Fruit Flyer

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FF•IPM

Fruit Flies In-silico
Prevention & Management
FF•IPM

This is the second Newsletter Publication of the EU-funded research project FF-IPM, with the aim to protect fruit production and trade from threats posed by fruit flies.

The newsletter will be published quarterly, highlighting the actions, news, progress related to the issue at hand.

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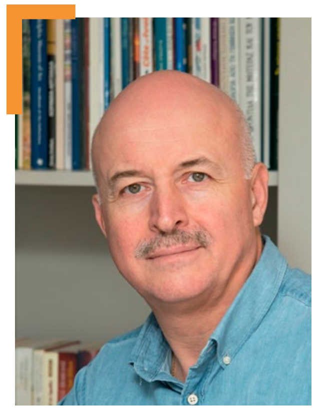

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FF-IPM Project Manager

Over the last six months, despite the hurdles faced due to the COVID-19 pandemic, the FF-IPM project successfully concluded a series of important field studies that set the stage for future developments. Additional data have been generated and technological and modeling developments have progressed.

The first annual meeting of our project took place online in mid-October and included presentations of all work packages and a thorough discussion on achievements and future plans. During this meeting, we were pleased to host an interesting talk from Prof. David Horta Lopes from the University of Azores, Portugal, who presented the major findings of the European funded project "Euphresco" which addresses issues regarding fruit fly management. This was a wonderful opportunity to learn about the Euphresco project activities and establish a tight interaction with this group.

Early in October, the fourth International TEAM meeting, a major event for fruit fly workers in Europe Africa and the Middle East, was successfully organized in South France. The FF-IPM partners Marc de Meyer and Helene Delatte served in the organizing committee of the meeting, chaired by Valerie Balmes. An interesting, whole evening, round table discussion regarding "New concepts and approaches in fruit fly management in Europe" was coordinated by the FF-IPM project within the premises of the TEAM meeting. The short introductions by Marc de Meyer, Slawomir Lux, Josep Jaques, Ana Larcher and myself, stimulated a long and lively discussion that was highly attended.

One of the main, environmentally friendly, tools that are considered to combat fruit flies (and other pests) in many countries all over the world is the Sterile Insect Technique (SIT).

The FF-IPM project was introduced to participants of the Annual Meeting of the American Entomological Society that took place from 15/11/2020 to 25/11/2020 and of the 10th meeting of the fruit fly workers of the Western Hemisphere that was held from 2/11/2020 to 6/11/2020.

One of the main, environmentally friendly, tools that are considered to combat fruit flies (and other pests) in many countries all over the world is the Sterile Insect Technique (SIT). The International Atomic Energy Agency (IAEA) and especially the Joint FAO/IAEA Programme, has had major contributions in the development, promotion, support and implementation of the SIT against fruit flies and other insect pests. In the current newsletter, Ana Larcher and Uli Shiefer discuss with Rui Pereira (the Head of the Insect Pest Control in the FAO/IAEA) a range of subjects from the history of the SIT, to current important activities of the FAO/IAEA programme, and the future directions, with particular emphasis in Europe.

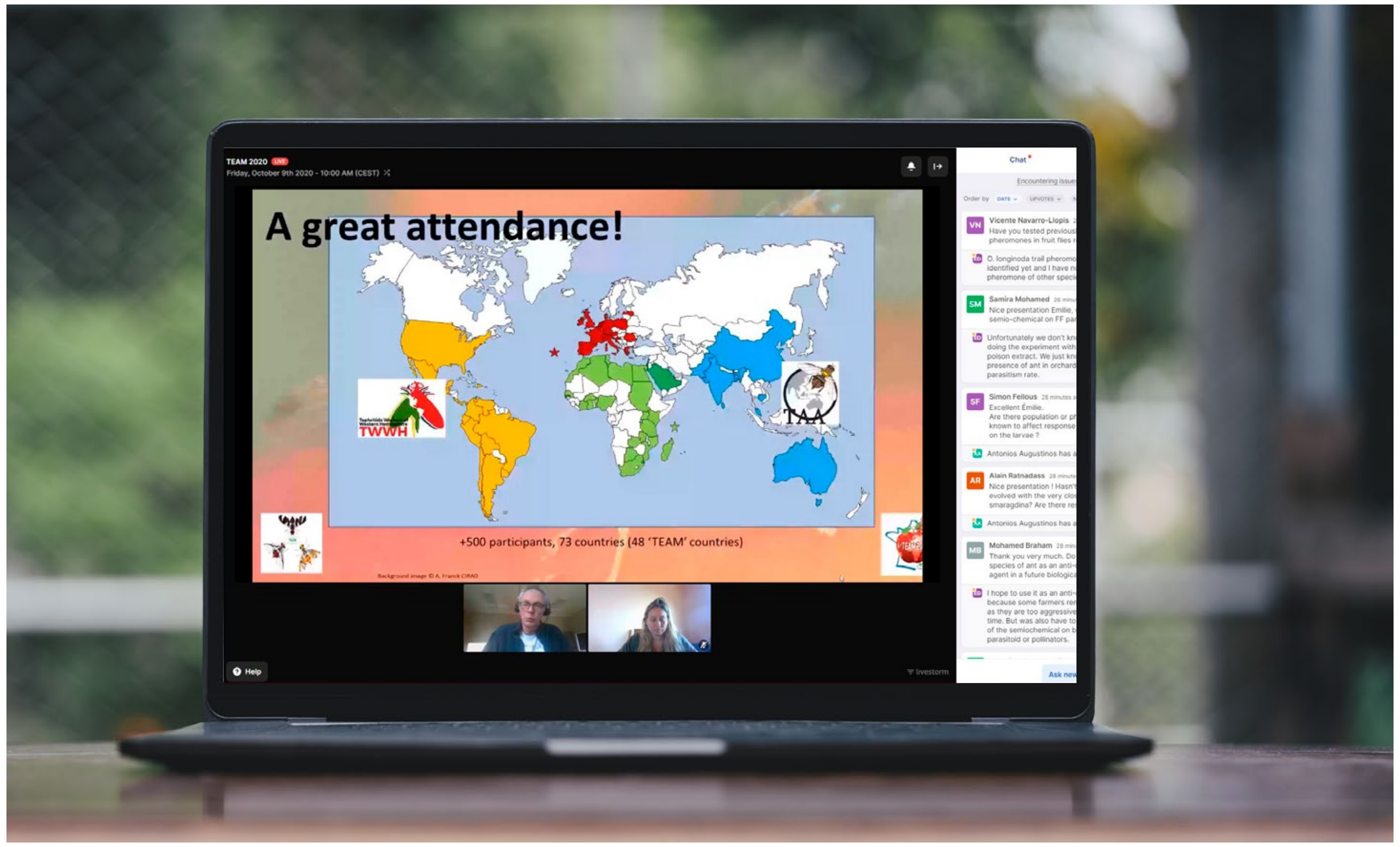
Biological control of fruit flies is a topic researched for many decades but the use of entomopathogenic nematodes has not been extensively exploited. Our colleagues Arne Peters and Tolis Kapranas give a comprehensive analysis on the state of the art of using entomopathogenic nematodes against the soil-dwelling stages of fruit flies.

We hope you enjoy reading the current newsletter that we envisage, besides becoming an important forum of knowledge exchange and discussion, to enhance the ongoing "relationship" between our project and all of you who are interested in fruit fly research and management.

Our second issue is out! We managed to give you the latest news of FF-IPM and to put you into the discussion of our research.

We want you to follow us and think how we can transform your knowledge and your interests in a fruitful discussion

The Fourth International Meeting of Tephritid Workers of Europe, Africa and the Middle East (TEAM)



The Fourth International TEAM Meeting was successfully held in La Grande Motte, France from the 5th to 9th of October 2020. The meeting was organized by researchers of French and Belgium institutions including ANSES (Mrs V Balmès and Mrs R Moutet), CIRAD (Dr H Delatte), INRAE, (Dr S Fellous), RMCA (Dr M De Meyer), and chaired by Mrs Valérie Balmès (ANSES). The local organizing committee together with the TEAM steering committee organized this event as a combined physical and virtual gathering. As a result, 511 persons from more than 70 countries registered for the webinar, including several delegates from other regional fruit fly networks such as Tephritid Workers of the Western

Hemisphere (TWWH) and Tephritid Workers of Asia, Australia and Oceania (TAAO). Although not all registered persons connected, at least 365 delegates followed partially or entirely the meeting throughout the week.

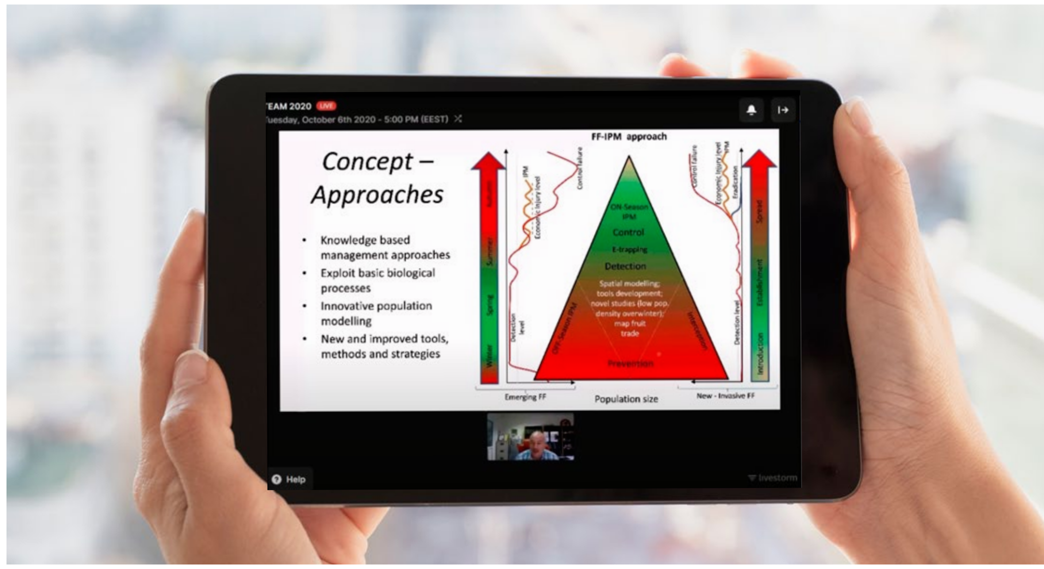
The programme of the symposium consisted of plenary speakers and talks, grouped in nine different sessions, over a period of five days, covering all major research aspects. In total, 36 presentations (including two plenary talks) were given throughout the week. Forty-four posters were on display and the authors could shortly summarize their findings and reply to questions by the delegates during two poster sessions. This meeting also, for the first time, included explicitly contributions of researchers focusing on the wing-spotted fruit fly *Drosophila suzukii (Drosophilidae)*.

Furthermore, a whole evening session was dedicated to a round table discussion organized on the theme "New concepts and approaches in fruit fly management in Europe". This session started with five short introductory speeches related to the FF-IPM project developed themes. A first talk presenting the FF - IPM project was made by Nikos Papadopoulos, which was followed by an "overview of fruit fly IPM in Europe and the TEAM area" by Hélène Delatte. Those well-known concepts were further discussed by Slawomir Lux through his talk entitled: "Is IPM a valid approach for fruit fly control in the European context?". Then, three other short communications were made on: "Alternative to insecticide applications", "Area Wide fruit fly management in Europe" and "The economics behind fruit fly management" by Josep Jaques, Rui Pereira, and Anna Larcher, respectively. Those talks made by the FF-IPM project participants opened the discussion and a debate around those questions was steered by M. De Meyer and N. Papadopoulos for 2.5 hours, with a very large audience, that included the whole congress participants.

Despite the difficult circumstances, this fourth TEAM meeting was considered a great success both by the organizers and the participants.

Although physical meetings do have several advantages and facilitate interactions and networking, having the option of a virtual attendance and presentation increases the number of people who can partake in the meeting. Members of the local organizing committee and the TEAM steering committee will edit the proceedings of the symposium, which will be published in a separate open access e-issue of the peer-review journal Fruits.

All relevant information will be made available through the Symposium's website: https://www.alphavisa.com/team/2020/



You can watch the **FF-IPM Round Table** on our YouTube channel:

https://www.youtube.com/channel/UCmOq5Svpilo_PFSfo7_8toQ

Rui Cardoso Pereira

Section Head of Insect Pest Control in the Joint FAO/IAEA Programme for Nuclear Techniques in Food and Agriculture, based in Vienna, Austria

Interview by Ana Larcher Carvalho and Ulrich Schiefer

The interest and concern with agriculture are one of the main motivations that guide Rui Pereira's life, since his childhood, growing up in a small rural village near Coimbra in Portugal. He pursued this interest throughout his academic life and went on to do a BSc in Agronomy with a specialisation in Plant Protection, and an MSc in Integrated Pest Management at the School of Agriculture, University of Lisbon [Instituto Superior de Agronomia].

In 2005, he received his PhD from the University of Florida, Gainesville-FL, USA, with a dissertation on the sexual behaviour of the Caribbean fruit fly. From 1994 he worked as head of field activities at the Madeira-Med SIT Programme in Portugal and, since 1997, as its Director.

In 2007, he went on to work at the Insect Pest Control Section of the Joint FAO/IAEA Programme and, in 2017, became Section Head. He continues to work on applied research and support to field programmes assisting several countries moving towards more environmentally friendly pest management and improved food security.

The sterile insect technique (SIT) is an environmentally-friendly insect pest control method involving the mass-rearing and sterilization, using radiation, of a target pest, followed by area-wide releases of sterile insects over defined areas, where they mate with wild females resulting in no offspring and a declining pest population.

Irradiation from gamma rays and X-rays is used to sterilize mass-reared insects so that, while they remain sexually competitive, they cannot produce offspring.

The SIT does not involve transgenic (genetic engineering) processes.

Adapted from: https://www.iaea.org/topics/sterile-insect-technique

Could you tell us about the history of the Joint FAO/IAEA Programme and the Insect Pest Control Section?

Some of the current groups dealing with agriculture, including the Insect Pest Control Section, were established at IAEA in the early 1960s. The Insect Pest Control Section was set up in response to Member States' requests for the technology following the successful screwworm SIT programme in Florida.

At the same time, the FAO had initiated a unit in support of nuclear applications in agriculture. As there were increasing overlaps between the activities of the Vienna and Rome groups, the Joint FAO/IAEA Programme was established in 1964, with the relevant FAO staff and resources in this area moving to Vienna. The IAEA already had laboratories working in nuclear applications at its Seibersdorf facility, south-west of Vienna, Austria and it was decided that the Joint Division Director would be from FAO to balance the allocation of resources from the two organizations.

The Joint Division is unique in the UN system in view of its research laboratories and Coordinated Research Projects (CRP), and because both FAO and IAEA contribute funds and staff salaries. The work programme and budget are jointly approved by the two organizations every two years and an oversight committee with representatives from both FAO and IAEA meets once a year.

What are some of the important activities of the Joint FAO/IAEA Programme in insect pest control?

The Insect Pest Control Section works to help countries combat plant pests, such as fruit flies and moths, and more recently the *Spotted Wing Drosophila* (SWD) and the European grape moth, as well as livestock pests, such as the screwworm and tsetse flies. In the past eighteen years, the Section has also advanced the method to combat human disease vectors, like *Aedes* and *Anopheles* mosquitos. We also have a research laboratory that conducts applied research and implements Coordinated Research Projects (CRPs).

The Joint FAO/IAEA Programme also provides technical backstopping to its IAEA Technical Cooperation projects, producing manuals, standard operation procedures, and guidelines to help Member States apply the technology. Our research is always demand-driven.

We also conduct research as part of Coordinated Research Projects. When we identify a bottleneck, we bring together scientists from all around the world to find technical solutions. Funding is made available for scientists in developing countries, but we also support costs for networking or meetings to exchange information and expertise. Together, using the same research questions and protocols, we try to overcome these bottlenecks. For example, in Madeira I participated in a CRP where female attractants for Mediterranean fruit fly were developed and tested in many countries and are today used all over the world.

What are some of the important insect pest control programmes that the Joint FAO/IAEA Programme participated in?

In our section, we are working on three groups of insects. One is in plant pests, mainly fruit flies and moths. In the past three years, we have also developed a SIT package for *Drosophila suzukii*, which is an emerging pest mainly in Europe and the Americas. The application of SIT for *Drosophila* can be very useful in greenhouses. In Europe, greenhouses are mostly using biological control methods.

When you have a pest and need to use insecticides you are not just damaging the environment, but you are jeopardising all your biological control programme because you are killing predatory mites, insect predators, parasitoids, everything. We are already testing in greenhouses and doing some pilot trials. We also started work on Lobesia botrana which causes problems in southern America. We don't have to develop the technology from scratch, we have to adapt it to the new species.

Then we work in livestock pests. After work started in the late 1950s in Florida, in a few years the screwworm was eradicated, first from all southern states of the USA and then in Mexico and Central American countries, and since 2004 as far south as Panama. Now there are talks that Uruguay might start to use SIT to fight the screwworm its southern region to stop spread towards the north.

Just a few years ago there was a screwworm introduction in the Florida Keys again and it was successfully controlled and eradicated using SIT.

We also work on tsetse; this pest was eradicated 20 years ago from Zanzibar which is still free from it. Work is going on in South Africa and Senegal; we hope to be able to declare one region close to Dakar as tsetse free soon. This agriculturally important region is isolated from other zones in the south where the pest continues to exist.

In the last 18 years, we have a group working on Mosquito vectors of disease. We have been working intensively after the Zika outbreak in 2015. With funding mainly from the USA, as well as from Japan and UK, and have been working on SIT for *Aedes* mosquitoes, both *Aedes aegypti* and *Aedes albopictus*. They are major vectors of Zika, dengue, chikungunya, etc.

We have been also working to a less extent on *Anopheles*, which is a malaria vector. We have been mainly working in South Africa, which is the southern limit for malaria in Africa, and Sudan, which is the northern limit, since in these regions there are only one or two species of malaria vectors, making it easier to control using the method. The SIT is species specific. In the central part of Africa, you have 10, 15 or 20 species that transmit the disease, so if you control one species, it will not effectively control the disease and SIT will not be effective.

One of our main goals is to expand SIT to other insect species. We are also working towards developing genetic sexing strains for mosquitoes to avoid the release of sterile females. We try to develop strains in mosquitoes where we can easily separate females and males. If we release sterile males it is ok, but if we release females, even if sterile, they are a vector as they bite, and this is ethically not acceptable. In fruit flies, if you release sterile females, they cause little damage, and it is not a major problem. But with human diseases this is not acceptable.

One of our main goals is to expand SIT to other insect species.

So, one of the bottlenecks is to have a cost-efficient sex separation method for mosquitos.

We are also working together with the FAO in supporting the International Plant Protection Convention (IPPC). We are very involved in the technical panel on fruit flies and phytosanitary treatments. There is a series of international standards that we have been supporting. This is the big picture of our work here.

What do you consider to be the most important contributions of the work of the Insect Pest Control Section?

The most important achievement is the contribution to trade if we look at fruit flies. Fruit flies are very relevant for trade because they can be easily spread inside the fruits and can cause major economic damage worldwide. In 2015, in the Dominican Republic, a fruit fly invasion caused import bans for fruits and led to a drop of 40 million euros of exports to the US in nine months. Within months, through cooperation with other international organisations and the Ministry of Agriculture, the fruit fly was eradicated and the year after the exports came back to the normal figures of about 60 million euros per year.

If we look at tsetse flies, poverty is also very relevant. Tsetse kills people and animals, where you have tsetse you have poverty. You have sleeping sickness, which is called Nagana when in animals. No meat, no milk, no traction for agriculture results in poverty in rural communities in low-income countries. In the region of Senegal where we are working, tsetse is still not eradicated, but strongly suppressed, so Senegal was able to import cattle that produce much more milk than the local breeds, which are tsetse resistant but produce little milk. The increase of milk production by the factor 20 has a huge impact and is a big achievement already.

These are some examples of successful projects.

There is an interesting research paper on the socio-economic impact of the fruit fly projects in Peru. It says that it is not only the big farmers who benefit but also the small farmers in areas that are under Integrated Pest Management (IPM) using SIT or where the fruit flies have been eradicated and that opened the doors to other markets. This indicates that the SIT benefits also small farmers.

How do you see the future of SIT in Europe?

In the last ten years a lot of cheap insecticides disappeared as they can no longer be used due to stricter regulations, so the need for SIT is there. The SIT was used in the past mainly as an eradication tool. Today it is much more used as a suppression tool in specific areas. In Spain, for example, you can establish a low prevalence for fruit fly considering SIT and then come with additional post-harvest measures and reach consumer markets.

There is an interesting project on the onion fly (*Delia antiqua*) but if some of the farmers do not participate in the suppression measures for their fields (area-wide approach), they are creating hotspots. This is one of the major problems faced.

The SIT is more and more used against the codling moth (*Cydia pomonella*), which attacks apples and pears. There are not many large cultivation areas for such production like you have for citrus in Spain, but you have some areas like in the valley of Trentino, where you can combine the sexual confusion technique with SIT. This combination of techniques considerably reduces insecticide use and fruits can thus be exported to low pesticide residue market.

It is more difficult to get area-wide programmes in Europe than in other places. In Europe, we have a lot of small farms. We know that SIT works area-wide, but if you don't get everybody involved, it gets complicated. For SIT to gain more ground in Europe, there is a need for everybody to work for the same objective. But this is more challenging when there are thousands of farmers who need to be involved.

Getting governments involved may also be difficult. The issue is not technology. We know that the technology works. It is how it is applied and how it is managed. It is very management intensive, which can be a problem.

When you have a situation where fruit production is not mixed, but relatively homogeneous, like citrus in Valencia or mandarins in the Neretva valley, where mandarins are 90% of the production areas and you have a product with a high commercial value, SIT is highly recommendable. However, if we go to places like Madeira, where I worked, it is extremely complicated, because you have a diversity of fruits, maturing one after the other, all year round. So you need to apply control methods all year round, as fruit flies are present all year round. It is much more complicated.

In Turkey, we have encountered favourable conditions for SIT. Turkey is a big producer and exporter of citrus fruit and so we have a project under design. Economics play a big role in decision making. You only can go ahead with a project with a technical and economic feasibility study done at the beginning.

What are the limitations of SIT?

The SIT is not applicable for all species. There are insect species where SIT has no role to play. I want to mention just a few relevant examples.

For example, locusts. We cannot release millions of locusts that are contributing to the damage. We cannot release *Homoptera* that are vectors of plant diseases, because as adults they transmit it. Another example is the European cherry fruit fly (*Rhagoletis cerasi*). Due to its dormancy, at the moment, we don't have a way to mass-rear the fly in the laboratory.

Recently the fall armyworm (*Spodoptera frugiperda*) invaded Africa, and now Asia. But, for control of the fall armyworm, SIT is not suitable, because the fall armyworm moves up to a hundred kilometres per generation so the area to be covered would be too vast and would not make economic sense. Their larvae are also cannibals, they eat each other when they are in confinement in small spaces in laboratories.

There are also differences in the context that affect the success of the technology. If you go to a country and if you have power failures twice a day, it is much more difficult to work and maintain a mass rearing facility than in a place with rare power cuts.

So, SIT is only feasible when it is economically important and when it is technically possible. Another consideration is the number of species present: I think it is feasible to use SIT for up to two or three species. In southern California they have been using two machines on the same plane to release Mediterranean and Mexican fruit flies at the same time in areas where they have outbreaks of both. Otherwise, it will turn the technology much more expensive.

The SIT is not applicable for all species. There are insect species where SIT has no role to play.

SIT is also management intensive and not always economically recommendable; it is not adequate for all species and it needs to be applied in area-wide integrated pest management [1]. If it is not in an area-wide approach, it does not work. And it should be combined with other control methods. It is not a standalone methodology nor a silver bullet.

What are the future areas of concern for pest control in the world?

The most relevant aspect is invasive species. People are moving more and more; backpackers and travellers are transporting fruits. I am really concerned. We have seen how quickly *Bactrocera dorsalis* invaded all of Africa in 2003 and

1 Area-wide integrated pest management (AW-IPM) is a coordinated, sustainable and preventive approach that targets entire pest populations. It aims at integrating environment-friendly control measures such as the Sterile Insect Technique, to reduce losses and insecticide use, and to facilitate the expansion of international agricultural trade, while minimizing the further global spread of some major invasive pests. Source: https://www.iaea.org/resources/book/area-wide-control-insect-pests-from-research-to-field-implementation

spread all over the Continent in the Sub-Saharan region.

In southern Europe, we have seen an increase in invasions. This is linked with the work that you are doing in the FF-IPM project. One of the objectives is to study in detail potential invasive species of relevance.

Of course, another aspect, that we cannot avoid, is climate change. Pests are expanding their range. For example, the Mediterranean fruit fly has started to appear more and more in Central Europe, we don't know for sure if it is established or if it comes every year. They are causing trouble in latitudes where they previously didn't.

Which invasive species do you consider most important?

For Europe, clearly *Bactrocera dorsalis* and *Bactrocera zonata*. This is clear. But other *Bactrocera* are a potential problem as well. In my opinion, the third most important one, the melon fly (*Zeugodacus cucurbitae*) that is now invading Africa as well.

Besides fruit flies, there have recently been invasions of mosquitoes in Europe related mainly to climate change. They are now in the southern European countries; in Portugal and namely in Madeira, this is very relevant. Anopheles was endemic in the Sado delta in Portugal in the first part of the XX century and then disappeared: I will not be surprised if it shows up again in some wetlands in southern Europe. For other species, I would not be surprised if the fall armyworm would reach Europe.

However, the Covid-19 situation does not favour invasive species. Fewer people are moving, fewer fruits are transported in backpacks.

But where I have more background information to share is about fruit flies. Clearly, the Oriental fruit fly (*Bactrocera dorsalis*) is by far the one with the most potential and the most dangerous at the same time. The Oriental fruit fly was detected in Italy, in Southern France, in Paris, and in Vienna.

Bactrocera zonata is also coming closer, it is already in Egypt and Libya. It is not as aggressive as the Oriental fruit fly. For example, *Bactrocera zonata* was in Mauritius for many years, and it was now almost completely displaced by the Oriental fruit fly, *Bactrocera dorsalis*. Maybe in a drier climate is different, because *Bactrocera dorsalis* seem better adapted to the tropics.

Bactrocera zonata displaces almost completely the Mediterranean fruit fly in Egypt. If it arrives in southern Europe, maybe it displaces Mediterranean fruit fly. It may be established, maybe not. The risk is high, in my opinion. There is a nice study that shows that *Bactrocera* always displaces *Ceratitis* because they are more aggressive. The damage they cause can be bigger despite the host range being not that different.

Also, you have some markets that Europe supplies, and which don't consider the Mediterranean fruit fly as quarantine pest, but if you have the Oriental fruit fly (*Bactrocera dorsalis*) or the *Bactrocera zonata* some trade barriers might go up.

How does the current crisis affect plant protection?

It is curious because 2020 was the International Year of Plant Health.

The Covid-19 pandemic has brought some constraints, for example on the shipments of insects from Europe to Senegal for the use of SIT against tsetse, and also some mass-rearing of insects decreased or stopped. Some researchers, instead of having the insects in the laboratory, are bringing them home to maintain the colony and keep the research going, if possible. Field experiments are also suffering constraints in some areas.

However, the Covid-19 situation does not favour invasive species. Fewer people are moving, fewer fruits are transported in backpacks. Less travel, less international movement, so there is less spread of pests this way. However, I don't think that the supply and access to fruit is a problem since the regulated fruit trade has kept going.

We want to thank you for this interview.

Entomopathogenic Nematodes for fruit-fly control

Arne Peters & Apostolos Kapranas

Introduction

Nematodes, if known at all, are usually regarded as a threat. Plant parasitic species cause significant crop losses every year. Other species infect livestock or pets and there are several species that cause severe human diseases. The vast majority, however, are non-parasitic free-living species.

Nematodes have hence explored almost every food source including insects. It is estimated that they recruit about 80% of all metazoan species worldwide. Among entomopathogenic nematodes, the rhabditid genera *Steinernema* and *Heterorhabdtis* have been developed into a powerful tool for controlling insect populations.

Their suitability for industrial mass production is a major reason for the successful commercialization of Entomopathogenic Nematodes.

Biology of entomopathogenic nematodes

Both nematode genera have similar life-cycles starting with an infective juvenile which vectors the symbiotic entomopathogenic bacteria inside the haemocoel of a suitable host. Subsequently, the bacteria multiply in the insect's haemocoel, the insect is killed, and the nematode propagates feeding on the bacteria. When the food in the insect cadaver is depleted, an enduring third stage juvenile, the infective juvenile, is formed and leaves the cadaver if conditions outside are suitable (i.e. sufficiently moist and of adequate temperature). The nematode and the symbiotic bacteria act together in overcoming the insect's immune response (Dowds and Peters, 2002).

The suitability for industrial mass production is surely a major reason for the successful commercialisation of entomopathogenic nematodes. Besides, they have a moderately wide host range allowing for applications against a variety of different insect groups but still minimising adverse effects to non-target insects. The infective juvenile, which is the only free-living stage, can be stored for one to several months. They are sufficiently small to pass through standard spraying equipment and they actively move in suitable moist environments like the soil or galleries in wood, fruits, or leaves (Wright et al. 2005). Soon after discovering the first *Steinernema* species by Krausse in 1917 the nematode Steinernema glaseri, produced on an artificial medium based on dog-food, was used in controlling the scarabaeid *Popillia japonica* in the USA in 1940. At that time, the symbiotic relation with bacteria was unknown and, subsequently, mass production on artificial media collapsed after a few cycles probably due to contaminating bacteria taking over, which did not support growth and propagation of the nematode. The renaissance of using *Steinernema* and *Heterorhabditis* started in the mid-1980s fostered by an increasing public concern about the use of chemical crop protection products and the widespread adoption of biological pollination and biocontrol in greenhouses. Since then, the market continues to grow rapidly at a rate of about 15% per year.

The use of nematodes to control fruit flies

Fruit flies are important pests because they cause direct economic losses to growers and also affect fruit trading since many species are considered quarantine pests such as the Mediterranean fruit fly or medfly, *Ceratitis capitata*, *Bactrocera zonata* and *Rhagoletis cerasi*. Fruit flies in the family Tephritidae and to a lesser extend other families (e.g., Drosophilidae) spend a period of their biological cycle in the soil, as mature larvae (maggots) fall and burrow in the soil to pupate or in some cases larvae and pupae overwinter in fallen fruits on the ground. The use of entomopathogens such as entomopathogenic nematodes and fungi against the soil-dwelling stage of tephritid flies offers an excellent opportunity for an effective management. The susceptibility of *C. capita* to entomopathogenic nematodes and their efficacy was assessed early from the 1980's (Poinar and Hislop 1981; Lindegren and Vail, 1986; Lindegren et al. 1990). Gazit et al. (2000) conducted detailed laboratory tests comparing many species and different strains showing that *Steinernema riobrave*, a species that is not cultured commercially, leads to >80% medfly larval mortality. Since then there have been numerous other studies assessing EPN (entomopathogenic nematodes) potential and efficacy in controlling medfly and other fruit fly species. Most of these

The use of Entomopathogenic Nematodes and Fungi against the soil-dwelling stage of Tephritid flies offers an excellent opportunity for an effective management

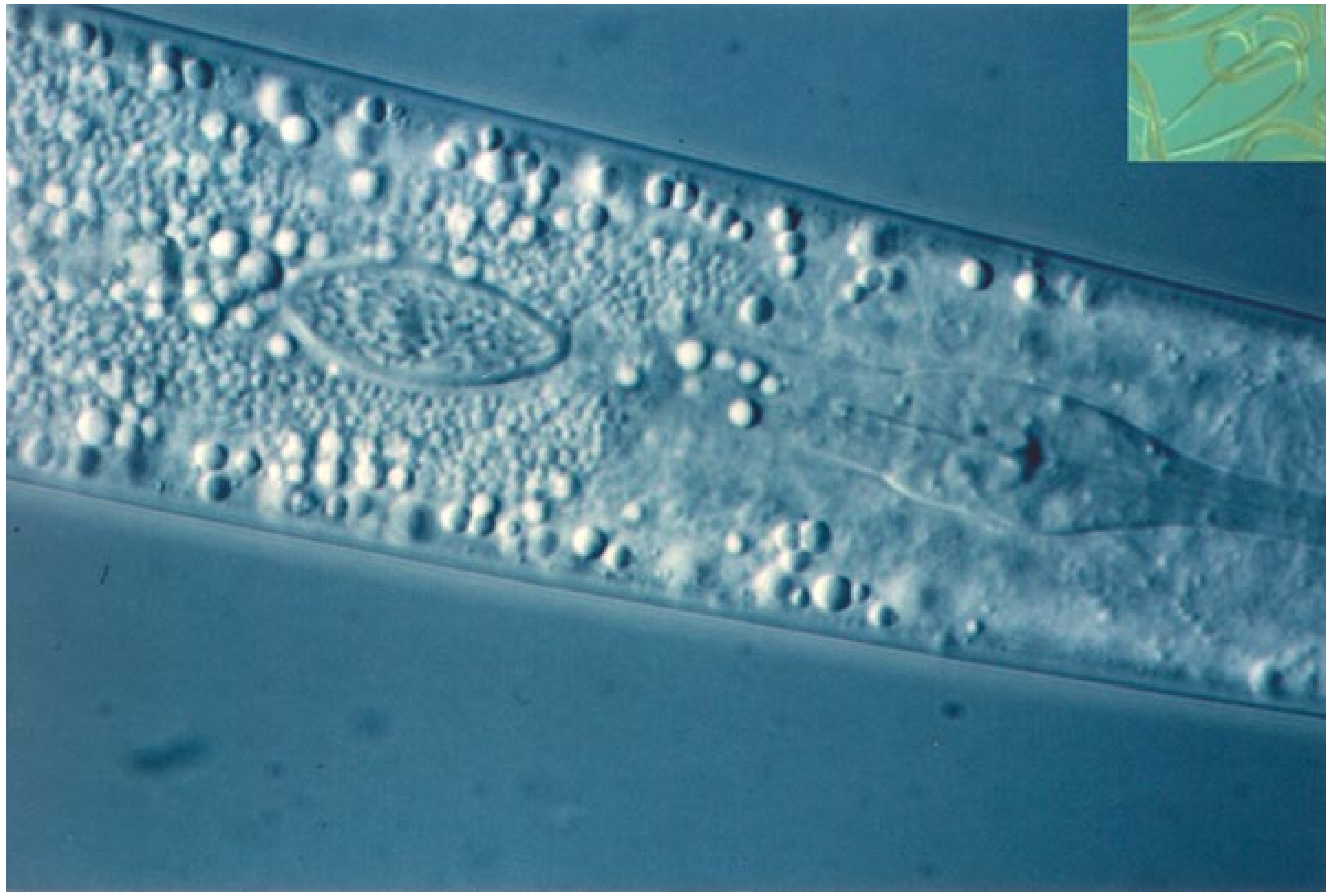


Fig. 1: Infective juvenile of the entomopathogenic nematode *Steinernema feltiae*. Close-up of the vesicle in the first part of the intestine containing the symbiotic bacteria *Xenorhabdus bovienii* (1000-fold magnification). The intake shows infective juveniles at full length (approx. 800 mm).

studies have been conducted almost exclusively in laboratory conditions. It is difficult to compare findings of these studies mostly because there is enormous variation in the trial conditions; different strains of nematodes of the same species, different temperature regimes, different soil media and different dose of nematodes/density of larvae and/or pupae used. Nonetheless the majority of these studies have shown at least the potential of using EPN for fruit fly control, especially the steinernematids *S. feltiae* and *S. carpocapsae*. In the field, few studies from Latin America have shown promising results: Minas et al. (2016) using *Heterorhabditis baujardi* against *C. capitata* in guava, Silva et al. (2010) using *H. indica* against medfly *larvae* in guava, Toledo et al. (2005) using *H bacteriophora* against *larvae* of *Anastrepha ludens* in Mangos, and Barbosa-Negrisoli et al . (2009) using *S. riobrave* and *H. bacteriophora* in peach orchards.

Other studies have also indicated that EPN can infect fruit fly *larvae* inside fruits (Toledo et al. 2006; Sirjani et al. 2009; Kamali et al. 2013; Mokrini et al. 2020) which can serve as a sanitation measure of the infested fruits that fall to the ground at the end of the season.

There are certain challenges in using EPN against fruit flies such as the correct species of nematode, determining the right dose based also on the density of fly pest population, timing of the application, based on temperature and pest phenology as well as assessing the influence of soil composition/ texture and/ or possible cover crop and its interaction with all these parameters. Many studies that documented increased efficacy against fruit flies have been conducted using local, indigenous strains that are specific in this area and not commercially available; for instance, *Steinernema riobravae, Steinernema yirgalemense, Heterorhabditis baujardi, Heterorhabditis noenieputensis* seem particularly adapted on medfly showing increased efficacy in laboratory and field tests (Gazit 2000; Minas et al. 2016; James et al. 2018). The same also holds true for different locally adapted strains of commercially available EPN species (e.g., *Mokrini* et al. 2020).

Therefore, whether and under what conditions, commercial EPN species are effective for fruit fly control remains an important and up-to-date research quest. Furthermore, the timing of application and residual activity of EPN species at different conditions should also be investigated, in every pest-specific context.

Within the FF-IPM project, four commercially available nematode species (*Heterorhabditis bacteriophora, H. downesi, Steinernema carpocapsae,* and *S. feltiae*) have been tested for the efficacy against medfly larvae. Besides, nematodes were applied as a mulch-barrier to infest emerging fruit-fly adults. The susceptibility of the adults was low but, interestingly, the life-expectancy of treated medfly adults was shortened. As expected, *medfly larvae* were more susceptible and the most efficient nematode was *Steinernema feltiae*. This nematode even infested *larvae* inside the fruit on the soil when applied to the soil, so they are actively searching for susceptible hosts. The nematode S. feltiae is infecting insects at temperatures from 8 to 28°C and is therefore ideally suited for off-season control of medflies. The efficacy in suppressing medfly populations will be tested within the FF-IPM project this winter.

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news update

Annual Meeting of the American Entomological Society

The FF-IPM Project and its expected results were presented at the Annual Meeting of the American Entomological Society by Prof. Papadopoulos (University of Thessaly), project coordinator.

EXPECTED RESULTS

- Tools and databases to predict where and when invasive pests are likely to enter Europe
- Rapid detection and identification tools - electronic traps or electronic noses
- Management toolkit to suppress any established fruit flies
- Design a novel approach for all pest organisms putting EU horticultural industry at risk

Prof. Papadopoulos shared the FF-IPM vision to create a paradigm shift towards the off-season management of emerging pests.

Temperature monitoring within fruit on the tree system developed and successfully tested

A custom-made prototype logger has been developed by our colleague (Efi Bataka, Laboratory of Biometry UTH) to collect temperature data within overwintering fruits in UTH's Pilot Site, Lehonia, Magnesia, Greece.

The first successful preliminary test has been conducted from 12 to 14 September 2020. Temperature was recorded for 2 consecutive days every 5-6 mins in fruit core, under fruit surface and outside fruit using needle-like probes. Commercial apples were selected as hosts from the official Pilot Units in the Site, and preliminary results are presented below.

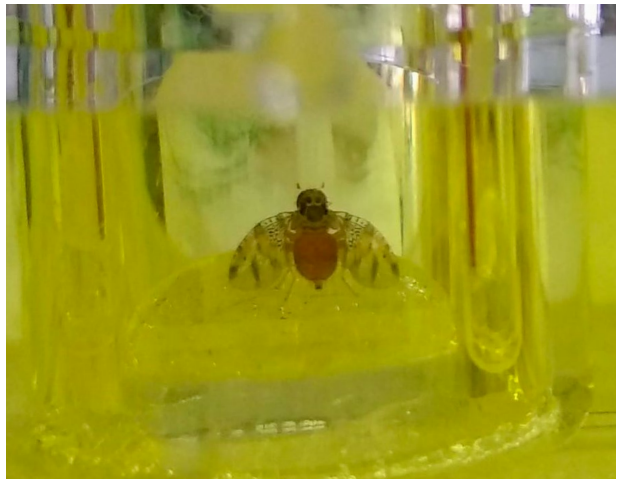
The developed equipment will be used to precisely assess temperature in overwintering hosts of the Mediterranean fruit fly in the frameworks of the FF-IPM project.

Establishment of traps in S. Africa

FF-IPM South African team (Citrus Research International) collecting baseline information on the phenology of the invasive fruit fly species- *Bactrocera dorsalis* (Oriental fruit fly) in several areas of low prevalence in northern South Africa. Data collected over two years will be used for development of an optimized detection system for this pest. The novel automated early detection system will integrate e-Traps developed and deploy them in novel spatio-temporal arrangements to test hypothetically efficient surveillance strategies.

University of Thessaly
Approximation of critical temperatures

Insect Biology Lab - UTH's team is conducting trials for the approximation of CTmin and CTmax for 3 medfly biotypes to identify physiological and molecular mechanisms that regulate plasticity and adaptive responses to stressful conditions.



Autumn application of Entomopathogenic nematodes

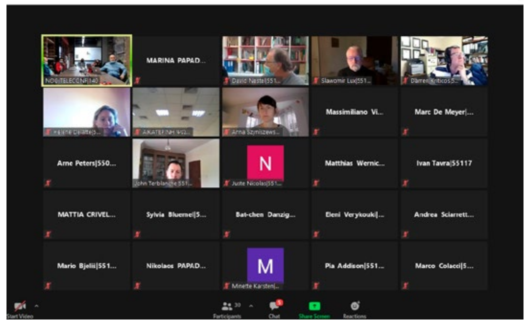
Benaki Phytopathological Institute applied Entomopathogenic nematode *Steinernema feltiae* suspension in citrus for Off-season control of medfly larvae in the soil and fallen fruits. The activity took place in Koniario Institute, Korinthos, Greece.

PROJECT HIGHLIGHTS

Milestone achieved Electronic FF detection trap advanced & tested	Extensive testing of mass trapping devices at UTH	Evaluation of e-trap & e-nose	Temperature monitor system by UTH
APR 2020	JUN 2020	AUG 2020	SEP 2020
TEAM meeting	Application of Entomopathogenic nematodes in Greece	FF-IPM Annual meeting	Trap installation in S.Africa
OCT 2020	OCT 2020	OCT 2020	NOV 2020

Establishment of traps in Israel

David Nestel's group in the Agricultural Research Organization of Israel (ARO) realized the establishment of e-traps at an apple orchard in the Northern border of Israel. The scope of this experiment is to monitor the presence of fruit flies in the area. In addition and in order to compare the results, a conventional trap was also placed in the region.



Annual meeting

The Annual Meeting brought together more than 40 scientists from 16 countries (representing 21 project partners) to share progress and findings achieved during the 1st year of the project. The overall project overview was presented by Prof. Nikos Papadopoulos from the University of Thessaly, project coordinator. Regardless of COVID-19 pandemic restrictions and the seasonality of data collection, FF-IPM's researchers managed to produce the high-quality results expected. Following a series of presentations, participants had the opportunity to attend the session given by Prof. David João Horta Lopes (University of Azores, Portugal) who outlined the main findings of the recently concluded European funded project "Euphresco", offering a view on comparative research on the fruit fly's challenge.

American Congress of Fruit Flies

Congreso Americano de moscas de la fruta **2-6 November 2020**

Dr. David Nestel presented FF-IPM EU at the American Congress of Fruit Flies that took place in Colombia, among the works of the 10th Meeting of the Working Group on Fruit Flies of the Western Hemisphere.

Dr. Nestel stressed that since neonicotinoids were banned, which was an additional burden on fruit growers in Europe, and along with the new knowledge we gained for the FF control, a solid starting base for the FF-IPM project was created.

The second important part of his presentation was the synergy that emerged via the FF-IPM project among many international stakeholders. This synergy helped the FF-IPM project to establish a prevention system based on EU needs which are different from the regulatory uniform, macro-regional scales of the USA and Australia, which are the main providers of pest control knowledge and pest handling systems.

Fruit Flies In-silico
Prevention & Management
FF•IPM

Horizon 2020
European Union Funding
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