize defense: dynamic profiling of phytohormones, benzoxazinoids, volatiles and gene transcripts elicited by *Ostrinia furnacalis* attack
Poster 08	Edimon Cheruiyot	Promoting food security: developing a predictive model for fall armyworm (*Spodoptera frugiperda*) intervention in Kenya, East Africa
Poster 09	Edimon Cheruiyot	Fall armyworm (*Spodoptera frugiperda*) growth and development as driven by temperature
Poster 10	Katarina Mikac	Modelling western corn rootworm wing structure and wing shape differences based on crop resistance using finite element analysis
Poster 11	Darija Lemic	Two decades of invasive western corn rootworm surveillance in Croatia
Poster 12	Stefan Toepfer	Simplifying damage rating scales for fall armyworm in maize
Poster 13	Szabolcs Toth	Diapause and hatching patterns of *Diabrotica v. virgifera* (Coleoptera: Chrysomelidae) to better plan experimentation with neonate larvae
Poster 14	Benedikt Kurtz	Tracking wireworm burrowing behaviour in soil over time using 3D X-ray Computed Tomography
Poster 15	Benedikt Kurtz	Lambda-cyhalothrin as a model compound to study the effect of insecticide placement on western corn rootworm larvae behavior's
Poster 16	Yee Yee Myint	Identification of *Trichogramma*, an egg parasitoid on *Ostrinia furnacalis* (Lepidoptera: Crambidae) in eastern Myanmar
Poster 17	Brad Coates	A draft genome sequence assembly for the western corn rootworm, *Diabrotica virgifera virgifera*
Poster 18	Tom Sappington	Migratory behavior of *Ostrinia nubilalis* and *Diabrotica virgifera virgifera* inside their year-round range: not about tracking host crops or escaping winter

ABSTRACTS
ORAL
PRESENTATIONS

Neonicotinoids in maize: bee health and the EU moratorium

Lars Straub[1]

[1]*Institute of Bee Health, Vetsuisse Department, University of Bern, Bern, Switzerland*

Bees provide a key ecosystem service that is essential for both human food security and maintenance of natural plant biodiversity. However, increasing evidence and reports of declines of numerous wild bee species and unsustainably high annual losses of managed honey bee colonies, *Apis mellifera*, have caused for much concern. It is thought that a wide array of interacting stressors play a key role in this phenomenon. In particular, a specific class of neurotoxic insecticides, neonicotinoids, have recently triggered a vehement debate on their potential role as a significant contributor to wild bee declines and honey bee colony losses. Based upon numerous prominent studies revealing negative effects caused by neonicotinoids, the European Union (EU) implemented a moratorium in 2013 on the use of three neonicotinoid insecticide seed dressings for mass-flowering crops that appeal to honey bees and other pollinators insects. During the implementation of this moratorium, the EU foresaw to review new scientific information evaluating the risk of these insecticides and to then take a decision of whether to lift, maintain or adjust a full ban. Despite overwhelming evidence of sublethal effects of neonicotinoid insecticides, our understanding until today on how these insecticides affect bees and other insect pollinators in practice is still limited. Insufficient data on wild bees and variable data on honey bees between countries and time are yet to enable any meaningful conclusions on the role of neonicotinoid insecticides alone. It is self-evident that the use of insecticides for agricultural pest control purposes represent a risk to bees, yet, in light of the numerous other environmental factors governing declines and losses of bees, separating the effects of neonicotinoids from the rest is extremely challenging if not impossible. In conclusion, the precautionary principle should be applied and future efforts should aim to develop a new generation of pest species-specific insecticides.

Session 1-T 2 - Neonicotinoid seed treatments in maize: how important to seedling pest management?

The role of neonicotinoid seed treatments to manage early season corn pests in Ontario, Canada

Jocelyn Smith[1] & Arthur Schaafsma[1]

[1]*University of Guelph, Ridgetown, Canada*

A multi-year study was conducted to characterize the value of neonicotinoid seed treatments in commercial corn and soybean production in Ontario, Canada. The objectives of this study were to evaluate the effects of neonicotinoid seed treatments on plant stand, plant vigor, insect injury, and grain yield under a range of corn and soybean production conditions. To allow the correlation of any observed effects on crop growth and yield with pest densities, these trials were also used to determine the incidence of early season soil insect pests of corn and soybeans in Ontario. Over four years, approximately 130 corn and 30 soybean replicated on-farm trials were evaluated with the cooperation of Ontario grain producers.

Session 1-T 3 - Neonicotinoid seed treatments in maize: how important to seedling pest management?

Insecticide seed treatments – a tool to meet farmers' needs

Keri Carstens[1] & Clint Pilcher[1]

[1]*Corteva Agriscience, Johnston, U.S.A.*

Humans have used substances to coat or treat seeds for millennia, as we recognized the need to protect seeds and seedlings from pests and diseases. Modern seed treatments include pesticides and biologicals specifically designed to protect seeds and seedlings during the vulnerable early stages of plant life. Seed-applied insecticides are one such tool adopted by farmers, and have been evaluated for direct and indirect benefits. Multi-year data indicate value to farmers for early season insect protection, and suggest potential to enable conservation practices such as cover crops.

Session 1-T4 - Neonicotinoid seed treatments in maize: how important to seedling pest management?

Insecticide resistance implications of widespread neonicotinoid use in field crops

Anders Huseth[1] & George Kennedy[1]

[1]*North Carolina State University, Raleigh, North Carolina, U.S.A.*

Insecticide Resistance Management (IRM) practices primarily involve insecticide rotation or toxin-free refugia within a single crop species to preserve pest susceptibility. Though IRM focuses on single crops, insect pests can experience selection from multiple insecticide-treated crops within agroecosystems. Recurring use of neonicotinoid seed treatments in multiple agronomic crops across the US landscape has increased the probability of increased resistance selection in polyphagous pest species at a broad spatial scale. Here, we explore the relationship between the production intensity of neonicotinoid treated crops and insecticide resistance selection. Using a geospatial approach, this research linked the abundance of neonicotinoid-treated crops to neonicotinoid resistance in a polyphagous pest. We show that spatiotemporally intensive production of neonicotinoid treated crops is related to resistance across nine US states, and demonstrates that cross-crop resistance selection has important effects on polyphagous pests. Results suggest that IRM focus for popular insecticides, like neonicotinoid seed treatments, should incorporate a cross-crop perspective in agroecosystems.

Session 1-T 5 - Neonicotinoid seed treatments in maize: how important to seedling pest management?

Neonicotinoid insecticides on *Bt* seed – balancing contributions to crop protection, resistance management, and environmental residues

Sally Taylor[1] & Christian Krupke[2]

[1]*Virginia Polytechnic and State University, Suffolk, Virginia, U.S.A.*
[2]*Purdue University, West Lafayette, Indiana, U.S.A.*

Neonicotinoid seed treatments are applied to all *Bt* corn seeds in the United States despite data suggesting that universal use may be excessive and unnecessary. A clear assessment of the relative contributions of *Bt* toxins and seed applied insecticides is essential to develop successful integrated pest management (IPM) and insect resistance management (IRM) programs. Field experiments in two different corn production regions are being used to determine how separating neonicotinoid seed treatments from *Bt* corn affects grain yield, insecticide residues in soil and water, and rootworm survival in *Bt*/refuge corn systems. Specifically, this project is evaluating how neonicotinoid seed treatments affect emergence of rootworms in non-*Bt* refuges (i.e., safe havens that ideally produce a surplus of *Bt*-susceptible insects) whose survival is meant to dilute resistant alleles within a given population. We aim to identify where *Bt* corn and neonicotinoid seed treatments should be consistently deployed together to preserve crop yield and where insecticides can be removed from corn seed without increasing losses. Our goal is to understand how neonicotinoid seed treatments and *Bt* corn can be deployed to slow the pace of resistance without profit loss for growers.

Session 2a-T 1 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Bt maize within a changing IPM paradigm

Michael Meissle[1] & William Hutchison[2]

[1]*Agroscope, Zurich, Switzerland*
[2]*University of Minnesota, St. Paul, Minnesota, U.S.A.*

Maize is attacked by a number of serious Lepidoptera pests, such as corn borers or members of the Noctuidae. Genetically engineered maize has been cultivated for more than 20 years. Maize expressing Cry proteins from *Bacillus thuringiensis* (*Bt*) is an efficient and environmentally friendly tool for targeting Lepidoptera pests. However, the prevailing challenge with *Bt* maize is the evolution of resistance to the produced Cry proteins. Resistant target pests limit the durability of this valuable plant protection tool. Therefore, efficient resistance management, such as the planting of non-*Bt* refuge areas, is crucial for the sustainable use of *Bt* crops. To ensure a responsible use of *Bt* maize with reduced environmental impact, principles of Integrated Pest Management (IPM) need to be followed with the aim that existing problems are solved without creating new ones.

This presentation will provide an overview of the global cultivation of *Bt* maize, the principles of IPM, and the global challenges with pests resistant to *Bt* maize. This global overview will allow drawing conclusions about the requirements of the maize production system, the characteristics of the Lepidoptera pest complex, and the actions needed for sustainable use of current and future *Bt* maize traits.

Session 2a-T 2 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Success with *Bt* maize for corn borers in Spain: farmer views, 20 years of resistance monitoring and challenges

Gema P. Farinós[1] & Félix Ortego[1]

[1]*Centro de Investigaciones Biológicas (CIB, CSIC), Madrid, Spain*

Bt maize expressing the protein Cry1Ab has been grown in Spain since 1998, effectively controlling two key maize pests: the European corn borer (ECB), *Ostrinia nubilalis,* and the Mediterranean corn borer (MCB), *Sesamia nonagrioides*. At present, cultivars derived from the event MON810, the only approved for cultivation in the EU, are mainly grown in Spain (95% in 2018), representing ~30% of maize grown in the country.

Some studies have shown that the view of Spanish farmers cultivating *Bt* maize is quite favourable to the use of transgenic seeds. The main reasons were the capability of *Bt* maize to reduce losses due to corn borers, what led to higher yields in regions where pest pressure was high, and savings in corn borers control.

Insect resistance management in the EU is based in the high-dose/refuge (HDR) strategy and in the implementation of monitoring programs to assess the potential development of resistance of both target pests to *Bt* maize. These programs started in Spain in 1998 in areas with different adoption rates; however, nowadays they are focused in the Ebro Valley (NE Spain), the only hotspot for resistance evolution in the EU, where the adoption rate of *Bt* maize is above 60%. The results of 20 years of monitoring show that no major shifts have occurred in the susceptibility of target pests to the Cry1Ab protein over time, and no field failures have been notified so far, suggesting that HDR strategy is effectively delaying resistance evolution. This has been favoured by the compliance of farmers with refuge requirements.

Challenges facing *Bt* maize cultivation in Spain include the uncertainties of EU policy for GM crops and the reduced set of tools available for resistance management, since pyramided *Bt* maize varieties cannot be used. Even more so when a resistance allele has already been detected in a MCB field population. Thus, it is essential the strict compliance of refuges, as well as continuing the monitoring of resistance evolution in the Ebro Valley.

Session 2a-T 3 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Factors that contribute to management of resistance evolution in pests of *Bt* maize in African small holder farming systems

Johnnie Van den Berg[1]

[1]*North-West University, Potchefstroom, South Africa*

The most important Lepidoptera pests of maize in Africa are *Spodoptera frugiperda, Chilo partellus* and *Busseola fusca*. *Bt* maize is effective against these pests. Since both *B. fusca* and *S. frugiperda* are known for their propensity to evolve resistance to Cry proteins expressed in *Bt* maize, compliance to insect resistance management (IRM) strategies is essential to delay resistance evolution of target pests. IRM strategies such as seed blends and the high-dose/refuge strategy is commonly employed to delay resistance evolution. The later strategy requires planting of structured refuges in close proximity to *Bt* maize fields to sustain susceptible pest individuals that mate with resistance ones to reduce the frequency of resistance alleles in the population. This IRM strategy is effective in industrial farming systems but its application has unique challenges in small holder farming systems where farmers' fields are often smaller than 1.5 ha, where seed systems function poorly and where compliance to IRM requirements will be low. Existing farming practices and IPM strategies that suppress pest numbers on the main crop, and therefore also the rate of resistance evolution, should be identified and their possible contribution to IRM exploited. Using aspects of ecological trap theory could result in reduced selection for resistance alleles in pest populations. Apparently-favourable pest habitats which result in poor pest survival are abundant in small holder African farming systems. Some examples of these ecological traps or attractive sinks are certain intercropping practices, the push-pull habitat management system and trap crops. Furthermore, conservation biocontrol can add to what farmers are currently doing to suppress pest numbers and subsequently delay insect resistance evolution.

Session 2a-T 4 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Success with *Bt* maize for European corn borer in the U.S.: benefits of areawide pest suppression in maize and surrounding non-*Bt* crops

William Hutchison[1], Eric Burkness[1], Paul Mitchell[2] & Galen Dively[3]

[1]*University of Minnesota, St. Paul, Minnesota, U.S.A.*
[2]*University of Wisconsin, Madison, Wisconsin, U.S.A.*
[3]*University of Maryland, College Park, Maryland, U.S.A.*

During the past 24 years, genetically engineered (GE) crops expressing insecticidal proteins from *Bacillus thuringiensis* (*Bt*) for insect control have experienced high adoption rates in both industrial and developing countries, with ~470M acres planted globally in 2017 by >17M farmers (ISAAA, 2018). However, despite the success with increased yields and reduced pesticide use, at least 15 insect species have evolved resistance to one or more *Bt* proteins (*Bt* maize and *Bt* cotton). The resistance challenge has generated renewed interest in revisiting how GE crops should best be incorporated into Integrated Pest Management (IPM) programs. Parallel to the evolution of resistance, the IPM concept is being re-defined by several researchers to allow for an increased emphasis on a risk-based framework to support reduced economic volatility, an increased awareness of the role of farmer communication networks, and at the same time promote ecosystem services and environmental sustainability. In this presentation, the *Bt* maize, European corn borer (ECB, *Ostrinia nubilalis*) system will be discussed with regard to on-going success in the central and eastern U.S. corn production areas. The compatibility of *Bt* maize with naturally occurring biological control agents is offered as an example of a system where natural enemies continue to be active and may also contribute to the long-term sustainability of the *Bt*-maize IPM system. Data for the microsporidium, *Nosema pyrausta,* and a generalist predator, *Orius insidiosus* will be reviewed. Cultural practices such maintaining non-*Bt* refuge acres for *Bt* resistance management (including economic incentives), and early-harvest for silage (green) corn, with or without additional tillage, will also be discussed as components of IPM that have also likely contributed to the long-term success of *Bt* maize for *O. nubilalis*.

Session 2a-T 5 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Sweet corn sentinel network for monitoring lepidopteran resistance to *Bt* traits

Galen Dively[1], Tom Kuhar[2], Sally Taylor[2], Helene Doughty[3], Dominic Reisig[4], David Owens[5], Joanne Whalen[5], Kris Holmstrom[6], Joseph Ingerson-Mahar[7], Daniel Frank[8], Shelby Fleischer[9], Brian Nault[10] & Dan Gilrein[11]

[1]*University of Maryland, College Park, Maryland, U.S.A.*
[2]*Virginia Tech, Blacksburg, Virginia, U.S.A.*
[3]*Virginia Tech, Painter, Virginia, U.S.A.*
[4]*North Carolina State, Plymouth, North Carolina, U.S.A.*
[5]*University of Delaware, Newark, Delaware, U.S.A.*
[6]*Rutgers University, New Brunswick, New Jersey, U.S.A.*
[7]*Rutgers University, New Brunswick, New Jersey, U.S.A.*
[8]*West Virginia University, Morgantown, West Virginia, U.S.A.*
[9]*Penn State University, State College, Pennsylvania, U.S.A.*
[10]*Cornell University, Geneva, New York, U.S.A.*
[11]*Cornell University, Riverhead, New York, U.S.A.*

A cooperative network of sweet corn sentinel plots was started in 2017 to provide an in-field diagnostic screen to detect early shifts in lepidopteran pest susceptibility to *Bt* toxins. In 2019, the network expanded to 27 sites in 16 states (TX, MN, WI, SC, NC, VA, MD, OH, WV, DE, PA, NJ, NY, NH, VT, ME) and four Canadian provinces (OR, QC, NB, NS). Each site consisted of plots of *Bt* and non-*Bt* sweet corn planted side-by-side, so that the attractive silking period coincided with the highest level of moth activity at each location. Plots included: Attribute 'BC0805' expressing Cry1Ab, Attribute II 'Remedy' expressing Cry1Ab and Vip3Aa, and their non-*Bt* isoline 'Providence' (Syngenta US); and Performance Series 'Obsession II' expressing Cry1A.105+Cry2Ab2, and its non-*Bt* isoline 'Obsession I' (Seminis). Ears were examined at fresh market maturity (18-21 days after silk emergence) to record the instar stage of live larvae, amount of kernel area consumed (cm^2), and location of damage by species. For *H. zea*, the percentage of 4^{th}, 5^{th} and 6^{th} instars (late larvae) was also computed. Results further support previous findings that *H. zea* populations have developed field-evolved resistance to the Cry1Ab and pyramided Cry1A.105+Cry2Ab2 toxins. Additionally, results provide evidence of increasing resistance to these toxins during the past three years and also unexpected injury levels in Vip3Aa sweet corn at several sites starting in 2018. The sweet corn sentinel approach may be a more efficient and less variable method to monitor resistance by measuring relative changes in control efficacy between isogenic pairs of non-*Bt* and *Bt* plots. The side-by-side planting lowers the risk of 'false positives' compared to sampling for unexpected injury levels in *Bt* only fields, because the approach quantifies year-to-year differences in pest pressure. In addition, sentinel plots would not be subject to intervening management strategies should an action threshold be reached, which facilitates laboratory confirmation of resistance.

Session 2b-T 1 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Challenges for managing *Helicoverpa zea* with *Bt* maize in the southeastern United States

Francis Reay-Jones[1], Dominic Reisig[4], David Buntin[2] & Silvana Paula-Moraes[3]

[1]*Clemson University, Florence, South Carolina, U.S.A.*
[2]*University of Georgia, Griffin, Georgia, U.S.A.*
[3]*University of Florida, Jay, Florida, U.S.A.*
[4]*North Carolina State University, Plymouth, North Carolina, U.S.A.*

Transgenic maize hybrids that express insecticidal toxins from the bacterium *Bacillus thuringiensis* (*Bt*) can reduce injury from the corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae). Susceptibility to Cry toxins has, however, declined in recent years in *H. zea* populations in the southern United States. While previous work showed reduced pupal weights among *H. zea* surviving on *Bt* maize, a longitudinal study from 2012-2019 revealed that the effects of *Bt* toxins on pupal weights have declined over time. On-going work in North Carolina, South Carolina, Georgia and Florida will be presented on the significance of reduced pupal weights on *H. zea* biology, with implications for insecticide resistance management. Concurrent with this, laboratory bioassays have shown highly variable levels of susceptibility to Cry1A.105 and Cry2Ab2 among field collected *H. zea* populations. The toxin Vip3A that is included in maize pyramids expressing one or more Cry toxins currently provides excellent levels of control of *H. zea*, with no injury to the ear tip or kernels, and only eight 1st instar larvae found in the silk out of 520 ears in a study in South Carolina. While *H. zea* is generally not an economic pest in maize, selection pressure in *Bt* maize has implications for pest status and injury to *Bt* cotton, where the insect is a major economic pest. Implications of on-going work for resistance management strategies will be discussed.

Session 2b-T 2 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

The first case of field failure of *Bt* corn to control European corn borer *Ostrinia nubilalis* (Lepidoptera: Crambidae) discovered in Nova Scotia, Canada

Art Schaafsma[1], Yasmine Farhan[1] & Jocelyn Smith[1]

[1]*University of Guelph, Ridgetown, Canada*

When *Bt* maize to control European corn borer was first released in North America modellers predicted durability of these early single traits for 20 to 30 years if the high dose refuge strategy of insect resistance management was followed. Cry1F-traited maize was first marketed in Nova Scotia around 2006. After hearing rumours of higher than expected damage in 2017, in 2018 several fields experienced control failure and these were assessed and sampled. Unexpected injury (UXI) ranged from 30-70%. Significantly greater survival of UXI collections was observed when larvae were exposed to a diagnostic concentration of Cry1F (200 ng cm^{-2}) in diet-overlay bioassays and in Cry1F leaf tissue assays compared to susceptible laboratory colonies. Our data show that this population of European corn borer developed complete resistance to Cry1F within 11 or 12 generations in the field. Possible factors leading to development of Cry1F-resistance in what might be considered an insignificant maize-growing region will be discussed.

Session 2-T 3 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

First report of European corn borer resistance against Cry1F in Nova Scotia, Canada

Amit Sethi[1], Ashley Miles[1], Matt Wihlm[1], Jeanette Dyer[1], Kelly Jordan[1], Benchie Ortegon[1] & Andre Crespo[1]

[1]Corteva Agriscience, Johnston, Iowa, U.S.A., amit.sethi@corteva.com

First report of European corn borer resistance against Cry1F in Nova Scotia, Canada will be discussed.

Evaluation of susceptibility in multiple lepidopteran pests to major toxins expressed by *Bt* corn

Guoping Li[1], Hongqiang Feng[1] & Tingjie Ji[1]

[1]*Institute of Plant Protection, Henan Academy of Agricultural Sciences, Zhengzhou, P.R. China*

The Huang-Huai-Hai summer corn region is the biggest region of corn production in China. In this region corn is damaged by not only the Asian corn borer *Ostrinia furnacalis* (Guenée), but also the peach pink moth *Conogethes punctiferalis* (Guenée), cotton bollworm *Helicoverpa armigera* (Hübner), black cutworm *Agrotis ypsilon*, and oriental armyworm *Mythimna separata*. The fall armyworm, *Spodoptera frugiperda* (Smith), invaded this region recently, which made the pest control more difficult. Transgenic corn producing *Bacillus thuringiensis* (*Bt*) toxins offers a good choice to control multiple lepidopteran pests in this region. *Bt* corn has been proved effective to control the European corn borer *O. nubilalis*, and its sibling species *O. furnacalis*, but *S. frugiperda* has developed resistance to Cry1F corn. It is very useful to evaluate the efficacy of different *Bt* toxins expressed by current *Bt* corn hybrids to multiple lepidopteran pests before widely commercialization. In contrast to *O. nubilalis, O. furnacalis*, and *S. frugiperda*, we have very little knowledge about the efficacy of *Bt* corn to the other four pests. To determine whether the information obtained from *Ostrinia* species can be used for making decision to control other lepidopteran pests with *Bt* corn, we evaluate the susceptibility of the six lepidopteran pest species to different *Bt* toxins. The bioassay results revealed that *O. furnacalis* and *C. punctiferalis* presented a similar pattern of susceptibility to all tested toxins, and both were highly susceptible to Cry1Ab, Cry1Ac and Cry1F, while other four pest species exhibited different sensitivity pattern to Cry1, Cry2 and Vip3 toxins. *Helicoverpa armigera* showed equally high sensitivity to Cry1Ab and Cry1Ac, but was more tolerant to Cry1F than *O. furnacalis* and *C. punctiferalis*. *Helicoverpa armigera* was the most sensitive species to Cry2Ab. *Spodoptera frugiperda* and *M. separate* showed less susceptibility to Cry1Ab and Cry1F, than *O. furnacalis* and *C. punctiferalis. Spodoptera frugiperda* was the most sensitive species to Vip3A. Planting stacked or pyramided hybrids was necessary in the Huang-Huai-Hai summer corn region of China to control the damage from multiple lepidopteran pests.

Session 3-T 1 - Emerging lepidopteran challenges in the maize agro-ecosystem

Challenges with landscapes dominated with genetically engineered crops

Richard Hellmich[1,2]

[1]*USDA, Corn Insects and Crop Genetics Research Unit, Ames, Iowa U.S.A.*
[2]*Department of Entomology, Iowa State University, Ames, Iowa, U.S.A.*

In the U.S. Corn Belt many landscapes are dominated by maize, soybeans and cool-season perennial grasses such as smooth brome and reed canary. Over the past two decades genetically engineered crops increasingly have become part of this landscape. *Bt* maize has drastically reduced pressure from European corn borer, *Ostrinia nubilalis*, while herbicide-tolerant maize and soybeans have simplified weed control. There are concerns that herbicide use associated with herbicide-tolerant crops reduced common milkweed (*Asclepias syriaca*) in crop fields. Common milkweed is the most important host plant of the monarch butterfly (*Danaus plexippus*) in the Corn Belt. Monarch populations have declined dramatically over the past two decades due to multiple factors, including loss of overwintering habitat in Mexico, breeding habitat in the United States, and milkweed within crop fields. Research has focused on ways to increase biodiversity in agricultural landscapes in Iowa by planting native plants near and sometimes in borders of crop fields and along roadsides. These plantings provide shelter and food for butterflies, pollinators, birds and other organisms. Strategically placed habitat also can be stacked with edge of field practices designed to control erosion and nutrient runoff. The Iowa Monarch Conservation Consortium that includes agricultural, conservation, academic and governmental organizations was formed to improve survival and reproduction success through voluntary action. The goal is to establish native plant habitats throughout Iowa with a focus on areas near agricultural land by working with the more than 30 consortium members and partners. Science-based approaches are used to develop practical, cost-effective guidelines to help landowners establish habitats in filter strips, bioreactors and grass-dominated land. The premise is that growers do not want milkweeds on productive land but they would consider establishing them and nectar plants on non-crop and non-productive land.

Session 3-T 2 - Emerging lepidopteran challenges in the maize agro-ecosystem

Development of caterpillars with low susceptibility to *Bt* on diets enriched with vitamins

Carmen López[1], Pilar Muñoz[1] & Matilde Eizaguirre[1]

[1]Matilde Eizaguirre, Lleida, Spain
[2]Carmen, López, Spain
[3]Pilar Muñoz, Muñoz, Spain

Biofortified *Bacillus thuringiensis* (*Bt*) crops with enhanced nutritional traits, as the accumulation of high levels of β-carotene and vitamin C (ASA), are under development or nearing commercialization. Little is known about the effects of biofortified crops on herbivorous insects. Studies on their effect for the on non-target caterpillars with low susceptibility to the *Bt* toxin could be particularly interesting, as these caterpillars might be favoured by the increased contents of vitamins in *Bt* plants. In laboratory experiments, the addition of C vitamin (ascorbic acid: ASA) and β-carotene, to the *Bt* diet produced different effects on the mortality and development of *M. unipuncta* (Mu) or *H. armigera* (Ha) larvae. The development of both Mu and Ha was extended and the weight of resulting pupae was lower than of larvae fed on the non-*Bt* diet; Mu showed lower susceptibility to the toxin than Ha. Moreover, the amount of *Bt* toxin in the diet was not sufficient to cause any mortality in Mu larvae while a 75% of the Ha larvae died before pupation. Mortality of Ha larvae decreased significantly when the amount of ASA in the diet increased or when β-carotene was added to the *Bt* diet. However, neither the development of Mu nor that of Ha larvae that achieved pupation was favoured by the presence of these two vitamins; on the contrary, vitamins were detrimental to Mu larval development. Response, or activity of three enzymes known to be implicated in the toxin detoxification defence, catalase, superoxide dismutase and glutathione S-transferase, to the *Bt* ingestion was also different to the response previously reported for other species. These results show that, although they appear to be similar; there are important differences in the responses to *Bt* enriched with vitamins ingestion by non-target Lepidoptera that could be related to the different plant tissues on which larvae feed or to the different nutritional requirements between lepidopteran species.

Session 3-T 3 - Emerging lepidopteran challenges in the maize agro-ecosystem

Fall armyworm, *Spodoptera frugiperda*, spread quickly northward threaten the corn production in China

Zhenying Wang[1], Jingfei Guo[1] & Kanglai He[1]

[1]State Key Laboratory for Biology of Plant Diseases and Insect Pests, MARA – CABI Joint Laboratory for Bio-safety, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, P.R. China

The fall armyworm, *Spodoptera frugiperda* (Smith), is native to the tropical and subtropical regions of the Americas. As of the 10th June 2019, it had spread across China's southern border and impacted about 250,000 hectares of grain production in Anhui, Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hainan, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Shaanxi, Shanghai, Sichuan, Tibet, Yunnan and Zhejiang since it was first detected in China in January 2019. The above listed provinces where fall armyworm occurred until early June belong to the South Hilly Corn Region and Southwest Mountain Corn Region, and part of Qinghai-Tibet Corn Region with about 15% of corn planting in China. However, as the fall armyworm population invades from those regions, it will migrate northward, with the movement of the Asian monsoon, to Huang-Huai-Hai Summer Corn Region in June, at seedling stage of summer corn in middle and late June, and even to the southern part of the North Spring Corn Region. These are the two major corn planting area with nearly 80% of corn planting acreage. Fall armyworm is very dangerous and threatens corn production. Its rapid spread northwards has caused extensive concern. Chinese authorities have employed an emergency action plan to monitor and tackle the pest in order to reduce the potential damage in the major corn planting regions.

Session 3-T 4 - Emerging lepidopteran challenges in the maize agro-ecosystem

Challenges and management efforts of fall armyworm in Brazil

Eliseu Pereira[1,3], Oscar Santos-Amaya[1], Clébson Tavares[1,2], Jaciara Gonçalves[1], Silvana Orozco-Restrepo[1,3], João Victor Rodrigues[1], Fernanda Sousa[1], Natália Leite[1], Hugo Monteiro[1], Josélia França[1], Thadeu Souza[1,3], Simone Mendes[5], Camila Oliveira[1,3], Laura Machuca-Mesa[1], Nataly DeLaPava-Suárez[1] & Silvana Paula-Moraes[2]

[1]Department of Entomology, University of Viçosa, Viçosa, MG, Brazil
[2]Entomology & Nematology Department, West Florida Research Education Center, Jay, Florida, U.S.A.
[3]National Institute of Plant-Pest Interactions, INCT/BIOAGRO, Viçosa, Brazil, eliseu.pereira@ufv.br
[4]Department of Entomology and Nematology, University of Florida, Gainesville, Florida, U.S.A.
[5]Embrapa Maize & Sorghum, Sete Lagoas, MG, Brazil

Since 2010 we started a research program addressing the concern that low-dose *Bt* maize hybrids could be rapidly overcome by fall armyworm (*Spodoptera frugiperda*) larvae. We also developed Cry1F-resistant strains to learn about the resistance, hoping to manage it, but Cry1F field resistance developed faster than expected. Non-random oviposition preference by FAW moths on *Bt* and non-*Bt* refuge plants may have increased the selection pressure and reduced the efficacy of resistance management. However, our data from diverse agroecosystems and greenhouse assays indicate that FAW moths do not prefer *Bt* over non-*Bt* plants for oviposition and that maize plants injured by conspecific larvae do not interfere in the oviposition choice. Importantly, non-random mating may also compromise the efficacy of the refuge. In collaboration with chemical ecologists, we found that Cry1F-resistant females produced more mature eggs and had calling behavior starting earlier and lasting longer, with more and longer calling bouts than susceptible females. The proportion of main sex pheromone compounds was different in susceptible and resistant females. In the wind tunnel, a higher percentage of resistant males responded to the resistant females and their pheromone glands, as did susceptible males to susceptible females, a pattern also observed in the field, indicating the likelihood of assortative mating. With Cry1F resistance spread in FAW populations, the concern became on its cross-resistance to other *Bt* toxins. Cry1F showed cross-resistance to Cry1A, but not to Vip3Aa. In addition, studies on FAW resistance to Cry1A.105/Cry2Ab showed strong fitness costs of the resistance, which may be sufficient to select against it. Following up, we studied the effects of alternative host crops on the fitness of *Bt*-toxin resistant FAWs and their interactions with *Bt* maize, seed treatments, and foliar insecticides. These are some of our efforts to manage fall armyworm, a challenging invasive species.

Session 3-T 5 - Emerging lepidopteran challenges in the maize agro-ecosystem

Noctuids associated with maize in tropical and temperate areas: updates and what we still need to learn

Silvana V. Paula-Moraes[1]

[1]*University of Florida, Entomology & Nematology Department, WFREC, Jay, Florida, U.S.A.*

Several species of insects are associated with maize. One of the most destructive group of pests in tropical and temperate areas of American continents are the noctuids, which can feed on the crop during maize vegetative and reproductive stages. This presentation will summarize the findings associated with intraguild interaction between *Helicoverpa zea* and *H. armigera* in South America and the role played by maize as a source of infestation to other crops in the agricultural landscape. This presentation will also discuss the emergent problem of *Elaphria* spp. feeding in maize in the Brazilian savannah region, and the occurrence and ecology of noctuids in a transition zone between tropical and temperature areas in the Florida Panhandle. An overall view of the challenges for IPM and IRM for noctuids will be discussed.

Session 3-T 6 - Emerging lepidopteran challenges in the maize agro-ecosystem

Plant-insect relationship: trade-off between growth and defense

Inoussa Sanané[1,2,3], Christine Dillmann[2], Judith Legrand[2] & Frédéric Marion-Poll[3]

[1]University of Paris Sud, Orsay, France
[2]Génétique Quantitative et Evolution – Le Moulon, INRA, Univ. Paris-Sud, CNRS, AgroParisTech, Université Paris-Saclay, Gif-sur-Yvette, France
[3]Evolution, Génomes, Comportements et Ecologie, CNRS, IRD, Université Paris-Sud Université Paris-Saclay, Gif-sur-Yvette, France

Plants can escape herbivores either by building up defenses or by shortening their life-cycle to become mature before herbivores attack. We used maize plants from two independent Divergent Selection Experiments (DSEs) for flowering time, each derived from a single inbred line F252 or MBS. The resulting Early and Late evolved populations exhibited pronounced phenotypic divergence for flowering, comprised between mid-July (Early F252) to mid-August (Late MBS). Pyralids (*Ostrinia nubilalis*) prevalence was monitored throughout the season on plants from generation G22 on plants grown in the field. The result shows that early populations were more attacked than late ones, especially in MBS populations.

In the meantime, we constructed an experimental device to measure insect appetence through the rate of consumption of plant leaf disks, taken from the fields. Automated image analysis allowed to compare up to six plant genotypes, each represented by 50 leaf disks in a single batch. Representative plant lineages from the DSEs taken at three developmental stages before and after flowering were proposed to L2 pyralid larvae.

Dynamics of insect feeding behaviours was clustered into 14 categories that ranged between fast consumers to haters (no feeding) and validated using known antifeedants. Multinomial logistic regression on the proportion of each behavioral category showed significant differences between plant lineages: insects did prefer Early lineages as compared to Late lineages. These results confirm field measurement of insect's prevalences.

Altogether, our results suggest a trade-off between growth and defense: Everything equal, Early plants seemed preferred by insects and may have fewer defenses.

Session 4-T 1 - Environmentally friendly management of rootworms, wireworms and other soil pests in maize

Pleurotus aegerolysin proteins are selectively toxic to western corn rootworm (*Diabrotica v. virgifera*) and Colorado potato beetle (*Leptinotarsa decemlineata*)

Jaka Razinger[1], Anastasija Panevska[2], Špela Modic[1], Miki Zarić[2], Peter Maček[2] & Kristina Sepčić[2]

[1]Plant Protection Department, Agricultural Institute of Slovenia, Ljubljana, SIovenia
[2]Department of Biology, Biotechnical Faculty, University of Ljubljana, Ljubljana, SIovenia

Aegerolysin proteins from the fungal genus *Pleurotus* interact with ceramide phosphoethanolamine (CPE), a membrane sphingolipid specific to invertebrates. Additionally, the *Pleurotus* genomes harbour sequences that encode proteins with a membrane attack complex/perforin (MACPF) domain. Combined, aegerolysins and MACPF proteins can perforate artificial and biological membranes that contain the specific lipid receptor, by forming transmembrane pores. Several bacterial aegerolysin protein complexes demonstrated selective insecticidal properties, and were successfully introduced into plants *via* genetic transformation. Accordingly, our aim was to investigate whether similar aegerolysin complexes deriving from *Pleurotus* spp. show potential as biopesticides. Three recombinant *Pleurotus* aegerolysins, namely ostreolysin A6 (OlyA6), pleurotolysin A2 (PlyA2) and erylysin A (EryA), and their MACPF-protein partner pleurotolysin B (PlyB) were purified and characterized. The insecticidal properties of these aegerolysins, either alone or in combination with PlyB, were studied on western corn rootworm (WCR; *Diabrotica v. virgifera*), Colorado potato beetle (CPB; *Leptinotarsa decemlineata*), spotted wing drosophila (*Drosophila suzukii*), mealworm (*Tenebrio molitor*), grain aphid (*Sitobion avenae*) and greater wax moth (*Galleria mellonella*). OlyA6/ PlyB, PlyA2/ PlyB and EryA/ PlyB complexes have shown a selective toxic effect to WCR and CPB, but not to other tested insect pests. Exposure of WCR to artificial food containing OlyA6/ PlyB resulted in a significant increase of larval and beetle mortality during the 5- and 7-day experiments. Exposure of CPB to leaf disks treated with protein mixtures significantly increased larval mortality and decreased larval feeding during the 5–day experiment. The ability of aegerolysins from the fungal genus *Pleurotus* to target CPE, and to form transmembrane pores with PlyB, suggest their potential use as biopesticides for controlling WCR and CPB.

Session 4-T 2 - Environmentally friendly management of rootworms, wireworms and other soil pests in maize

Field efficacy evaluation of *Heterorhabditis bacteriophora* Poinar (Rhabditida: Heterorhabditidae) and synthetic insecticides for control of western corn rootworm larvae

Špela Modic[1], Primož Žigon[1], Aleš Kolmanič[1] & Jaka Razinger[1]

[1]Agricultural Institute of Slovenia, Ljubljana, SIovenia

The western corn rootworm (WCR), *Diabrotica virgifera virgifera* LeConte, (Coleoptera, Chrysomelidae) is an important insect pest of maize in North America and across Central and Eastern Europe. The larvae emerge in May in Central Europe and its three instars intensely feed on maize roots in June causing plant lodging leading to economic yield losses.

Three-year field experiments were conducted (2016-2018) to compare the effectiveness of i.) the soil applied granular insecticide Force 1.5 g (active substance tefluthrin, pyrethriod); ii.) insecticide seed dressing Sonido (a.s. thiacloprid, neonicotinoid); and iii.) entomopathogenic nematodes (EPN) *Heterorhabditis bacteriophora* Poinar (Rhabditida: Heterorhabditidae, product Dianem, e-nema GmbH, Germany), against WCR larvae. Additionally soil conditioner (alcohol ethoxylate, product Transformer) was used with the EPN, to check for potential increase of EPN effectiveness. Field tests were carried out in two naturally infested fields in a), Bučečovci (eastern Slovenia) and b), Šmartno na Gorenjskem (northern Slovenia). The efficacy of the treatments was very similar at both locations, despite the approximately 5-fold lower WCR population in northern compared to eastern Slovenia, as well as consistent over time. The highest WCR beetle emergence was observed in the negative control, followed by the treatment Sonido (insignificant decrease). Treatments Force, Dianem with and Dianem without Transformer significantly decreased the number of emerged beetles and were statistically indistinguishable. We conclude that biological control of WCR larvae in maize using EPN *Heterorhabditis bacteriophora* is comparable to conventionally used chemical control and could thus offer a good alternative for sustainable WCR management in Europe.

Session 4-T 3 - Environmentally friendly management of rootworms, wireworms and other soil pests in maize

From proof of concept to optimization: the use of soil-dwelling predatory mites to control western corn rootworm population

Antoine Pasquier[1,2], Thibault Andrieux[1], Paloma Martinez-Rodriguez[1], Elodie Vercken[2] & Maxime Ferrero[1]

[1]Bioline AgroSciences, Valbonne, France
[2]Université Côte d'Azur INRA CNRS ISA, Sophia Antipolis, France

Soil-dwelling predatory mites already proved their efficiency as biocontrol agents against many pests (Carrillo *et al.*, 2015). Western corn rootworm (WCR), *(Diabrotica virgifera virgifera)* (LeConte) is an important pest of maize (Krysan et *al.*, 1986; Wesseler et Fall 2010) whose eggs and larvae also inhabit the first centimeters of soil (Vidal *et al.*, 2005).

To evaluate predatory mites potential as biological control agents against WCR, we first investigated the predation capacity of three predatory mites species in controlled conditions. Then, we observed the effect of predatory mites in presence of WCR on plant health.

Our predation test showed that none of the species considered WCR eggs as prey. However, the three species tested attacked first instar larvae in 35%, 55% and 65% of assays by *S. scimitus*, *G. aculeifer,* and *M. robustulus*, respectively. Our test in semi-natural conditions confirmed this trend with a positive effect on plant health in the presence of a large population of *G. aculeifer*.

This need for a large population could be an issue if we considered treating the pest when it emerges. However, if we release a smaller population of the biocontrol agent before that timing, the natural population dynamics may increase the number of individuals available to control the pest as well as protect the plant against WCR earlier emergence. Predatory mites population dynamics being dependent of temperature (Amin *et al.*, 2014), humidity and food quality (Lobbes and Schotten, 1980), it can differ across geographical areas. To consider this variability and optimize WCR control in actual environmental conditions, we are developing a model to predict the number of predatory mites to introduce depending on local parameters of temperature, humidity, and soil organic matter.

Session 4-T 4 - Environmentally friendly management of rootworms, wireworms and other soil pests in maize

Factors influencing the efficacy of soil insecticides and entomopathogenic nematodes at reducing the maize pest *Diabrotica v. virgifera* (Coleoptera: Chrysomelidae) under field conditions

Szabolcs Toth[1,2], Mark Szalai[1], Jozsef Kiss[1] & Stefan Toepfer[1,2]

[1]Plant Protection Institute NVI; Szent Istvan University, Gödöllö, Hungary
[2]CABI Switzerland, c/o Plant Protection Directorate, Hódmezővásárhely, Hungary

Control methods against the root feeding larvae of the maize pest *Diabrotica virgifera virgifera* (Coleoptera: Chrysomelidae) can lead to inconsistent efficacies under field conditions. To better understand dynamics and persistence of effects of crop protection agents on the root-feeding larvae, we analysed the temporal effects of three granule soil insecticides (chlorpyrifos, cypermethrin, tefluthrin) and a commercial entomopathogenic nematode (*Heterorhabditis bacteriophora*, Rhabditida: Heterorhabditidae), reflected in temporal changes in beetle emergence. This 8-year study (2010-2018) with 12 field-scale experiments in southern Hungary confirmed that all treatments, regardless of chemical or biological, are able to reduce *D. v. virgifera* although with high variability; but failed in 20 to 25% of cases. However, there were hardly any indications on temporal changes in treatment effects on the pest. All treatments seem to be able to continuously reduce *D. v. virgifera* larvae over time, and this regardless of sex. Only chlorpyrifos seem to slightly loose efficacy with time, reflected in a better reach of early than late females. Contrarily, tefluthrin‘s comparative efficacy seems to slightly increase with time. Other influencing factors are discussed, all widening our understanding behind successes and failures of control agents against this difficult-to-manage maize pest.

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Assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa

Melanie Bateman[1], Roger Day[2], Belinda Luke[3], Steve Edgington[3], Ulrich Kuhlmann[1] & Matthew J. W. Cock[3]

[1]CABI, Delémont, Switzerland
[2]CABI, Nairobi, Kenya
[3]CABI, Egham, United Kingdom

The fall armyworm (FAW, *Spodoptera frugiperda*) originates from the tropical and sub-tropical regions of the Americas. Recently it was reported for the first time in Africa and has since spread rapidly across more than 30 countries in the continent. Chemical pesticides are being promoted and used for FAW management, but where application practices and/or the active ingredients are unsafe there is a need to make effective, low-risk products available. Given that biopesticides such as microbials and microbial extracts, macrobials and semiochemicals are generally considered to be lower risk options for pest management, they are a promising avenue for exploration. When used in conjunction with good crop management, they can help to keep pest levels under control, reducing the need to apply other pesticides. This study provides a basis for designing interventions to make biopesticides more widely available for FAW control in Africa. It summarizes assessments of the registered pesticides and biopesticides for 30 countries, 11 in FAW's native range and 19 in Africa. The report identifies biopesticide active ingredients (AI) which are registered for use against FAW and provides an assessment of how appropriate these will be for use by smallholder farmers in Africa. For each biopesticide AI identified, detailed profiles were developed which covered the efficacy of the AI against FAW; the human health and environmental hazards associated with the AI; the agronomic sustainability of the AI; and whether or not the AI is practical for smallholder farmers to use. Using these data, a list of priority biopesticides for which follow-up action is recommended was compiled. Fifty biopesticide AI were identified, which have been registered in one or more of the 30 countries for FAW management. Twenty-three of these are recommended for follow-up, for example field trials or bioassays.

Session 5-T 2 - Sustainable non-chemical methods for fall armyworm control

Controlling fall armyworm with the use of baculoviruses and fungi

Felix Dubach[1]

[1]*Andermatt Biocontrol, Grossdietwil, Switzerland*

The fall armyworm has been controlled in South America with the use of biological pesticides, such as baculoviruses, with success. For Africa, such data is not widely available. Andermatt Biocontrol have conducted field trials with several biopesticides, based on baculoviruses and fungi, against the fall armyworm in Africa and Asia and the U.S. during the past two years. The use of such products enables farmers to protect their crops without being subject to the potentially dangerous side effects from the use of chemical pesticides. The experience and data from those trials are clearly showing that biopesticides provide a viable alternative to chemical pesticides. These data shall be presented and discussed to a wider public for the first time at the IWGO conference in 2019.

Session 5-T 3 - Sustainable non-chemical methods for fall armyworm control

Native genetic resistance to fall armyworm in Africa: breeding progress by CIMMYT and prospects

Anani Bruce[1]

[1]*International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya*

Fall armyworm (FAW) has emerged as a serious threat to maize production in Africa since 2016. Host plant resistance is an important component of integrated pest management (IPM) of FAW. Leveraging on CIMMYT's maize germplasm, during the last two years we have initiated breeding program for identification of diverse sources of native genetic resistance to FAW. Here, we describe the progress and achievements in terms of (a) development of insect-rearing and screen-house facilities for screening maize germplasm against FAW under artificial infestation; and (b) identification of native genetic resistance sources from CIMMYT germplasm. FAW insect-rearing facilities and protocols, with a capacity to supply 300,000-400,000 neonates per year have been established at KALRO-Katumani. A screenhouse complex has been established at KALRO-Kiboko. A total of 1600 maize genotypes, including inbred lines and pre-commercial hybrids from CIMMYT have been screened in these screenhouses. Seven inbred lines (CML71, CML338, CKSBL10153, CKSBL10008, CKSBL10004, CKSBL10021 and CKSBL10002) were identified as promising trait donors for FAW tolerance. A total of 1000 pre-commercial hybrids developed from FAW tolerant parents were evaluated at Kiboko under FAW artificial infestation. In one of the trials, the top 10 hybrids produced 47 to 77% higher grain yield than the best commercial check. The best FAW tolerant hybrids are currently being validated under FAW artificial infestation, and at 10-15 FAW hotspot sites, for ascertaining their grain yield and responses to major foliar diseases. The best first-generation FAW tolerant maize hybrids will be announced to partners latest by first quarter of 2020 for further evaluation under NPTs, varietal release and commercialization.

Session 5-T 4 - Sustainable non-chemical methods for fall armyworm control

Prospects for biopesticides and local farmer's methods to achieve sustainable control of fall armyworm

Dirk Babendreier[1], Lakpo Koku Agboyi[3], Patrick Beseh[3], Chiluba Mwape[4], Gilson Chipabika[5] & Marc Kenis[1]

[1]CABI CH, Delemont, Switzerland
[3]CABI Ghana, Accra, Ghana
[4]CABI Zambia, Lusaka, Zambia
[5]ZARI, Lusaka, Zambia

Following the recent introduction to Africa, the fall armyworm, *Spodoptera frugiperda* (J.E. Smith), is causing considerable economic losses in maize. As emergency action, farmers throughout the continent were starting to use insecticides, which not only are costly but also have high potential to disrupt integrated- or generally low-input maize production systems. To address this, several biological control approaches were field tested in Ghana and Zambia including neem-based products, a baculo-virus, ash and soil as well as Maltodextrin and alata samina (a soap). While ash or local soil applied to the whorl as well as alata samina did not provide relevant pest control, the other products tested had positive effects on fall armyworm larval numbers, crop damage as well as cob damage and yield. However, the positive control, emamectin-benzoate, generally showed the strongest pest control characteristics and only the two neem-based treatments were comparable with it. Including also basic data on cost efficiency, prospects of these biological methods for being picked up by farmers are discussed.

Session 5-T 5 - Sustainable non-chemical methods for fall armyworm control

Development of entomopathogenic fungi-based biopesticides for the management of the invasive fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), in Africa

Komivi Senyo Akutse[1], Ruth Murunde[2], Jane Wanjiru Kimemia[1], Sunday Ekesi[1], Fathiya Mbarak Khamis[1], Fidelis Levi Odhiambo Ombura[1] & Sevgan Subramanian[1]

[1]*International Centre of Insect Physiology and Ecology, Nairobi, Kenya*
[2]*RealIPM Kenya, Thika, Kenya*

The fall armyworm (FAW), *Spodoptera frugiperda,* has rapidly spread across cereal growing areas of the continent in 44 countries. The pest has emerged as a threat to food security and livelihoods with estimated crop losses of US$ 1.1 – 4.7 billion a year. Emergency responses to counter FAW have predominantly involved chemical pesticides, which are expensive for smallholders and have undesirable environmental and health risks. Fall armyworm (FAW) is known to be susceptible to various insect pathogens, key among which are Baculoviruses, *Bacillus thuringiensis* (*Bt*) and entomopathogenic fungi (EPF). Biopesticides developed from these insect pathogens could be ecologically balanced and eco-friendly alternatives to pesticides for FAW management.

In the scope of searching for sustainable management approaches, we screened 20 entomopathogenic fungal (EPF) isolates (14 *Metarhizium anisopliae* and 6 *Beauveria bassiana*) for their efficacy against eggs and second instars of FAW. Among the isolates tested, only *B. bassiana* ICIPE 676 caused moderate mortality of 30% to second instar FAW. However, against eggs of FAW, *M. anisopliae* ICIPE 78, ICIPE 40, ICIPE 20 and ICIPE 7 caused more than 79% egg mortality. These fungi also infected the neonate larvae emerging from surviving eggs, and cumulated mortality of eggs and neonates was higher than 92%, with ICIPE 41 being the most effective isolate (97.5% mortality). Further screening of adult FAW for susceptibility to EPFs, indicated that *M. anisopliae* (ICIPE 315, ICIPE 7) and *B. bassiana* (ICIPE 621, ICIPE 676) isolates caused 100% mortality.

Field efficacy trials on maize with ICIPE 78 and 7, which are commercialized for spider mite and ticks' control, respectively, were conducted in partnership with the private sector partners, RealIPM. Outcomes of the field trials indicated that both isolates were effective against FAW, significantly reducing foliar damage and could emerge as candidate biopesticides for FAW management in Africa.

Session 5-T 6 - Sustainable non-chemical methods for fall armyworm control

Parasitism of *Spodoptera frugiperda* in Ghana, West Africa

Lapko Koku Agboyi[1], Patrick Beseh[4], Samuel Adjei Mensah[1], Victor Attuquaye Clottey[1], Ivan Rwomushana[3], Raymond Glikpo[4], Roger Day[3] & Marc Kenis[2]

[1]CABI, Accra, Ghana
[2]CABI, Delémont, Switzerland
[3]CABI, Nairobi, Kenya
[4]Plant Protection and Regulatory Services Directorate (PPRSD), Accra, Ghana

The cereal pest fall armyworm, *Spodoptera frugiperda*, originating from the Americas recently invaded most African countries, where it is seriously threatening food security. Severe damages caused by the pest to maize production were reported in several African countries including Ghana, since 2016. For the moment, management methods heavily rely on the use of synthetic insecticides but there is a need for more sustainable control methods, including biological control. However, little information exists on the diversity and potential of local natural enemies of *S. frugiperda* in Africa, especially West Africa. Therefore, surveys were made for parasitoids in different localities of Ghana. Eight species were found and they included one egg parasitoid; one egg-larval; four larval and two larval-pupal parasitoids. The two most abundant parasitoids were two Braconidae, the egg-larval parasitoid *Chelonus bifoveolatus* and the larval parasitoid *Coccygidum luteum*. Quantitative data on parasitism were gathered in three Ghanaian regions. Parasitism rates varied from 0% to 75% between sites and from 5% to 39% on average between regions. These data provide an important baseline for the development of various biological control options. The egg parasitoid, *Telenomus remus* can be used in augmentative biological control and investigations should be conducted to assess how cultural practices can enhance the activity of the main parasitoids in the field.

Session 5-T 7 - Sustainable non-chemical methods for fall armyworm control

Evaluation and registration trials of Fawligen, a baculovirus-based biological control for fall armyworm, in Africa and South Asia

Shachi Gurumayum[1], Paula Marcon[1], Anthony Hawes[1] & Peter Berweger[1]

[1]AgBiTech LLC, Fort Worth, Texas, U.S.A.

According to the FAO, fall armyworm (FAW) has caused economic losses worth $4.8 billion from maize production alone across the African continent ever since it first appeared in early 2016 in West Africa. The pest spread rapidly and is now present in all of Sub-Saharan Africa (SSA). If untreated, FAW can lead to a total loss of maize crops making the life of smallholder farmers who rely on the crop for food security or some additional cash at jeopardy.

In response to this, AgBiTech, a US-headquartered biological control company, has been working proactively in partnership with key players like CABI, IITA, CIRAD and various national research institutions such as ZARI, KALRO and ISRA to evaluate and carry out registration trials across multiple agroecological zones in SSA for one of its products, Fawligen. Fawligen is a formulation of *Spodoptera fruigiperda* NucleoPolyhydro Virus (SfNPV) with a concentration of 7.5 X 10^{12} Occlusion Bodies per litre of the product that can form a critical component of any Integrated Pest Management program for FAW, and can be applied using a knapsack sprayer, a boom sprayer or via a centre pivot irrigation system.

In this presentation, we will give an introduction to the world of baculoviruses, and present the results and data from the different countries where Fawligen is being tested. We will also present some practical work done to demonstrate the commercial efficacy of Fawligen as well as its stability in a normal operating environment in Africa. This will include work done with large scale export growers in West Africa and the application of Fawligen to smallholder fields in South Sudan under a partnership with USAID, CIMMYT, CABI and the FAO. Some indicative results from early-stage work being done in two South Asian countries will also be presented.

Session 6-T 1 - Advances in the development of biological control solutions for the management of fall armyworm

Effectiveness of locally recruited egg parasitoids for biological control of the fall armyworm in the Sahel

Malick Ba[1], Amani Lamine[1] & Laouali Karimoune[1]

[1]*International Crops Research Institute for the Semi-Arid Tropics, Niamey, Niger*

The fall armyworm (FAW), *Spodoptera frugiperda*, an insect native to tropical and subtropical Americas has recently spread to Africa and become a serious pest mainly to maize but also sorghum in some places. The emergency response relied on the spray of synthetic insecticides. Biological control can offer an economically and environmental friendly alternative and contribute to an integrated pest management approach. Consequently, surveys of FAW natural enemies were conducted in maize and sorghum fields in different locations in Niger in 2017 and 2018. The parasitoids encountered included several Braconidae, Ichneumonidae and Tachinidae fly parasitizing larvae of the fall armyworm. In addition, two egg parasitoids were also encountered among which, *Trichogramma* sp. and *Telenomus remus* Nixon (Hymenoptera: Platygastridae). Interestingly *T. remus* is the main egg parasitoid of *S. frugiperda* in the Americas where it is also used in augmentative biological control programmes. The effectiveness of the two egg parasitoids was assessed in the laboratory. The most effective parasitoid is *T. remus* as it parasitized up to 75% of FAW eggs compared to only 27% for *Trichogramma* sp. Likewise *T. remus* yielded more progeny (7-fold) than *Trichogramma* sp. Females of *T. remus* had a lifespan of nearly 17 days, and the development from egg to adult took 10 days at a temperature of 27.8 ± 1°C and a relative humidity of 85.5 ± 0.5%. Culture of *T. remus* has been successfully established in the laboratory, laying the groundwork for using *T. remus* in augmentative releases against the FAW in Africa.

Session 6-T 2 - Advances in the development of biological control solutions for the management of fall armyworm

Natural enemy complex of the fall armyworm on maize in South-Eastern Zambia

Léna Durocher-Granger[1,4], Marc Kenis[2], Tibonge Mfune[3], Monde Musesha[3], Gilson Chipabika[3] & Marcel Dicke[4]

[1]CABI, Leusden, Netherlands
[2]CABI, Delémont, Switzerland
[3]ZARI, Chilanga, Zambia
[4]Wageningen University and Research, Wageningen, Netherlands

Fall armyworm (FAW) (*Spodoptera frugiperda*, JE Smith), an invasive insect pest from the Americas, causes considerable losses on maize to smallholder farmers in Zambia since late 2016. The increase use in pesticides to control FAW in Africa raises concerns for health and environmental risks resulting in a grown interest in research on biological control options for smallholder farmers. In order to evaluate the relative abundance of local natural enemies attacking FAW, we have collected weekly FAW eggs and larvae over a maize crop cycle during the rain season of 2018-2019 in four locations in the South-Eastern region of Zambia. Larvae and eggs were placed individually in petri dishes and checked daily for parasitoid emergence and dead FAW larvae and pupae were dissected to record parasitism. For each location and date of collection, crop stage, the number of plants checked, and damage were recorded to analyse which factors best explain the abundance and occurrence of the natural enemy species on maize. Preliminary results from field collections indicate a low parasitism rate from local natural enemies by 13 different species of parasitic wasps and tachinid flies. All species found killed larval stages and no parasitoid emerged from eggs. These results show that even if a high number of species are attacking FAW in Zambia, the parasitism rate of local natural enemies is too low to successfully control FAW at high density. However, these findings point out to potential for increasing local natural enemies' populations through augmentative or conservation biological control programmes for developing safe and practical control methods for smallholder farmers.

Session 6-T 3 - Advances in the development of biological control solutions for the management of fall armyworm

Novel approaches to control the fall armyworm with entomopathogenic nematodes

Patrick Fallet[1], Lara De Gianni[1], Joelle Kajuga[2], Bancy Waithira[2], Ricardo A. R. Machado[5], Gaetan Glauser[3], Stefan Toepfer[4] & Ted Turlings[1]

[1]Laboratory of Fundamental and Applied Research in Chemical Ecology, University of Neuchâtel, Neuchâtel, Switzerland
[2]Rwanda Agriculture and Animal Resources Board, Southern Agricultural Division, Huye, Rwanda
[3]Neuchâtel Platform of Analytical Chemistry, University of Neuchâtel, Neuchâtel, Switzerland
[4]CABI Switzerland, Delémont, Switzerland
[5]Institute of Plant Sciences, University of Bern, Bern, Switzerland

Native to the Americas, fall armyworm (FAW; *Spodoptera frugiperda*, Lepidoptera: Noctuidae) recently invaded most of Africa and large parts of Asia. Its caterpillars cause tremendous damage to a large variety of crops, but most importantly to maize. Therefore, effective control measures, which do not endanger humans or the environment, are urgently needed. We explore possibilities of using entomopathogenic nematodes (EPN) to control FAW caterpillars. We intend to use locally well-adapted EPNs that have been isolated from soils in Rwanda in 2014 and 2018. To assess the potential of Rwandan EPNs in infecting and killing FAW, we conducted a comparative screening of Rwandan, Mexican and commercially available EPNs. Results show that different steinernematid and heterorhabditid species and strains can effectively infect and kill FAW larvae. The most promising EPNs are currently being incorporated into a carrier that will protect them from desiccation and UV radiation. Such carriers might be alginate beads, alginate gels or sand. To increase the efficacy and specificity of the control measure, we aim to identify attractants and feeding stimulants that could be added to the carrier in order to encourage FAW to feed on the EPN-containing substrate. We plan to apply the carrier into the whorl of maize plants, where FAW caterpillars are mostly found. First laboratory trials showed that this approach has good potential to control FAW.

This study is financed through a PhD scholarship by the Canton of Neuchâtel as well as through CABI by the Department for International Development (DFID, UK) and the Directorate-General for International Cooperation (DGIS, Netherlands).

Biological characteristics of the egg parasitoid *Trichogramma pretiosum* (Hymenoptera, Trichogrammatidae) against the new invasive pest, fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in China

Jincheng Zhou[1], Hui Dong[1] & Bin Cong[1]

[1]Shenyang Agricultural University, Shenyang, P.R. China

The fall armyworm (FAW), *Spodoptera frugiperda* (Lepidoptera: Noctuidae), is the most dangerous invasive pest across sub-Saharan Africa, South Asia, and now mainland China, which originates from the Americas. Recently, this exotic species has rapidly spread to at least 18 provinces of China with the southeast monsoon. The enemy release hypothesis (ERH) predicts that the successful invasion of an alien species is often caused by a decrease in regulation by natural enemies. ERH assumes there will be fewer specialist enemies in the invaded range when compared with the native range. The egg parasitoid *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) is the principal natural enemy against FAW in its native range and has been introduced into China since 1979. Our results revealed the potential advantages of *T. pretiosum* for the control of FAW. The results will supply the basic reference for the usage of *T. pretiosum* production as a superior biological control agent against FAW.

Prospects for the classical biological control of *Spodoptera frugiperda* in Africa and Asia using parasitoids from the Americas

Marc Kenis[1]

[1]CABI, Delémont, Switzerland

Since its recent arrival in Africa and Asia, the fall armyworm, *Spodoptera frugiperda*, has become a major pest of maize and other cereals throughout the two continents, threatening the livelihood of millions of smallholder farmers. So far, emergency responses have consisted mainly in the use of chemical insecticides and more sustainable management methods, such as biological control, are urgently needed. *Spodoptera frugiperda* could potentially be controlled in Africa and Asia by the introduction of a natural enemy from its area of origin, the Americas, a method named classical biological control. However, in contrast to many other invasive pests, *S. frugiperda* is also a pest in its area of origin, suggesting that natural enemies alone may not be able to control it. Nevertheless, even a partial control leading to a reduction of yield losses and pesticide use would have, at continental scale, a tremendous effect on food security, health and the economy. The main criteria for the selection of American natural enemies are their efficiency as control agent and their specificity for the target pest. All known predators of *S. frugiperda* in the Americas are highly polyphagous. Egg parasitism is usually low and the main egg parasitoid, *Telenomus remus*, is already present in Africa and Asia. In contrast, some larval parasitoids could be considered for introduction. In the Americas, larvae are attacked by a large complex of parasitoids and, in areas with no or limited insecticide applications, parasitism rates can be high. Some of the main parasitoids, such as the ichneumonid *Eiphosoma laphygmae*, are known nearly exclusively from *S. frugiperda* whereas, for others, specific biotypes or cryptic species cannot be excluded. Some of these species are presently being studied in various quarantine laboratories. At the same time, the parasitoid complex in Africa and Asia has to be investigated to assess potential competitive interactions with introduced parasitoids.

Session 6-T 6 - Advances in the development of biological control solutions for the management of fall armyworm

Alien invasive *Spodoptera frugiperda* in Africa encounter indigenous natural enemies: new parasitoid-host association

Samira A. Mohamed[1], Subramanian, Sevgan[1], Francis Obala[1], Mark Wamalwa[1], Komi Fiaboe[2] & Sunday Ekesi[1]

[1]International Centre of Insect Physiology and Ecology, Nairobi, Kenya
[2]IITA, Yaoundé, Cameroon

The invasion and wide spread of the fall armyworm, *Spodoptera frugiperda,* represent a real impediment to food security and the livelihood of the millions of maize, sorghum and millet farming communities in sub-Saharan and Sahel regions of Africa. The use of biological control can offer more economically and environmentally safer alternative for the commonly used synthetic chemical insecticides for management of this pest. In this study, the performance of the newly described parasitoid *C*. *cotesia* against FAW was assessed. Furthermore, the potential area for its establishment under current and future climate scenarios have been projected using maximum entropy algorithm (Test Area under the receiver-operator curve (AUC) = 0.997). *Spodoptera frugiperda* immature stages were differentially accepted by *C. icipe* sp. for oviposition. The females accepted more 1st and 2nd instar larvae with parasitism level of more than 60%, while the 4th larval instar was the least accepted for oviposition. No egg was oviposited in the egg, 5th, 6th larval instar and pupal stage. Among the larval stages accepted for oviposition the percent cocoon formed as well and the number of emerged wasps varied considerably with age of the larval instar, with 1st and 2nd yielded the highest. Percent female progeny also varied with host instar, and it was female bias. Developmental duration both in term of time to cocoon formation and overall developmental time was significantly affected by the larval stage at initial parasitism being longest on 4th instar. Egg-load varied remarkably with wasp age. Prospects for augmentative and classical biological control of *S. frugiperda* in Africa and beyond is highlighted in the light of the findings of study.

Industry's role in collaborating with key stakeholders to manage food security threats like *Spodoptera frugiperda*

Clinton Pilcher[1]

[1]*Corteva Agriscience, Johnston, Iowa, U.S.A.*

The fall armyworm has recently invaded many countries across Africa and Asia. Key stakeholders have convened across numerous venues to determine how best to address country needs. Here we discuss the opportunity among these stakeholders to address three critical areas; 1) knowledge development; 2) developing tools to address production needs, and 3) policy that enables the availability of critical management tools. Given historical knowledge in managing fall armyworm, Africa and Asian countries provide unique challenges, along with unique opportunities, to effectively and sustainably manage this pest using integrated approaches.

Session 7-T 2 - Addressing a significant food security threat: *Spodoptera frugiperda* invading new geographies

MIPs for moths

Nicholas Miller[1], Gérald Bermond[1], Juan Luis Jurat-Fuentes[2] & Dominic Reisig[3]

[1]Illinois Institute of Technology, Chicago Illinois, U.S.A.
[2]University of Tennessee, Knoxville, Tennessee, U.S.A.
[3]North Carolina State University, Plymouth, North Carolina, U.S.A.

Population genetic analyses can provide detailed information about the sequence of introduction events that take place when an invasive species spreads into new locations. Genetic marker systems suitable for the analysis of invasion processes should satisfy three key criteria.

1. They survey multiple independent loci throughout the genome.
2. They can be used with DNA from specimens that have been collected under a variety conditions.
3. They allow for the discovery of new alleles as additional populations are analysed, avoid problems of ascertainment bias.

Molecular Inversion Probes (MIPs) enable the targeted re-sequencing of up to thousands of loci from hundreds of individuals in a cost-effective manner. We have evaluated the suitability of MIPs as a tool for studying the population genetics of migratory and invasive Noctuid moths, including fall armyworm, *Spodoptera frugiperda*.

Session 7-T 3 - Addressing a significant food security threat: *Spodoptera frugiperda* invading new geographies

The crop resources in China and ecological consequences of fall armyworm invasion

Li Xijie[1] & Baoping Zhai[1]

[1]Nanjing Agricultural University, Nanjing, China, P. R. China

Fall armyworm (FAW), *Spodoptera frugiperda*, is a native species in America and an invasive species in Asia. It is a polyphagous pest and has strong dispersal ability. China and the U.S.A. are both large countries in the northern hemisphere, which have similar latitude and similar territory. In this paper, comparison of the two regions will help us to create a scenario of how FAW will perform in China.

From the perspective of migration, insect source basement in East Asia is better than that in the U.S. because there is more land at low latitude in Asia. Indo-China peninsula has a high biological diversity, both vegetation and animals. Thus, predators for pests are abundant. But as they leave there and enter the crop production area in China. The number of predators drops sharply, offering great convenience to FAW population explosion.

The three plains, which are Middle-lower Yangtze River Plain, North China Plain and Northeast Plain, are all located in the subtropical monsoon climate zone. Although the “Southeast Hills” area is not plain, but the low latitude leads to a high effective accumulative temperature and considerable yield. Southeast Hills and the three plain located in a south-north string in monsoon climate zone, along with the trend of East Asia Summer Monsoon. This string, it's not only the corridor of monsoon, also the highway for migratory insects' annual journey. The overlap makes production of crops expose to the threat of migratory pests. Besides, activity time of migratory insects is also synchronized with plants. Plants begin growing from south to north, migratory insect pests appear in the same way.

Session 7-T 4 - Addressing a significant food security threat: Spodoptera frugiperda invading new geographies

Spodoptera frugiperda management in South America – past, present and future

Analiza Piovesan Alves[1], Silvana V. Paula-Moraes[2] & José M. Waquil[3]

[1]Corteva Agrisciences, Johnston, Iowa, U.S.A.
[2]Entomology & Nematology Department, West Florida Research and Education Center, Jay, Florida U.S.A.
[3]Universidade Federal de São João del-Rei, Sete Lagoas, Brazil

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith), is one of the most destructive maize pests in the tropical zone of the American continents, and recently has been reported in several countries in Africa and Asia. This species is highly polyphagous and can cause significant yield losses in maize crops under moderate-high infestations. Historical *S. frugiperda* management in South America relied on plant protection with synthetic insecticides, ranging from 1-10 applications per crop cycle, depending on pest pressure and crop system management. However, this strategy has not been satisfactory in many situations because of larval feeding site and the biotic potential of this species. More recently, genetically modified maize plants expressing insecticidal *Bt* proteins gained significant role in managing this pest in the region due to its effectiveness. Nonetheless, local environment, agricultural landscape, and agronomic practices can create intense selection pressure favouring resistance development to both chemistries and biotech control tools, representing a significant challenge to effective long-term control of this pest in maize and other important crops. Understanding regional landscape, pest ecology and genetic variability is fundamental for establishment and deployment of effective, locally adapted practices, and the utilization of a variety of control tactics is a key strategy for sustainable management and cropping systems.

Session 7-T 5 - Addressing a significant food security threat: *Spodoptera frugiperda* invading new geographies

Resistance of insect pests to *Bt* crops: implications for fall armyworm management in Asia and Africa

Fangneng Huang[1]

[1]*Louisiana State University Agricultural Center, Baton Rouge, Louisiana, U.S.A.*

Since first being commercialized in 1996, *Bt* crops have gained widespread acceptance in the world. To counter the threat of insect resistance to the *Bt* crops, two resistance management (IRM) strategies (e.g. high dose/refuge and gene pyramiding) have been implemented in the U.S. and other countries. The long-term use of *Bt* crops in the world provides an excellent opportunity to analyze the effectiveness of the adopted IRM plans. After 20+ years of intensive use of *Bt* crops, four major target pests (European corn borer, southwestern corn borer, tobacco budworm, and pink bollworm) in the U.S. still remain susceptible to *Bt*, while field resistance in fall armyworm and other target pests has occurred in at least 24 cases in the world. This presentation will discuss the circumstances that led to these successes and failures of resistance management so that improved IRM strategies can be developed and problems in the future can be avoided. Knowledge gained from the 20+ years of *Bt* crop use in world should also be valuable for management of the recent outbreak of the fall armyworm in Asia and Africa.

Session 7-T 6 - Addressing a significant food security threat: *Spodoptera frugiperda* invading new geographies

Fall armyworm management through educational training: an industry perspective

Marlin Rice[1], Marlene Van Rooyen[1], Somsak Samanwong[1] & Clinton Pilcher[1]

[1]Corteva Agriscience, Johnston, Iowa, U.S.A.

The fall armyworm invaded Africa in 2016, and since that time it has continued its dispersal across India and into southeastern Asia. The initial economic impact in these geographies has been significant. Corteva Agriscience is broadly and intensely involved in training both internal employees and external stakeholders on the significance of the insect and crop management solutions. We will discuss our educational efforts and present results from short surveys that give perspectives from stakeholders on management strategies.

Session 8-T 1 – Field-evolved insecticide resistance in maize pests

Can CRISPR mutations mimic field-evolved resistance?

Marcé Lorenzen[1]

[1]*Department of Entomology and Plant Pathology, North Carolina State University, Raleigh, North Carolina, U.S.A.*

Western corn rootworm (WCR) is an important pest of maize, in part because it is highly adaptable and known to rapidly evolve resistance to control methods. While much effort has gone into understanding the genetic basis of field-evolved resistance in WCR, particularly as it pertains to resistance to *Bt*, pin-pointing causative mutations can be a long and laborious task. Here we ask the question: Can CRISPR/Cas9-based genome editing be used to mimic mutations known to be associated with field-evolved resistance? And if so, how could these strains be used? Most of what we know about *Bt* toxicity comes from research in lepidopterans, where several genes have been implicated in the development of resistance. Although *Bt* toxins have almost no cross-reactivity between lepidopterans and coleopterans, it is possible that they could share some mechanisms of toxicity, and, therefore, resistance development. In fact, it was recently shown that expression of Cry1Ia12 in cotton protected the plant from both a lepidopteran pest, *Spodoptera frugiperda* and a coleopteran pest, *Anthonomus grandis*, suggesting that *Bt* toxicity may share more commonalities between clades than previously thought. If so, we could gain a better understanding of *Bt* toxicity in WCR by using the CRISPR/Cas9 system to mimic mutations known to confer *Bt* resistance in lepidopterans. Moreover, these mutant strains could be used in complementation studies with field-caught WCR to potentially speed discovery of the genetic basis of field-evolved resistance in this major pest.

Session 8-T 2 – Field-evolved insecticide resistance in maize pests

Mechanisms, frequency and dispaersal of resistance to transgenic corn in fall armyworm (*Spodoptera frugiperda*)

Caroline Placidi de Bortoli[1], Rahul Banerjee[1], Robert Meagher[2], Heba Abdelgaffar[1], Fei Yang[3], David Kerns[3], Fangneng Huang[4], Komivi Akutse[5], Eliseu Pereira[6], Clebson Tavares[6], Tejas Rao[1] & Juan Luis Jurat-Fuentes[1]

[1]University of Tennessee, Knoxville, Tennessee, U.S.A.
[2]USDA-ARS Behavior and Biocontrol Unit, Gainesville, Florida, U.S.A.
[3]Texas A&M University, College Station, Texas, U.S.A.
[4]Louisiana State University, Baton Rouge, Louisiana, U.S.A.
[5]International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya
[6]Universidade Federal de Viçosa, Viçosa, Brazil

Populations of the fall armyworm (*Spodoptera frugiperda*) in Puerto Rico, Florida, North Carolina, Brazil and Argentina have developed practical field-evolved resistance to transgenic corn producing the Cry1F insecticidal protein from the bacterium *Bacillus thuringiensis* (*Bt*). Recent identification of this insect as a devastating invasive pest in Africa, India and China highlights the importance of understanding the mechanisms and the frequency of the alleles responsible for resistance in *S. frugiperda* populations. We previously reported that resistance in *S. frugiperda* from Puerto Rico is genetically linked to a mutation (PR1 allele) in an ATP Binding Cassette subfamily C2 gene (*SfABCC2*) resulting in a truncated, non-functional Cry1F toxin receptor (SfABCC2) protein. We now report on a second resistance allele isolated from a Cry1F-resistant population from Florida and the ue of genotyping tests to detect and determine the frequency of Cry1F-resistance alleles in field *S. frugiperda*. We will also share infromation on candidate resistance mechanisms to the Vip3A toxin in a *S. frugiperda* strain originally isolated from Louisiana.

Session 8-T 3 – Field-evolved insecticide resistance in maize pests

Bacillus thuringiensis resistance in western bean cutworm populations and the influence of refuge structure and larval movement

Julie A. Peterson[1], Brad S. Coates[2], Katharine A. Swoboda Bhattarai[1], Craig A. Abel[2], Sarah N. Zukoff[3] & Thomas E. Hunt[4]

[1]Department of Entomology, University of Nebraska-Lincoln, West Central Research & Extension Center, North Platte, Nebraska, U.S.A.
[2]USDA-ARS Corn Insects & Crop Genetics Research Unit, Iowa State University, Ames, Iowa, U.S.A.
[3]Department of Entomology, Kansas State University, Southwest Research and Extension Center, Garden City, Kansas, U.S.A.
[4]Department of Entomology, University of Nebraska-Lincoln, Haskell Agricultural Laboratory, Concord, Nebraska, U.S.A.

Despite the implementation of insect resistance management (IRM) plans, field-evolved resistance to genetically modified maize hybrids that express transgenic *Bacillus thuringiensis* (*Bt*) toxins has been documented within numerous insect populations. Functional resistance among western bean cutworm (WBC; *Striacosta albicosta*, Lepidoptera: Noctuidae) field populations towards Cry1Fa toxin-expressing hybrids suggests that the high-dose/refuge strategy within mandated IRM plans may be insufficient to prevent resistance. We evaluated factors that may lead to low-dose exposures from plant tissues, which may in turn facilitate the survival of heterozygote larvae and the accumulation or resistant phenotypes in the field. Results of field studies: 1) Determined the tolerance of larvae to Cry1F and Vip3A toxins across geographic regions where control issues have occurred using toxin overlay and tissue incorporated bioassays; 2) Estimated cross-pollination rates in integrated refuge scenarios; and 3) Described larval movement behavior under structured and integrated refuge scenarios. The evaluation of factors that may contribute to resistance within WBC populations is likely applicable to other ear-feeding species of Lepidoptera. Furthermore, these results will provide critical data to stakeholders and government regulatory agencies for the development and implementation of IRM plans that improve the durability of plant-incorporated protectants.

Session 8-T 4 – Field-evolved insecticide resistance in maize pests

The interwoven impacts of *Bt* maize, *Bt* cotton, and soybean on *Helicoverpa zea* in the United States

Dominic Reisig[1], Lewis Braswell[6], Sebe Brown[2], David Kerns[3], Fred Musser[4], Francis Reay-Jones[5] & Fei Yang[3]

[1]North Carolina State University, Plymouth, North Carolina, U.S.A.
[2]Louisiana State University, Alexandria, Louisiana, U.S.A.
[3]Texas A&M University, College Station, Texas, U.S.A.
[4]Mississippi State University, Starkville, Mississippi, U.S.A.
[5]Clemson University, Florence, South Carolina, U.S.A.
[6]Syngenta Crop Protection Inc., Greensboro, North Carolina, U.S.A.

Plant incorporated *Bt* toxins have successfully managed many lepidopteran pests in the United States for over 20 years. One species, *Helicoverpa zea*, has developed resistance to the Cry toxins in both maize and cotton in the southern US. As a result, in cotton expressing only Cry toxins, growers are relying on foliar oversprays of a single insecticide, chlorantraniliprole. Furthermore, while the plant incorporated VIP toxin has been introduced as a pyramid to some maize and cotton cultivars expressing Cry toxins, this is essentially a single mode of action, since there is resistance to Cry toxins. Maize is thought to be the primary driver in the system placing selection pressure on VIP, while soybeans are thought to be the primary driver in the system placing selection pressure on chlorantraniliprole. Both experimental and observational evidence suggest that *H. zea* is evolving resistance to VIP. Although true baselines were not established before the commercialization of VIP and chlorantraniliprole, current toxicity data suggest that *H. zea* have a range of susceptibility to VIP and that this toxin is expressed in plants at a moderate dose. In contrast, *H. zea* is still well controlled by chlorantraniliprole. In conclusion, we suggest changes in management to delay the development of resistance of plant incorporated *Bt* toxins as well as chlorantraniliprole for *H. zea*, including restricting the use of insecticides in maize and soybean and the need for studies to evaluate the role of cultural tactics, such as cover crops and tillage.

Session 9-T 1 - The use of emerging technologies in maize pest surveillance, reporting and forecasting

Smart Armyworm Surveillance

James Bell[1], Aislinn Pearson[1] & Sevgan Subramanian[2]

[1]Rothamsted Research, Harpenden, United Kingdom
[2]icipe, Nairobi, Kenya

In January 2016, the fall armyworm (FAW), an invasive moth pest native to tropical and subtropical regions of the Americas, was recorded for the first time in West Africa. In the past 3 years, the FAW has spread across sub-Saharan Africa into 44 countries, causing unprecedented yield losses in maize, its principle host. Management of the FAW by farmers is complex because individual moths have a prolific rate of spread, migrating distances >100 km per night; females have prodigious lifetime fecundities of ~1000 eggs and, although moths feed on maize, they may select from over 100 host plant species, including cotton, sorghum, sugarcane and rice. These traits indicate that real-time monitoring is essential to track rates of infestation in the region as well as develop appropriate management strategies for their control.

In November 2018, we launched the Smart Armyworm Surveillance project in Kenya, funded by the Bill & Melinda Gates Foundation under the Tools and Technologies for Broad-Scale Disease Surveillance of Crop Plants in Low-Income Countries initiative (Round 21). Our aim is to automatically identify the FAW in real-time, providing Kenya, a lower middle-income country, with a regional scale early warning system, thus facilitating timely and effective management interventions.

We have installed three types of infrastructure for our super-large experiment. We have imported and commissioned an entomological radar and erected a network of 20 smart traps that span from Mombasa to the shores of Lake Victoria and north to Mount Elgon; these pheromone-based smart traps are capable of automatic recognition and real-time reporting to the cloud. We have also added a layer of hand-held computer vision app technology to enable farmers and crop consultants with smart phones to identify and distinguish the FAW from the 20 common species of moth pest found in the region. In this talk, we will review those activities and present some preliminary data.

Studying the behavioral ecology of insects in the field using multiple video cameras to produce 3-d tracks for quantification of flight behavior

Michael Caprio[1]

[1]Mississippi State University, Mississippi State, U.S.A., mcaprio@entomology.msstate.edu

The ability to track insects in flight will increase our ability to measure and understand insect responses to stimuli while airborne. Tracking can address such questions as what behavioral events lead up to a parasitoid locating a host, what flight behaviors lead a mosquito to its prey? While tracking organisms with cameras has a long history, recent advances in computer vision have simplified the process. We developed an open-source program (Ikhnaie) to semi-automatically track insects in flight using two video cameras. Three-dimensional tracks for western corn rootworm in flight over cornfields, odonate (*Pachidiplax longipennis*) territory defense and *Culex quinquefasciatus* approaching CO_2 emitting targets demonstrate potential utility of the software. Our goal is to understand and quantify the chain of behaviors leading to resource location with the goal of manipulating the environment to either increase or decrease location depending on desired outcomes.

Session 9-T 3 - The use of emerging technologies in maize pest surveillance, reporting and forecasting

Use of spectral remote-sensing methods for *H. armigera* detection in maize

Fruzsina Enikő Sári-Barnácz[1], Márk Szalai[1], József Kiss[1] & Vince Láng[2]

[1]Szent István University, Plant Protection Institute, Gödöllő, Hungary
[2]AgriDron Ltd., Gödöllő, Hungary

Digitalisation and technologies available have gone through great development, thus, previously unimaginable amount of data has become reachable due to the development of spectral remote sensing methods. At the same time, global climate change favours pests such as *Helicoverpa armigera.* This pest is expected to cause more serious crop damages for higher rate of potential pupal diapause and higher gradations due to the increasing frequency of arid years. The aim of our investigation was to analyse the correlation of different spectral ranges/vegetation indexes with *H. armigera* damage.

Damage rate of *H. armigera* was determined as the percentage of infected maize cobs on sampled plants. Condition of maize crops was analysed by UAV recorded spectral data in blue, red and NIR range, moreover, different vegetation indexes were calculated. Landsat provided Normalised Difference Vegetation Index (NDVI) data of different time intervals was also considered.

Landsat NDVI showed strong or moderate negative correlation between the damage rate of maize fields and average NDVI value of fields during the vegetation period of 2017. By UAV recordings, significant, moderate to high positive correlation (r= 0.65 - 0.73) was found between the damage rate and the average reflection values in green and blue range in all experimental fields. However, the correlation with NIR was not evinced. Each vegetation index showed significant, high negative correlation with the damage rate (r= -0.76 - -0.85). Significant moderate (r= 0.75) correlation have been revealed between humus content of the soil and GDVI (Green Difference Vegetation Index) and high correlation with the infection rate (r= -0.86). Our study indicates, that real-time spectral analysis of maize has great potential to determine the spatial variability of *H. armigera*, and to utilize in pest models.

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Session 10-T 1 - Free topics

Development of resistance to *Bt* toxins in *Ostrinia furnacalis* under spatiotemporal alternation scenery of multiple single-gene events

Yueqin Wang[1], Xiaorui Yan[1], Yudong Quan[2], Zhenying Wang[1] & Kanglai He[1]

[1]Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, P.R. China
[2]Department of Genetics, Universitat de València, València, Spain

Control of insect pests have been upgraded since the commercialization of *Bt* maize. However, the benefits of this approach have been threatening by rapid development of pest resistance. High-dose refuge strategy plus 'pyramid strategy' for delaying resistance have been widely adopted, especially in the developed countries. However, multiple single-gene events developed by different companies are usually deployed simultaneously in the small landscape farms in developing countries such as China and India, especially in the initial stage of *Bt* crops commercialization. Therefore, two different events expressing different toxins are planted in simultaneously across fields and/or in subsequent seasons, which could be considered as "toxin rotation" across generations, i.e. spatiotemporal alternation strategy of multiple single-gene events. Hereby we set out laboratory selection experiments to examine resistance evolutionary trend in *Ostrinia furnacalis* under alternation of multi-toxins by mixing individual toxins (Cry1Ab, Cry1F, or Cry1Ie) in artificial diet to emulate single-gene *Bt* maize plants. In conclusion resistance evolution to individual *Bt* toxins was virtually independent in *O. furnacalis* under spatiotemporal alternation scenery of multiple single-gene events.

Session 10-T 2 - Free topics

Development of resistance to *Bt* toxins in oriental armyworm

Jing Yang[1], Yueqin Wang[1], Yudong Quan[1], Xiaorui Yan[1], Zhenying Wang[1], P Sivaprasath[1] & Kanglai He[1]

[1]*Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, P.R. China*

Oriental armyworm (OAW), *Mythimna separate* (Walker), is a destructive pest of agricultural crops in the Asia and Australia, which frequently outbreak on maize in China. Toxicity of 7 Cry toxins and 3 Vip toxins against OAW neonate larvae were evaluated by using diet incorporated bioassay. In addition, development of resistance to Cry1Ab, Cry1F, Vip3Aa19 toxins in OAW were assessed in the laboratory experiment by exposing neonates to those toxins for 10 days, respectively. Finally, inheritance of resistance in Vip3Aa19-selected strain was investigated. The bioassays results revealed that LC_{50} (lethal concentration for 50% mortality) values ranged from 1.6 to 78.6 µg/g (toxin/diet) for these toxins. Among them, Vip3 proteins along with Cry1A proteins and Cry2Aa, were the ones with the highest potency, with LC_{50}values ranging from 1.6 to 7.4 µg/g. The susceptibility of Cry1F selected strain to Cry1F toxin was not significantly different from susceptible strain after 10 generations of selection. Also, the susceptibility of Cry1Ab selected strains to Cry1Ab toxin were not significantly different from susceptible strain after 5 or 8 generations of selection with Cry1Ab under selection pressures of 99% or 75-80% of mortalities. However, Vip3Aa19-selected strain evolved 278-folds and over 3,000-folds resistance to Vip3Aa19 after 2 and 8 generations of selection, respectively. The effective dominance (*h*) of resistance in Vip3Aa19-selected strain decreased as toxin concentration increased. Resistance to Vip3Aa19 was partly dominant inheritance with maternal effect.

Session 10-T 3 - Free topics

Baselines susceptibility establishment and development of diagnostic concentrations of Asian corn borer (Lepidoptera: Crambidae) populations to Cry1 from Huanghuaihai Summer Corn Region in China

Guoping Li[1], Hongqiang Feng[1], Tingjie Ji[1], Jianrong Huang[1], Houlu Jia[2], Bo Huang[1] & Xincheng Zhao[2]

[1]Institute of Plant Protection, Henan Academy of Agricultural Sciences, zhengzhou, P.R. China
[2]Department of Entomology, College of Plant Protection, Henan Agricultural University, Zhengzhou, P.R. China

Ostrinia furnacalis (Guenée), often called the Asian corn borer (ACB), a sibling species to *O. nubilalis*, is the dominant species and the most destructive pests of maize in Huanghuaihai Summer Corn region in China. Planting transgenic *Bt* corn is effective tool to control it. However, target insects evolved resistance to *Bt* crops is a big threat for the transgenic *Bt* crops sustainable planting. Susceptibility to Cry1Ab, Cry1Ac and Cry1F was determined for 15 populations of neonate *O. furnacalis* from the Huanghuaihai Summer Corn region during 2015-2016. Further, diagnostic concentrations were development and validation in 2017. The median lethal concentrations (LC_{50}s) to the three *Bt* toxin for the different collections ranged from 0.42 to 6.465 ng/cm^2, respectively. The bioassay results suggest that Huanghuaihai Summer Corn region corn borer populations were highly susceptible to *Bt* protein prior to the widespread cultivation of *Bt* corn. The estimated each LC_{99} and its the upper and down limits to Cry1Ab, Cry1Ac and Cry1F from the pooled bioassay data were selected as the candidate diagnostic concentrations and subsequently tested on 8 ACB populations collected in 2017. Results of the validation assays showed that the mortality response of all the tested ACB populations to Cry1Ab, Cry1Ac and Cry1F on each LC_{99} and upper limit of LC_{99} ng/cm^2 were higher than the expected mortality (99%). Therefore, the LC_{99} to Cry1Ab, Cry1Ac and Cry1F was used as diagnostic concentrations to monitor susceptibility in ACB populations in the Huanghuaihai Summer Corn region. This study provides the baselines of susceptibility and diagnostic concentrations for future estimates of ACB susceptibility changes after deployment of *Bt* corn in Huanghuaihai Summer Corn region.

Session 10-T 4 - Free topics

Molecular identification of invasive fall armyworm *Spodoptera frugiperda* in Yunnan Province

Lei Zhang[1], Lei Zhang[1], Minghui Jin[1] & Yutao Xiao[1]

[1]*Agricultural Genomics Institute, Chinese Academy of Agricultural Sciences, Shenzhen, P.R. China*

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith), is an important agricultural invasive pest that is native to tropical and subtropical America. At present, the insect has crossed the Myanmar and entered the southwestern Yunnan of China, and has the trend to overspread the surrounding areas. Rapid and accurate identification is the key to early warning, monitoring and prevention of invasive species. In this study, genetic methods based on two molecular markers, mitochondrial cytochrome oxidase subunit I gene (*CO1*) and triose-phosphate isomerase (*Tpi*), were used to characterize 83 samples collected from five regions in Yunnan Province. Samples could be accurately indentified to be *Spodoptera frugiperda* or close-related species such as *S. exigua* by sequence alignment based on *CO1* gene fragment. Subpopulation of "con strain" was confirmed by subsequent studies based on *Tpi* haplotype analysis. This study provides methodological support for rapid species identification of *Spodoptera frugiperda*, and provides early basic data for further origin analysis and genetic traceability.

Session 10-T 5 - Free topics

Migration processes and patterns of fall armyworm in China: comparative perspectives on migration arena in the New World and East Asia

Baoping Zhai[1] & Xijie Li[1]

[1]College of Plant Protection, Nanjing Agricultural University, Nanjing 210095, P.R. China

In January 2019, the invasive fall armyworm (FAW), *Spodoptera frugiperda*, arrived in East Asia. Since then, the southern half of the mainland of China has been invaded by FAW within half a year. What will happen to this invader in China when its colonization is complete in this late autumn? We draw up the migration processes and patterns of FAW in China by comparative perspectives on migration arena in the New World and East Asia.

1. The Asian Monsoon systems will provide dominant wind direction during spring, summer and autumn to accelerate the northward and southward migration processes of FAW in East Asia, from Indochina Peninsula to Russian Far East, and to Korean Peninsula and Japan Islands.
2. In the tropical New World, the year-round easterly winds prevent the moths of FAW immigrating to North America, that makes a small overwintering population of FAW located the most southern parts of Texas and Florida. So, the outbreak frequency of FAW in North America is not high and the outbreak areas are limited to local scale.
3. But in East Asia, all over the Indochina Peninsula there are suitable habitats of FAW and these will form the permanent year-round breeding areas of the source population of FAW for China. Meanwhile, the vast planting areas of staple grain crops in China will provide unlimited food resources to the pest. Therefore, the population size of FAW in mainland of China will become larger and larger and FAW will become a super pest to outbreak year after year all over China.
4. The southwest low-level jets over the Great Plains shape the north and eastward migration patterns of FAW in North America. But before the summer monsoon emerged and during the transition period between summer monsoon and winter monsoon, there are no dominant winds in spring and early autumn in China. So the FAW will show multidirectional migration patterns to establish vast spatial distribution across the mainland, especially the westward migration to colonize the western China.

ABSTRACTS
POSTER
PRESENTATIONS

Session 2-P 1 - *Bt* maize within a changing IPM paradigm: success stories and challenges with lepidopteran pests

Corn borer cycles, the response of farmers to outbreaks and the adoption of transgenic crops

James Bell[1], Alice Milne[1] & Bill Hutchison[2]

[1]*Rothamsted Research, Harpenden, United Kingdom*
[2]*University of Minnesota, Minnesota, U.S.A.*

We will highlight key findings from Bell *et al*. (2012) and Milne *et al* (2015) that used long-term data on the European corn borer moth (*Ostrinia nubilalis*) from Minnesota (1963–2009) and Wisconsin (1964–2009) to show how moth populations change following the introduction of *Bt* maize.

Bell *et al*. (2012) showed that at the state level, the local population cycle length was in a steady state of 5–7 years until 1996 when the introduction of *Bt* maize reduced survival rates. Our results demonstrate cycle damping, particularly in Minnesota where *Bt* maize adoption rates were initially higher compared to Wisconsin.
Decision-making by farmers is often based on the perception of a pest threat; if the threat is believed to be low, then farmers may instead purchase cheaper conventional maize seed; conversely, if the threat is high, widescale adoption of *Bt* maize is likely, implying a profit-based decision structure driven by a range of external influences, from the advice of neighbours to information from extension specialists. We modelled farmer data derived from Kaup (2008) *Rural Sociol* **73**: 62–81 and used this to show that adoption rates oscillated in response to the prevalence of European corn borer in the landscape, and, that the communication network and responsiveness of the farmer to loss influenced the amplitude and frequency of this oscillation.

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Milne, A.E., Bell, J.R., Hutchison, W.D., Van Den Bosch, *et al*. (2015) The effect of farmer decisions on pest control with *Bt* crops: a billion dollar ecology game. *PLOS Computational Biology* 11, e1004483

Session 3-P 2 - Emerging lepidopteran challenges in the maize agro-ecosystem

Factors influencing first generation European corn borer abundance and damages

Zrinka Drmić[1], Helena Virić Gašparić[1], Maja Čačija[1], Martina Kadoić Balaško[1], Darija Lemić[1] & Renata Bažok[1]

[1]*University of Zagreb Faculty of Agriculture, Zagreb, Croatia*

European corn borer (ECB) is one of the most significant maize pests in the world and also in Croatia. ECB causes yield reduction from 2 to 25%, even more in years favorable for its development. According to estimations, these losses are around 7%. Overwintering success, together with climatic conditions, are the key factors determining the abundance and intensity of the attack of the 1st generation. Additionally, the tolerance to the 1st generation ECB infestation is very often connected with maize FAO maturity group. The main aim of this work was to establish the differences among FAO maturity groups and among different climatic regions in damage caused by ECB larvae. Altogether 32 different FAO hybrids belonged to four FAO maturity groups (eight hybrids per group) in the two-year field trials located at four sites with different climatic conditions (Adriatic coast, North West, East and Central Croatia) were investigated. The damage caused by moth larvae on different FAO maturity groups significantly differ but might be correlated with climatic conditions as well. The analysis showed a strong positive correlation between the average monthly air temperature and the first generation attack (r = 0.6306 to 0.7386) in both research years. Additionally, the analysis showed a strong negative correlation between the total amount of rainfall in June and first generation attack (r = 0.7105 to 0.758). The maize of the higher FAO groups has high and robust stems with large number of big leaves. That intensive vegetative growth is a biological characteristic that attracts first generation of ECB to intensifying egg lying. However, the weather conditions are a crucial factor influencing moth activity in June and egg laying. For egg laying warm and dry June is the most favourable conditions. High population level of the first generation may lead to high level of second ECB generation which ultimately causes yield reduction.

Session 3-P 3 Emerging lepidopteran challenges in the maize agro-ecosystem

Newly found maize insect pest *Amphipoea burrowsi* Chapman, in Jilin, the northeast province of China

Xue Chang[2] & Xue Chang[2]

[2]*Jilin Academy of Agricultural Sciences, Changchun, P.R. China*

A new species of maize seedling insect pest was found in Jilin province, which maize production accounting for 12% of the total maize production in China. This insect pest was identified as *Amphipoea burrowsi* Chapman which belonged to Amphipoea, Noctuidae, Lepidoptera. *A*. *burrowsi* larvae drill and eat maize stem, which lead to seedling maize whorl leaves wither, even die. Although *A*. *burrowsi* has not threaten the maize production of Jilin province yet, its population occurrence dynamics still need to be monitored with the farming system reform and maize varieties change.

Session 4-P 4 - Environmentally friendly management of rootworms, wireworms and other soil pests in maize

How to use entomopathogenic nematodes against the root-damaging *Diabrotica* larvae in maize?

Stefan Toepfer[1,2], Szabolcs Tóth[1,2] & Michael Zellner[3]

[1]CABI Switzerland, c/o Plant Protection Directorate, Hodmezovasarhely, Hungary
[2]Plant Protection Institute NVI; Szent Istvan University, Gödöllő, Hungary
[3]Bavarian State Research Centre for Agriculture LfL, Freising, Germany

The chemical control of the root feeding larvae of the western corn rootworm (*Diabrotica virgifera virgifera*, Chrysomelidae) is challenging due to restrictions in neonicotinoid seed coatings, bans of highly toxic *tefluthrin*–soil insecticides, or simply due to lack of any registered soil pesticide against rootworms in some countries. Alternatives are entomopathogenic nematodes which are commercially mass-produced in many world regions. A product based on *Heterorhabditis bacteriophora* (Rhabditida: Heterorhabditidae) has been developed jointly by research institutions, universities and SMEs, and is now registered in a number of European countries. However, its use on a larger scale in maize is still limited. Whilst laboratory and plant-scale field experiments have shown high control efficacies, field-scale trials by farmers lead to more variable results. We herewith summarise results from 22 field-scale trials implemented with farmer machinery and based on artificial *Diabrotica* infestations between 2005 and 2018 analysing the dose-efficacy response and its variability under such conditions. Nematodes were applied as fluid stream sprays into the sowing furrow after seed placement, which is the currently most common application method. Results showed that nematodes appeared as effective as standard pesticides at reducing *Diabrotica* populations, and usually similarly effective and occasionally slightly less effective at preventing root damage. Variability is high making it difficult to define clear dose-response curves. Regression models suggest that the recommended dose of 2 billion nematodes per hectare is likely enough in most cases. To assure higher consistencies across locations, conditions, and different grower skill-levels, a slightly higher dose might be applied. Findings support a nematode-based solution for the biological control of *Diabrotica* larvae.

The studies were supported through the CTI Innovation Promotion Agency of the Federal Office for Professional Education and Technology of Switzerland, through the Ministry for Rural Areas and Consumer Protection of Baden-Wuerttemberg and through the Bavarian State Ministry of Food, Agriculture and Forestry.

Session 4 P 5 - Environmentally friendly management of rootworms, wireworms and other soil pests in maize

Do we need to worry about WCR adult silk clipping in sweet maize?

András Gyeraj[1], Márk Szalai[1,2], Zoltán Pálinkás[1,2], Fruzsina Enikő Sári-Barnácz[1,2] & József Kiss[1]

[1]1 Szent István University, Faculty of Agricultural and Environmental Sciences, Plant Protection Institute, Gödöllő, Hungary
[2]PlasmoProtect Ltd., Martonvásár, Hungary

The western corn rootworm (WCR, *Diabrotica virgifera virgifera* LeConte) is an economic pest of maize in the U.S.A. and in most maize growing regions in Europe. Although the primary damage is caused by its larvae feeding on the root system of maize, yield losses in inbred lines and commercial grain maize due to silk clipping by WCR adults and related economic thresholds are known from Hungary. However similar data for sweet maize is not available. We aimed at determining silk feeding damage and subsequent loss in this crop. This study was conducted in field sweet maize (cv. Suregold) in Hungary in 2016, 2017 and 2018. Bridal veil cages were placed over the ear at R1 stage of maize with 0, 1, 2, 4 and 8 beetles in 2016, with 0, 1, 2, 4, 8 and 12 beetles in 2017 and 2018 inside while uncovered plants were marked as untreated ones. The cages were securing the number and feeding of adults, on the other hand kept off the silk and cob from harmful pests. Silk length was measured daily till the end of silking. Then adults were removed from the ear cages keeping the isolators on the ears until harvest, protecting them from other pests. After harvest, cob weight was measured and the fertility ratio assessed.
Our three years results suggest that WCR adult infestation level up to 8 adults/ear is not likely to lead to economic damage, although meteorological conditions (rain, air humidity) and multiple pest presence (cotton bollworm and WCR) as well as IPM considerations (reduction of egg-laying female density) may impact the control decisions.

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Session 5-P 6 - Sustainable non-chemical methods for fall armyworm control

110 years' research on the fall armyworm: where we are?

Hongmei Li[1,2], Min Wan[1,2], Lulu Liu[1,4], Fengying Nie[3], Zhenying Wang[1,5] & Feng Zhang[1,2]

[1]MARA-CABI Joint Laboratory for Bio-safety, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, P.R. China
[2]CABI East Asia, Beijing, P.R. China
[3]Agricultural Information Institute, Chinese Academy of Agricultural Sciences, Beijing, P.R. China
[4]College of Bioscience and Resource Environment, Beijing University of Agriculture, Beijing, P.R. China
[5]State Key Laboratory for Biology of Plant Diseases and Insect Pests, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, P.R. China

The fall armyworm, *Spodoptera frugiperda*, is a highly polyphagous migratory lepidopteran pest species of tropical-subtropical origin in the western hemisphere from the United States to Argentina. Since 2016, the fall armyworm has invaded into a number of African and Asian countries, and became a major global threat to maize production in the invaded regions. Therefore, a bibliometric study on *S. frugiperda* has been conducted by using Endnote X6 and Vosviewer 1.1.6 to analyse its' research publications recorded in CAB Abstracts and Web of Science in English, and CNKI, Wanfang and VIP in Chinese between 1910 and May 2019 and thereby understanding global research progress and trend of the fall armyworm. The key findings were summarized as follows.

1) Totally, 5030 publications have been published in the past 110 years. The first publication was published in Journal of Economic Entomology in 1912. However, there were less than 100 publications in the first five decades. There were 100 publications in 1988, and since then more and more publications have been published. The total number of annual publications in average was over 100 in the 1990s. In 2013, over 160 publications were published on *S. frugiperda*. There were 1265 publications in the recent 10 years.
2) Scientific journals and conferences were the key media to publish and communicate among the researchers. The top ten international journals included Journal of Economic Entomology, Florida Entomologist, Journal of Virology, Journal of Invertebrate Pathology, PLoS ONE, Journal of General Virology, Virology, Insect Biochemistry and Molecular Biology, Southwestern Entomologist and Journal of Chemical Ecology.
3) Numbers of researchers from 87 countries published articles, and the institutes and researchers from U.S.A., Brazil, Mexico, Argentina, France, China, German, Canada, UK and Japan were ranked highest in producing publications.
4) Research hotspots on *S. frugiperda* were closely related to its sustainable prevention and control and virology, particularly including a great number of studies in the field of biological control and IPM. It is highly expected that these researched and existing pest management solutions would help current effort of research and development communities, extension agencies and farmers towards sustainable management of the fall armyworm in the invaded countries or regions.

Session 6-P 7 - Advances in the development of biological control solutions for the management of fall armyworm

Integrated deciphering of *Ostrinia furnacalis*-induced maize defense: dynamic profiling of phytohormones, benzoxazinoids, volatiles and gene transcripts elicited by *Ostrinia furnacalis* attack

Jingfei Guo[1], Kanglai He[1] & Zhenying Wang[1]

[1]State Key Laboratory for Biology of Plant Diseases and Insect Pests, MOA – CABI Joint Laboratory for Bio-safety, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, P.R. China

The Asian corn borer, *Ostrinia furnacalis* (Guenée), is a destructive pest in maize. Despite its serious damage in maize production, very limited information is obtained on the maize defensive responses to *O. furnacalis* herbivory and how these defenses function in maize direct and indirect defenses to the pest. In this study, the maize leaves previously fed upon by *O. furnacalis* for 24 h showed an obvious inhibition for the subsequent *O. furnacalis* performance, and maize volatiles induced by *O. furnacalis* for 24 an 48 h attracted the male and female *Macrocentrus cingulum* (Brischke). We also integrated transcriptome and biochemical analyses to research maize dynamic responses to *O. furnacalis* herbivory from phytohormones, benzoxazinoids, volatiles and gene expression. *Ostrinia furnacalis* feeding elicited stronger and rapid changes in the maize transcriptome (i.e. 2 h), and more differential gene expression (DEGs) were up-regulated than down-regulated at all induction time (i.e. 2, 4, 12 and 24 h). KEGG pathway analysis indicated that the DEGs induced by *O. furnacalis* herbivory involved in benzoxazinoids biosynthesis, plant-pathogen interaction, plant hormone signal transduction, phenylalanine metabolism, terpenoid backbone biosynthesis and other metabolic pathways related to maize resistance to herbivores. JA, JA-Ile, ABA, benzoxazinoids, and volatiles blends, as well as most of their biosynthesis-related genes were all strongly induced by *O. furnacalis* herbivory. In conclusion, these findings provided comprehensive insights into *O. furnacalis*-induced maize resistance from maize dynamic responses, as well as *O. furnacalis* peformance and their parasitoids, *M. cingulum* behaviour, and perhaps for developing new strategies for *O. furnacalis* control.

Session 7-P 8 - Addressing a significant food security threat: *Spodoptera frugiperda* invading new geographies

Promoting food security: developing a predictive model for fall armyworm (*Spodoptera frugiperda*) intervention in Kenya, East Africa

Edimon Cheruiyot[1], George Ongamo[1], MaryLucy Oronje[2] & Charles Agwanda[2]

[1]University of Nairobi, School of Biological Sciences, Entomology, Nairobi, Kenya
[2]CABI-Africa, Nairobi, Kenya

Fall armyworm, *Spodoptera frugiperda,* is an invasive maize pest which is about four years old in Kenyan agro ecosystems. Larval stage of the pest predominantly feeds on maize (*Zea mays)* which constitutes a staple food, hence threatening food security in Kenya. Limited biological information is available on its growth and development for effective mitigation, control measures and developing relevant tools / models.

Growth and development of fall armyworm *(Spodoptera frugiperda)* is being investigated at different temperatures under CABI/KALRO collaboration project. The purpose of the study is to ultimately assist farmers in timely intervention of control measures through developing a predictive model from our laboratory studies after correcting with relevant satellite data. Therefore, the laboratory study will enable us to simulate potential growth and development of the pest in growers field which have caused an intertwined tremendous losses in terms of crop losses and reduced household income among commercial and subsistence farmers.

Controlled temperature rooms (CT) are used to rear the pest until the cycle is completed from egg to adult. We have investigated temperature regimes ranging from 15°C to 44°C, i.e. temperatures of 15°C, 20°C, 25°C, 30°C, 35°C, 40°C, and 44°C have been investigated. So far six generations have been completed since the inception of the project in October last year and the study is still in progress.
Eggs are grafted on caged maize plants in each of the temperature regimes and observation is done every day to determine duration it takes to develop from one stage to the other. Larval head capsule width (HCW) is measured in five larvae in each cage. Therefore, a total of twenty larvae are scored per day and finally feed onto computer package in CABI-UK.

There is a need for collaboration among government agencies and international partners to control this menace and reduce potential awaiting hunger disaster. Improved technical understanding among extension workers and proper dissemination of information to farmers is fundamental to effective control.

Fall armyworm (*Spodoptera frugiperda*) growth and development as driven by temperature

Edimon Cheruiyot[1], George Ongamo[1] & MaryLucy Oronje[2]

[1]University of Nairobi, SBS, Nairobi, Kenya
[2]CABI-Africa, Nairobi, Kenya

Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith, 1797), is a destructive invasive maize pest recently introduced in most countries in Africa. FAW has made considerable damage to maize (*Zea mays)*, a key crop in Kenya's food security. While key pest management options including monitoring, use of insecticides have been recommended and approved, there is lack of information on the most vulnerable stage of larvae to target with insecticide sprays and general FAW development cycle as driven by weather parameters like temperature and humidity.

This study was undertaken to investigate the development of FAW under six different temperature regimes in controlled temperature rooms at 15°C, 20°C, 25°C, 30°C, 35°C, 40°C and 42°C. We observed the number of days to eggs hatching, larval head capsule width, mortality rate, and days to pupae and to adults. Using the collected data, we are developing the degree days pest development for FAW and defining the larval instar stages. These outputs are key in the predictive growth models for FAW for forecasting future FAW outbreaks and simulate the growth stages and to target the pest management options including biological control to the most vulnerable FAW larval stage.

Session 8-P 10 – Field-evolved insecticide resistance in maize pests

Modelling western corn rootworm wing structure and wing shape differences based on crop resistance using finite element analysis

Katarina Mikac[1]

[1]*University of Wollongong, Wollongong, Australia*

Intercontinental introductions of the worst insect pest of corn, the western corn rootworm from North America into Europe are still occurring. Through such introductions the spread of resistant alleles to various control techniques can occur and render once effective control programs ineffective, and as such innovative pest monitoring and surveillance tools and technologies must be implemented to mitigate this. Previous studies have repeatedly demonstrated evidence of distinct corn rootworm wing shape changes related to resistance development. Here, we investigate corn rootworm intraspecific flight morphology, in addition to modelling wing structure and wing shape differences based on crop resistance using finite element analysis. A deeper understanding of rootworm wing shape and flight morphology, aspect ratio and flight efficiencies will assist with discerning which resistant phenotypes are most likely to invade geographic areas where they not yet present (i.e. rotation resistant beetles entering Europe where such variants are absent). Such information is crucial to biosecurity measures and integrated pest management strategies for the western corn rootworm globally.

Session 9-P 11 - The use of emerging technologies in maize pest surveillance, reporting and forecasting

Two decades of invasive western corn rootworm surveillance in Croatia

Darija Lemic[1], Katarina Mikac[2], Martina Kadoić Balaško[1], Hugo Alejandro Benitez[3] & Renata Bažok[1]

[1]University of Zagreb, Faculty of Agriculture, Department for Agricultural Zoology, Zagreb, Croatia
[2]University of Wollongong, Centre for Sustainable Ecosystem Solutions, School of Biology, Faculty of Science, Medicine and Health, Wollongong, Australia
[3]Universidad de Tarapaca, Facultad de Ciencias Agronomicas, Departmento de Recursos Ambientales, Arica, Chile

The thorough knowledge of the western corn rootworm invasion in Croatia is unique in Europe, as no other European nation has demonstrated such a detailed and complete understanding of an invasive insect till now. After the beetle's first detection in Serbia in 1992, Croatia have established a national monitoring program. For more than two decades WCR adult population abundance and variability was monitored. With traditional density monitoring, more recent genetic monitoring, and the newest morphometric monitoring of WCR populations, Croatia possesses a great deal of knowledge about the beetle's invasion process over time and space. The combined use of traditional monitoring (attractant cards), which can be effectively used to predict population abundance, and modern monitoring procedures, such as population genetics and geometric morphometrics, has been effectively used to estimate interand intra-population variation. The combined application of traditional and modern monitoring techniques will enable more efficient surveillance, reporting and forecasting of WCR across Europe.

Session 9-P 12 - The use of emerging technologies in maize pest surveillance, reporting and forecasting

Simplifying damage rating scales for fall armyworm in maize

Stefan Toepfer[1], Patrick Fallet[2], Bancy Waithira Waweru[3], Joelle Kajuga[3] & Ted Turlings[2]

[1]CABI Switzerland, c/o Plant Protection Directorate, Hodmezovasarhely, Hungary
[2]Laboratory of Fundamental and Applied Research in Chemical Ecology, Institute of Biology, University of Neuchâtel, Neuchâtel, Switzerland
[3]Rwanda Agriculture and Animal Resources Board, Huye and Kigali, Rwanda

The American-origin fall armyworm (*Spodoptera frugiperda,* Lepidoptera: Noctuidae) is an intensively studied and discussed maize pest due to its recent invasion and damage in Africa and Asia. Different methods are used to assess the feeding damage of its caterpillars on leaves and cobs, leading to difficulties when comparing studies. The most used scale is the so-called “Davis damage rating scale for fall armyworm” (Davis & Williams 1992) and combines frequency and severity information at the same time, a common problem in many damage rating scales. Moreover, this rating scale leads to ordinal data which are extremely difficult to analyse. Although, we did not yet attempt to create a new rating scale based on absolute or interval data, we (a) tried to simplify the Davis damage rating scale, and (b) like to launch a discussion on how to better assess and analyse the feeding damage of this serious invasive maize pest.

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Davis, F. M., Williams, W.P. 1992. Visual rating scales for screening whorl-stage corn for resistance to fall Armyworm. Tech. Bull. 186, Mississippi State University, USA.

Session 10-P 13: Free topics

Diapause and hatching patterns of *Diabrotica v. virgifera* (Coleoptera: Chrysomelidae) to better plan experimentation with neonate larvae

Szabolcs Toth[1,2], Mark Szalai[1], Jozsef Kiss[1] & Stefan Toepfer[1,2]

[1]Plant Protection Institute NVI; Szent Istvan University, Gödöllő, Hungary
[2]CABI Switzerland, c/o Plant Protection Directorate, Hódmezővásárhely, Hungary

The maize pest *Diabrotica virgifera virgifera* (Coleoptera: Chrysomelidae) has an obligate diapause with eggs overwintering in field soils for approximately 7 to 9 months. When using eggs of this insect for experiments, they are often artificially overwintered at 6 to 8 degree Celsius. Diapause is terminated depending on rearing schedules and timing of experiments. However, there is a variability in egg hatching patterns depending on diapause length and temperature. Therefore, it is difficult to properly time experiments that require ready-to-hatch eggs or neonate larvae. We conducted hatching experiments using eggs from field-collected adults of the wild Central South-eastern European population as well as of a non-diapause laboratory strain under standardised laboratory conditions of 16, 20 and 24 degree Celsius and allowing eggs to diapause over different time periods (0 to 24 months). A too short diapause reduces overall egg hatching rates, slightly delays hatching, and de-synchronises the hatching of an egg-batch. Eggs can easily diapause for more months than their natural diapause, but hatching rates slowly decrease with time. Regressions are provided to predict hatching start and peak for *D. v. virgifera* eggs depending on diapause length and temperature.

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Session 10-P 14 - Free topics

Tracking wireworm burrowing behaviour in soil over time using 3D X-ray Computed Tomography

Samuel Booth[1], Benedikt Kurtz[2], Martine de Heer[3], Sacha J. Mooney[1] & Craig J. Sturrock[1]

[1]University of Nottingham, School of Biosciences, Nottingham, United Kingdom
[2]Syngenta Crop Protection, Research Biology, Stein, Switzerland
[3]Syngenta Crop Protection, Polymer Technology, Jeallott`s Hill, United Kingdom

Wireworms (larvae of the click beetle, Elateridae) are a significant agricultural pest, causing crop damage and reducing yields globally. Due to the complex nature and opacity of the soil environment, research to investigate wireworm behaviour in-situ has been scarce. X-ray Computed Tomography (CT) has previously been used independently to successfully visualise 3D root architecture systems, macroinvertebrates movement, and distribution of burrow systems in soil but not previously within the same sample. In this study, we applied X-ray CT to visualise and quantify wireworms, their burrow systems and the root architecture of two contrasting crop species (*Hordeum vulgare* and *Zea mays*) in a soil pot experiment scanning at different time intervals. The majority of wireworm burrows were produced within the first 20 hours post-inoculation, suggesting burrow systems are established quickly and remain at a similar volume. There was a significant difference in the volume of burrow systems produced between the varying crop species implying a behavioural difference in the wireworms elicited by crop species. There was no significant correlation between burrow volume and either crop root volume or surface area, indicating this behavioural difference is caused by a factor other than the mass of root systems. X-ray CT shows great promise for future studies to understand wireworm interactions with roots and soil and aid the development of effective pest management strategies to minimise negative impacts on crop production.

Session 10-P 15 - Free topics

Lambda-cyhalothrin as a model compound to study the effect of insecticide placement on western corn rootworm larval behavior

Mario Schuhmann[1], Benedikt Kurtz[2], Claudio Screpanti[2] & Stefan Vidal[1]

[1]Georg-August University, Göttingen, Germany
[2]Syngenta Crop Protection AG, Stein, Switzerland

Even though the behavior of corn rootworm (*Diabrotica v. virgifera*) larvae has been investigated in different studies over the years, the way plant protection products applied to the soil influence larval behavior, and how volume and concentration of specific products do interact on their activity remains to be further investigated.

The objective of the current study was to investigate the influence of different placements of a chemical insecticide on corn rootworm larval behavior. As active ingredient Lambda-cyhalothrin was selected, because even though it is not a relevant standard under field conditions, it has contact activity against corn rootworm larvae and is limited in soil mobility (KOC=380000-345000 ml/g, water solubility= 0.0042 mg/l). So under the conditions of the test this ensures that the compound stays in the treated soil volume. Lambda-cyhalotrin can therefore be used as a model for an insecticide with low mobility in soil and contact activity against corn rootworm larvae.

The distribution and knock down of larvae was well reflected the application patterns of the compound. With a larger soil volume treated (and lower concentration) a higher percentage of corn rootworm larvae were affected or killed. The effect occurred within 24-48 h. Lambda-cyhalothrin did not show any repellency effects against the corn rootworm larvae in soil. These results can help to identify the ideal placement of chemicals to ensure optimal biological efficacy. Learnings from this study can help the optimization of new insecticides with better behavior in soil and less impact on the environment.

Session 10-P 16 - Free topics

Identification of *Trichogramma*, an egg parasitoid on *Ostrinia furnacalis* (Lepidoptera: Crambidae) in eastern Myanmar

Yee Yee Myint[1], Zhenying Wang[1], Kanglai He[1], Shuxiong Bai[1] & Tiantao Zhang[1]

[1]Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, P.R. China

The Asian corn borer, *Ostrinia furnacalis* (Hübner, 1976) (Lepidoptera: Crambidae), is a major pest of maize which is the second largest export agricultural commodity of Myanmar. Due to the constant cultivation of maize, the damage caused by *O. furnacalis* has become a severe obstacle to farmers' income and national economy. *Trichogramma* species are the most commonly used egg parasitoids as the biological control agent of lepidopteran pests. Biological control has not yet been initiated in Myanmar and there is an urgent need for indigenous enemies on *O. furnacalis*. The genus *Trichogramma* comprises a large number of species, their morphological identification remains difficult due to the microscopic size and low interspecific morphological characters. Molecular technique has been widely used for identification and phylogenetic analysis on *Trichogramma* spp. The *Trichogramma* was collected in Shan State, Eastern Myanmar in 2017-2018. The objective of this study was to assess naturally parasitized egg masses of *O. furnacalis* by *Trichogramma* in Myanmar and identification of indigenous *Trichogramma* species by molecular and morphological methods. Firstly, molecular identification was determined by the amplification size and sequences of the internally transcribed spacer 2 (ITS2) of ribosomal DNA (rDNA). The ITS2 gene was sequenced and subjected to BLAST searches in NCBI database. Morphological diagnosis was performed focusing on the male genitalia and recorded the significant genitalia capsule. The result indicated that the majority of collected specimens were identified as *Trichogramma ostriniae* Pang and Chen, *Trichogramma chilonis* Ishii and *Trichogramma dendrolimi* Matsumura. *Trichogramma dendrolimi* was found to be in lower frequency. This is the first time in exploring Myanmar's indigenous *Trichogramma* species and developing biological control against *O. furnacalis*.

Session 10-P 17 - Free topics

A draft genome sequence assembly for the western corn rootworm, *Diabrotica virgifera virgifera*

Brad Coates[1], Nicholas Miller[3], Thomas Sappington[1], Blair Siegfried[4] & Hugh Robertson[2]

[1]USDA-ARS, Ames, Iowa, U.S.A.
[2]University of Illinois, Champaign, Illinois, U.S.A.
[3]Illinois Institute of Technology, Chicago, Illinois, U.S.A.
[4]University of Florida, Gainesville, Florida, U.S.A.

The western corn rootworm, *Diabrotica virgifera virgifera* (Coleoptera: Chrysomelidae), is an arthropod pest of cultivated maize across the major production regions of North America and Europe. Managing crop damage has become increasingly difficult due to adaptations of *D. v. virgifera* field populations to multiple control practices, including crop rotation, chemical insecticides and *Bacillus thuringiensis* (*Bt*) protein toxins expressed by transgenic maize hybrids. A draft assembly of the 2.56 Gbp flow cytometry-estimated *D. v. virgifera* genome, was assembled using short reads from Illumina paired end and mate pair libraries, and completed by a combination of transcript guided and proximity-ligation data for scaffolding. Following elimination of redundancy and applying a 1,000 bp minimum scaffold size cutoff, 43,342 scaffolds with N50 = 120.9 kb were submitted to GenBank (Accession PXJM00000000.2). Structural annotation via the NCBI Gnomon pipeline predicted 32,208 genes encoding 28,061 proteins. Although the resulting assembly is fragmented, the gene representation is relatively represented and complete [BUSCO score of 88.4% (C: 88.4%, S: 86.9% and D: 1.5%); F: 6.3%, M: 5.3%, *n* = 2442]. This is the first genome assembly for *D. v. virgifera*, and will provide a resource for genomic-scale research on this species.

Session 10-P 18 - Free topics

Migratory behavior of *Ostrinia nubilalis* and *Diabrotica virgifera virgifera* inside their year-round range: Not about tracking host crops or escaping winter

Thomas Sappington[1]

[1]*USDA-Agricultural Research Service, Ames, Iowa, U.S.A., Tom.Sappington@ars.usda.gov*

Insect migratory flight differs fundamentally from most other kinds of flight behaviour, in that it is non-appetitive. The adult is not searching for anything, and migratory flight is not terminated by encounters with potential resources such as host plants, mates, or overwintering habitat. Many insect pests of agricultural crops are long-distance migrants, moving from lower latitudes where they overwinter to higher latitudes in the spring to exploit superabundant, but seasonally ephemeral, host crops. The migratory nature of these pests is somewhat easy to recognize because of their sudden appearance in areas where they had been absent. Many other serious pests survive hostile winter conditions by diapausing, and therefore do not require migration to move between overwintering and breeding ranges. Yet there is evidence of migratory behavior engaged in by several pest species that inhabit high latitudes year-round, including both European corn borer (*Ostrinia nubilalis*) and western corn rootworm (*Diabrotica virgifera virgifera*). In these cases, migratory flight is not easily observed, making it somewhat "invisible", because displacement takes place within the larger year-round distribution where populations already exist. Nevertheless, the potential population-level consequences can be quite important in the contexts of pest management and insect resistance management. Here, I briefly review evidence for migratory flight behavior by corn borer and rootworm adults, and discuss why understanding it is important.

PARTICIPANTS

Agboyi, Lakpo Koku B.A.
CABI
No.6 Agostino Neto Road
233 Accra
GHANA
Email: l.agboyi@cabi.org

Alvarez, Fernando
EFSA
Via Carlo Magno 1A
43126 Parma
ITALY
Email:
fernando.alvarez@efsa.europa.eu

Ba, Malick
International Crops Research Institute
for the Semi-Arid Tropics
12404 Niamey
NIGER
Email: b.malick@cgiar.org

Babendreier, Dirk
CABI
Rue des Grillons 1
2800 Delemont
SWITZERLAND
Email: d.babendreier@cabi.org

Bateman, Melanie
CABI
Rue des Grillons 1
2800 Delémont
SWITZERLAND
Email: m.bateman@cabi.org

Bažok, Renata
University of Zagreb
Faculty of Agriculture
Svetošimunska cesta 25
10000 Zagreb
CROATIA
Email: rbazok@agr.hr

Beitzen-Heineke, Elisa
Georg-August-Universität Göttingen
Grisebachstraße 6
37077 Göttingen
GERMANY
Email: ebh@biocare.de

Bell, James
Rothamsted Research
West Common
AL5 2JQ Harpenden
UNITED KINGDOM
Email: james.bell@rothamsted.ac.uk

Brants, Ivo
Bayer
Tervurenlaan 270
1150 Brussels
BELGIUM
Email:
kristina.krestyanova.ext@bayer.com

Bruce, Anani
CIMMYT
1041
00621 Nairobi
KENYA
Email: A.bruce@cgiar.org

Burger, Regina
Fenaco Pflanzenschutz
Nordring 2
4147 Aesch
SWITZERLAND
Email: regina.burger@fenaco.com

Caprio, Michael
Mississippi State University
1149 Old Crawford Rd
39759 Starkville, MS
U.S.A.
Email:
mcaprio@entomology.msstate.edu

Chang, Xue
Jilin Academy of Agricultural Sciences
#1363 Shengtai Street
130033 Changchun
CHINA
Email: cxuesnow@163.com

Cheruiyot, Edimon
University of Nairobi
School of Biological Sciences
Box 30197 – 00100 GPO
University Way
Nairobi
KENYA
Email: kediche2003@gmail.com

Clark, Thomas
Provivi
1701 Colorado Avenue
90404 Santa Monica, CA
U.S.A.
Email: tclark@provivi.com

Coates, Brad
USDA-ARS
2333 Pammel Dr
50011 Ames, IA
U.S.A.
Email: brad.coates@ars.usda.gov

Dively, Galen
University of Maryland
Department of Entomology
20742 College Park, MD
U.S.A.
Email: galen@umd.edu

Dubach, Felix
Andermatt Biocontrol
Stahlermatten 6
6146 Grossdietwil
SWITZERLAND
Email: felix.dubach@biocontrol.ch

Durocher-Granger, Léna
CABI
Landgoed Leusderend, 32
3832 RC Leusden
NETHERLANDS
Email: l.durocher-granger@cabi.org

Eizaguirre, Matilde
Agrotecnio Center, University of Lleida
Av. Al. Rovira Roure, 191
25198 Lleida
SPAIN
Email: eizaguirre@pvcf.udl.cat

Fallet, Patrick
University of Neuchâtel
Institute of Biology
Rue Emile-Argand 11
2000 Neuchâtel
SWITZERLAND
Email: patrick.fallet@unine.ch

Feldmann, Pascale
Syngenta
Technologiepark
9052 Zwijnaarde
BELGIUM
Email:
pascale.feldmann@syngenta.com

Feng, Hongqiang
Institute of Plant Protection
Henan Academy of Agricultural Sciences
116 Huayuan Rd.
450002 Zhengzhou
CHINA
Email: feng_hq@163.com

Fiaboe, Komi K. M.
IITA- International Institute of Tropical Agriculture
IRAD Main Road
BP. 2008 (Messa)
2008 Yaounde
CAMEROON
Email: K.Fiaboe@cgiar.org

Flannagan, Ronald
GreenLight Biosciences
1013 Fairways Drive
63367 Lake Saint Louis, MO
U.S.A.
Email: rflannagan@greenlightbio.com

Guo, Jingfei
Institute of Plant Protection
CAAS
West Yuan Ming Yuan Road
Haidian District
100081 Beijing
CHINA
Email: guojingfei1989@126.com

Gurumayum, Shachi
AgBiTech LLC
14401 Sovereign Rd Suite 111
76155 Fort Worth, TX
U.S.A.
Email: sgurumayum@agbitech.com

Hailu, Girma
International Centre of Insect Physiology and Ecology
Kasarani, icipe drive, Off Thika Road
30772-00100 Nairobi
KENYA
Email: ghailu@icipe.org

He, Kanglai
Institute of Plant Protection
CAAS
No. 2, West Yuanmingyuan Road
Haidian District
100193 Beijing
CHINA
Email: hekanglai@caas.cn

Hellmich, Richard
USDA, Agricultural Research Service
2310 Pammel Drive, 638 Science II
50011 Ames, IA
U.S.A.
Email: richard.hellmich@usda.gov

Huang, Fangneng
Louisiana State University Agricultural Center
Dept. Entomology
LSU AgCenter
70803 Baton Rouge, LA
U.S.A.
Email: fhuang@agcenter.lsu.edu

Huseth, Anders
North Carolina State University
Campus Box 7630
NC State University
27695 Raleigh, NC
U.S.A.
Email: ashuseth@ncsu.edu

Hutchison, William
University of Minnesota
196 OAK HILL DR
55126 Shoreview, MN
U.S.A.
Email: hutch002@umn.edu

Jabeur, Rania
BIOGEMMA
Route d'Ennezat
63720 Chappes
FRANCE
Email: delphine.pierre@limagrain.com

Jiang, Xingfu
Institute of Plant Protection
CAAS
West Road 2 Yuanmingyuan
100193 Beijing
CHINA
Email: xfjiang@ippcaas.cn

Jurat-Fuentes, Juan Luis
University of Tennessee
370 Plant Biotechnology Building
37996 Knoxville, TN
U.S.A.
Email: jurat@utk.edu

Kadoić Balaško, Martina
University of Zagre
Faculty of Agriculture
Svetošimunska street 25
10 000 Zagreb
CROATIA
Email: mmrganic@agr.hr

Kansiime, Monica
CABI
633
00621 Nairobi
KENYA
Email: m.kansiime@cabi.org

Kenis, Marc
CABI
Rue des Grillons 1
2800 Delemont
SWITZERLAND
Email: m.kenis@cabi.org

Kuhlmann, Ulli
CABI
Rue des Grillons 1
2800 Delémont
SWITZERLAND
Email: u.kuhlmann@cabi.org

Kurtz, Benedikt
Syngenta Crop Protection AG
Schaffhauserstrasse 101
4332 Stein
SWITZERLAND
Email: benedikt.kurtz@syngenta.com

Lemic, Darija
University of Zagreb
Faculty of Agriculture
Svetosimunska 25
10000 Zagreb
CROATIA
Email: dlemic@agr.hr

Li, Hongmei
CABI
2 Yuanmingyuan West Road
100193 Beijing
CHINA
Email: h.li@cabi.org

Li, Guoping
Henan Academy of Agricultural Science
Institute of Plant Protection
116 Huyuan Rd
450002 Zhengzhou
CHINA
Email: liguoping1976@163.com

Li, Xijie
Nanjing Agricultural University
College of Plant Protection
210095 Nanjing
CHINA
Email: njlixj@163.com

Liu, Xinglong
Institute of Plant Protection
Heilongjiang Academy of Agricultural Sciences
368 Xuefu Road
150086 Harbin
CHINA
Email: hljliuxinglong@163.com

Lopez, Carmen
ETSEA. University of Lleida
Av. Al. Rovira Roure 191
25198 Lleida
SPAIN
Email: carmen.lopez@udl.cat

Lorenzen, Marce
North Carolina State University
Campus Box 7613
27695-0001 Raleigh
U.S.A.
Email: Marce_Lorenzen@ncsu.edu

Meissle, Michael
Agroscope
Reckenholzstrasse 191
8046 Zurich
SWITZERLAND
Email:
michael.meissle@agroscope.admin.ch

Mikac, Katarina
University of Wollongong UOW
School of Earth, Atmospheric and Life Sciences
2522 Wollongong
AUSTRALIA
Email: kmikac@uow.edu.au

Miller, Nick
Illinois Institute of Technology
3101 S Dearborn Street
60616 Chicago
U.S.A.
Email: nmiller11@iit.edu

Modic, Špela
Agricultural Institute of Slovenia
Hacquetova ulica 17
1000 Ljubljana
SLOVENIA
Email: spela.modic@kis.si

Mohamed, Samira
International Centre of Insect
Physiology and Ecology
Kasarani, icipe drive, OFF THIKA
ROAD
30772-00100 Nairobi
KENYA
Email: sfaris@icipe.org

Myint, Yee Yee
Institute of Plant Protection
No. 2 West Yuan Ming Yuan Road
100094 Beijing
CHINA
Email: yeeyeem@gmail.com

Nagy, Krisztina
Biocont Magyarország Kft.
Vértes u. 7.
6000 Kecskemét
HUNGARY
Email: nagyk@biocont.hu

Pasquier, Antoine
INRA / Bioline agrosciences
Route de Biot
06560 Valbonne
FRANCE
Email:
apasquier@biolineagrosciences.fr

Paula-Moraes, Silvana
University of Florida
4253 Experiment Dr., Hwy. 182
32565 Jay, FL
U.S.A.
Email: paula.moraes@ufl.edu

Pereira, Eliseu
University of Vicosa
Campus Universitario SN
36570-900 Viçosa
BRAZIL
Email: eliseu.pereira@ufv.br

Pérez Farinós, Gema
Centro de Investigaciones Biológicas,
CSIC
Ramiro de Maeztu, 9
28040 Madrid
SPAIN
Email: gpfarinos@cib.csic.es

Peterson, Julie
University of Nebraska-Lincoln
402 W State Farm Rd
69101 North Platte, NE
U.S.A.
Email: julie.peterson@unl.edu

Philips, Annelies
Syngenta
E.Helderweirdtstraat 86
9041 Ghent
BELGIUM
Email: annelies.philips@syngenta.com

Pilcher, Clinton
Corteva Agriscience
7100 NW 62nd St.
50131 Johnston, IA
U.S.A.
Email: clint.pilcher@corteva.com

Piovesan Alves, Analiza
Corteva
7250 NW 62nd Ave / PO Box 552
50131 - 0552 Johnston, IA
U.S.A.
Email: analiza.alves@corteva.com

Preukschas, Juliane
fenaco Pflanzenschutz
Nordring 2
4147 Aesch
SWITZERLAND
Email:
juliane.preukschas@fenaco.com

Razinger, Jaka
Kmetijski inštitut Slovenije
Hacquetova ulica 17
SI-1000 Ljubljana
SLOVENIA
Email: jaka.razinger@kis.si

Reay-Jones, Francis
Clemson University
2200 Pocket Road
29506 Florence, SC
U.S.A.
Email: freayjo@clemson.edu

Reisig, Dominic
North Carolina State University
207 Research Station Rd
27962 Plymouth, NC
U.S.A.
Email: ddreisig@ncsu.edu

Rice, Marlin
Corteva Agriscience
#30 Krug Bldg., 7301 NW 62nd Ave.
Box 85
50131 Johnston, IA
U.S.A.
Email: marlin.rice@corteva.com

Sallaud, Christophe
Biogemma
Route d'Ennezat
63720 Chappes
FRANCE
Email:
delphine.pierre@biogemma.com

Sanane, Inoussa
University of Paris Sud
10 reu d'Orgeval
Université Paris-Sud UMR GQE
91400 Orsay
FRANCE
Email: inoussa.sanane@u-psud.fr

Sappington, Thomas
USDA-Agricultural Research Service
CICGRU
2333 Pammel Dr.
50011 Ames, IA
U.S.A.
Email: Tom.Sappington@ars.usda.gov

Sári-Barnácz, Fruzsina Enikő
Szent István University
Páter Károly u. 1.
2100 Gödöllő
HUNGARY
Email: barnacz.fruzsina@gmail.com

Schaafsma, Art
University of Guelph
19890 Hill Road, RR 1
N0P 2C0 Ridgetown
CANADA
Email: aschaafs@uoguelph.ca

Schumann, Mario
KWS Saat SE
Phytopathology
Grimsehltrasse 31
37574 Einbeck
GERMANY
Email: mario-matthias.schumann@kws.com

Sethi, Amit
Corteva Agriscience
7301 NW 62nd Ave
50131 Johnston, IA
U.S.A.
Email: amit.sethi@corteva.com

Smith, Jocelyn
University of Guelph
120 Main St. East
N0P 2C0 Ridgetown
CANADA
Email: jocelyn.smith@uoguelph.ca

Straub, Lars
Institute of Bee Health
Schwarzenburgstrasse 161a
3097 Liebefeld Bern
SWITZERLAND
Email: lars.straub@vetsuisse.unibe.ch

Straumann, Tobias
Syngenta
Schaffhauserstrasse 101
4332 Stein
SWITZERLAND
Email: tobias.straumann@syngenta.com

Subramanian, Sevgan
International Centre of Insect Physiology and Ecology
ICIPE, Duduville, Off Thika Road
Kasarani
00100 Nairobi
KENYA
Email: ssubramania@icipe.org

Taylor, Sally
Virginia Tech
6321 Holland Rd
23437 Suffolk, VA
U.S.A.
Email: svtaylor@vt.edu

Thibord, Jean-Baptiste
Arvalis
21 chemin de Pau
64121 Montardon
FRANCE
Email: jb.thibord@arvalis.fr

Toepfer, Stefan
CABI Switzerland
c/o Plant Protection Directorate, Rarosi ut 110
6800 Hodmezovasarhely
HUNGARY
Email: s.toepfer@cabi.org

Tóth, Szabolcs
Plant Protection Institute NVI
Szent István University
Páter K u. 1.
2100 Gödöllo
HUNGARY
Email: toth.szabolcs.1990@gmail.com

Turay, George
Humanity's Team Sierra Leone
Green Street
00232 Freetown
SIERRA LEONE
Email: kamdawahorg@hotmail.com

Van den Berg, Johnnie
North-West University
Hoffman street
2520 Potchefstroom
SOUTH AFRICA
Email: johnnie.vandenberg@nwu.ac.za

Wang, Keqin
Institue of Plant Protection
Heilongjiang Academy of Agricultural Sciences
150086 Harbin
CHINA
Email: 13244664780@163.com

Wang, Zhenying
Institute of Plant Protection
Chinese Academy of Agricultural Sciences
#2 West Yuanmingyuan Road
100193 Beijing
CHINA
Email: wangzy61@163.com

Wang, Yueqin
Institute of Plant Protection
Chinese Academy of Agricultural Sciences
No. 2 West Yuanmingyuan Road
100193 Beijing
CHINA
Email: yueqinqueen@126.com

Wu, Shengyong
Institute of Plant Protection
CAAS
No.2 yuanmingyuan west road,
Haidian district
100193 Beijing
CHINA
Email: wushengyong2014@163.com

Xiao, Yutao
Agricultural Genomics Institute
CAAS
No. 7 Pengfei Road, Dapeng New District
518120 Shenzhen
CHINA
Email: lishuqu1234@163.com

Zellner, Michael
Bavarian State Research Center for Agriculture
Lange Point 10
85354 Freising
GERMANY
Email: Michael.Zellner@LfL.bayern.de

Zhai, Baoping
Nanjing Agricultural University
1 Weigang Road
210095 Nanjing
CHINA
Email: bpzhai@njau.edu.cn

Zukoff, Sarah
Kansas State University
4500 East Mary St.
67846 Garden City, KS
U.S.A.
Email: snzukoff@ksu.edu