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WORKING MATERIAL

INTEGRATION OF THE SIT WITH BIOCONTROL FOR GREENHOUSE AND OTHER CONFINED PEST INSECTS

REPORT OF THE CONSULTANTS' GROUP MEETING

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Table of contents

1 Introduction

Greenhouses and other confined locations provide ideal conditions for the rapid build-up of pest populations as they are largely protected from predators and parasitoids. Many of these pests have been exposed to high pesticide pressure over many generations, and resistance has developed in many of them. Biocontrol agents are widely used to combat these pests, but not all are well controlled with biocontrol agents and when a pest gets out of control it has to be controlled with pesticides, which then disrupts the biocontrol and pollination.

The SIT is compatible with biological control and can complement biocontrol for some of those pests that are difficult to control, reducing crop losses and pesticide residues in food.

Augmentative biological control has historically focused mainly on crops grown in confined areas. Recently there is more attention for crops grown outside. For SIT the opposite direction can be observed, historically SIT has focused on area wide pest management in open environments, but in the framework of this CRP it will be assessing the viability of integrating SIT to control some pests in confined areas such as greenhouses.

This expert meeting has focused on identifying the constraints on biocontrol in greenhouses and candidates where SIT may be integrated and supplement the current biocontrol and made recommendations for the establishment of the CRP.

2 Working process

This describes the strategic approach adopted by the expert committee to make recommendations about whether there is a need for a CRP in this area.

2.1 Listing of pests of confined areas.

We initiated with drawing up a list of major pests in confined environment, being mainly pests in greenhouse and tunnel crops, fruiting vegetables, soft fruits, ornamentals (See Table 1). Confined pests that still represent a bottleneck and therefore a disruptor of current biocontrol schemes (due to corrective chemical sprayings with broad spectrum PPPs) or that are less likely to be tackled by biocontrol due to their biology (e.g. Lepidoptera with scattered oviposition sites of single eggs, which would require highly efficient searcher parasitoids to control them) were identified.

The group notes that there are different levels of confinement and greenhouses tend to be less confined and less technical moving to warmer climates. Moving into warmer climates metallic structures with glass and high tech climate control and lighting make room for wooden or metal structures with plastic or mesh screens over it (“screenhouses”, “mesh houses”, “casa malla”). These structures are often open or opened up at the (end) sides whenever ventilation is required. Therefore, the group notes that from open field to confinement is a continuum rather than an absolute separation. Moving into more confined cropping systems it is to be expected to improve the efficacy of SIT or inherited sterility techniques because there is less immigration of fertile females.

2.2 Evaluating pest species for SIT

We evaluated if SIT could be a method of control for some major pests (see Table 2). The following parameters were considered:

Table 1. List of greenhouse, storage, livestock and beehive pests

Pest scientific name	Common name of pest	Taxonomic group	Host	Vector Y/N	Established biological control	Excluded because
Greenhouse pests						
Aculops	Tomato russet mite		tomato	*Hirsutella thompsonii*	no	too small and arrhenotokous
Anthonomus eugenii	Pepper weevil	Coleoptera: Curculionidae	pepper			adult feeding damage
Bactericera cockerelli	Tomato psyllid	Hemiptera: Triozidae	tomato	Y		Vector
Bemisia tabaci		Hemiptera: Aleyrodidae	several			Vector
Chrysodeixis chalcites	golden twin-spot moth	Lepidoptera: Noctuidae	pepper tomato banana		no (eggs scattered)	
Drosophila suzukii	spotted wing drosophila	Diptera: Drosophilidae	soft fruits		no	
Duponchelia fovealis	Southern European marshland pyralid	Lepidoptera: Crambidae	ornamentals		Bt?	
Echinothrips		Thysanoptera: Thripidae	cut flowers			adult feeding damage , parthenogenic
Frankliniella occidentalis	wft	Thysanoptera: Thripidae	soft fruits, sweet peppers, cut flowers,			adult feeding damage , parthenogenic
Halyomorpha halys	brown marmorated stink bug	Hemiptera: Pentatomidae				adult feeding damage
Helicoverpa armigera	cotton bollworm	Lepidoptera: Noctuidae	polyphagous		Bt, Granulose virus	
Leafhoppers		Hemiptera: Cicadellidae	sweet peppers	y		vector
Lygus hesperus		Hemiptera: Miridae	cucumber			adult feeding damage
Lyriomyza spp.	Leafminers	Diptera: Lyriomyzidae				
Planococcus citri		Hemiptera: Pseudococcidae	tomato, sweet pepper, ..			parthenogenic?, male longivity 2d

Pest scientific name	Common name of pest	Taxonomic group	Host	Vector Y/N	Established biological control	Excluded because
Neoleucinodes elegantalis	eggplant stem borer, tomato borer	Lepidoptera: Crambidae	tomato, capsicum, egg plant			
Nezara sp		Hemiptera: Pentatomidae				adult feeding damage
Scatella	Shore fly	Diptera: Ephydridae			yes	
Sciaridae	Fungus gnats	Diptera: Sciaridae			yes	
Scirtothrips mangiferae	blueberry leaf thrips	Thysanoptera: Thripidae	soft fruits			adult feeding damage
Spodoptera frugiperda	fall armyworm	Lepidoptera: Noctuidae	polyphagous		Bt?	
Spodoptera exigua	beet armyworm	Lepidoptera: Noctuidae	solanacea		Bt?	
Trialeuroides vaporarium	greenhouse whitefly	Hemiptera : Aleyrodidae	several	y	yes	
Tuta absoluta	Tomato leaf miner	Lepidoptera: Gelechiidae			EU yes not elsewhere	
Storage pests						
Araecerus fasciculatus	Coffee bean weevil	Coleoptera: Anthribidae	cassava:			adult feeding damage, digestive duct radiation sensitivity
Cadra figulilela	Dried fruit moth	Lepidoptera: Pyralidae				
Callosobruchus chinensis	Southern cowpea beetle	Coleoptera: Chrysomelidae				adult feeding damage, digestive duct radiation sensitivity
Callosobruchus maculatus	Cowpea beetle	Coleoptera: Chrysomelidae	pulses:			adult feeding damage, digestive duct radiation sensitivity
Carpophilus dimidiatus	Corn-sap beetle	Coleoptera: Nitidulidae				adult feeding damage, digestive duct radiation sensitivity
Corcyra cephalonica	Rice moth	Lepidoptera: Pyralidae				
Cryptolestes ferrugineus	Rusty grain beetle	Coleoptera: Laemophloeidae				
Cryptolestes pusillus	Flat grain beetle	Coleoptera: Laemophloeidae	paddy rice			adult feeding damage, digestive duct radiation sensitivity
Cadra cautella	Tropical warehouse moth	Lepidoptera: Pyralidae				

Pest scientific name	Common name of pest	Taxonomic group	Host	Vector Y/N	Established biological control	Excluded because
Lasioderrna serricorne	Cigarette beetle	Coleoptera: Anobiidae				adult feeding damage, digestive duct radiation sensitivity
Liposcelis entomophila	Psocid	Psocodea: Liposcelididae:				adult feeding damage
Lophocateres pusillus	Siamese grain beetle	Coleoptera: Trogossitidae	paddy rice			adult feeding damage, digestive duct radiation sensitivity
Oryzaephilus surinamensis	Saw-toothed grain beetle	Coleoptera: Sylvanidae				adult feeding damage, digestive duct radiation sensitivity
Plodia interpunctella	Indian flower moth	Lepidoptera: Pyralidae				
Rhyzopertha dominica	Lesser grain borer	Coleoptera: Bostrichidae				adult feeding damage, digestive duct radiation sensitivity
Sitophilus oryzae	Rice weevil	Coleoptera: Dryophthoridae	paddy rice:			adult feeding damage, digestive duct radiation sensitivity
Sitophilus zeamais	Maize weevil	Coleoptera: Dryophthoridae	rice			adult feeding damage, digestive duct radiation sensitivity
Sitotroga cerealella	Angoumois grain moth	Lepidoptera: Gelechiidae	paddy rice			
Tribolium castaneum	Red flour beetle	Coleoptera: Tenebrionidae				adult feeding damage, digestive duct radiation sensitivity
Phthorimaea operculella	Potato tuber moth	Lepidoptera: Gelechiidae	potato		Non commercial baculovirus, parasitoids?	
Animal husbandry						
Musca domestica	house fly	Diptera: Muscidae	poultry			adults vector or nuisance
Fannia canicularis	lesser house fly	Diptera: Fanniidae	poultry			adults vector or nuisance
Alphitobius diaperinus	darkling beetle	Coleoptera: Tenebrionidae	poultry			adults vector or nuisance
Hydrotaea aenescens	black garbage fly	Diptera: Muscidae	poultry			adults vector or nuisance
Dermestes maculatus	hide beetle	Coleoptera: Curculionidae	poultry			adults vector or nuisance
Ornithonyssus sp.	fowl mite	Mesostigmata: Macronyssidae	poultry			adults vector or nuisance
Dermanyssus galinae	chicken mite	Mesostigmata: Dermanyssidae	poultry			adults vector or nuisance

Pest scientific name	Common name of pest	Taxonomic group	Host	Vector Y/N	Established biological control	Excluded because
Cimex lenticularius	bed bug	Hemiptera: Cimicidae	poultry			adults vector or nuisance
Menopon gallinae	chicken lice	Phthiraptera: Menoponidae	poultry			
Musca domestica	house fly	Diptera: Muscidae	swine			adults vector or nuisance
Haematopinus suis	Hog louse	Phthiraptera: Haematopinidae	swine			adults vector or nuisance
Stomoxys calcitrans	stable fly	Diptera: Muscidae	swine			adults vector or nuisance
	ticks		cattle			adults vector or nuisance
	fly		cattle			adults vector or nuisance
	lice		cattle			adults vector or nuisance
	fleas		cattle			adults vector or nuisance
Beehive pests						
Aethina tumida	Small hive beetle	Coleoptera: Nitidulidae	bees	AFB vector		
Galleria mellonella	wax moth	Lepidoptera: Pyralidae	bees		good hive management	
Achroia grisella	lesser wax moth	Lepidoptera: Pyralidae	bees		good hive management	
Varroa destructor	varroa mite	Mesostigmata: Varroidae	bees	y		adults nuisance, arrhenotokous

Potential candidates for SIT

Table 2. List of species selected as potential candidates for SIT

Pest scientific name	Common name pest	Taxonomical group	Distribution	Host	Vector Y/N	Established BC	Comments	SIT existing	Mass rearing	Economic importance	References
Greenhouse pests											
Chrysodeixis chalcites	Golden twin-spot moth	Lepidoptera: Noctuidae	EU, MEA, new US, CAN	Solanaceae, Ornemantals, Cucurbitaceae, Rosaceae		Bt, Podisus, Trichogramma	seperate eggs	no data (*T.ni*)		2	
Drosophila suzukii	Spotted wing drosophila	Diptera: Drosophilidae	EU, US, S Am	Soft fruits		no		Part. bio radiation		1	
Tuta absoluta	Tomato leafminer	Lepidoptera: Gelechiidae	S Am, EU, India	Solenaceae		EU yes not elsewhere		No SIT, yes bio-radiation		EU 3, L AM 2, US 1, AS 2	Cagnotti et al 2012
Neoleucinodes elegantalis	eggplant stem borer, tomato borer	Lepidoptera: Crambidae	C (Mexico) - S Am	Tomato, capsicum, eggplant		no	female longevity of 6d	no data	YES	L AM 2, rest 1	Talekar et al 2002; Blackmer 2001
Helicoverpa armigera	cotton bollworm	Lepidoptera: Noctuidae	EU, MEA, S-Am, AS, OC	Polyphagous		Bt, Granulose virus		SIT and bio-radiation			Ocampo 2001; Pransopon et al 2000
Spodoptera frugiperda	fall armyworm	Lepidoptera: Noctuidae	Am (cont)	Polyphagous		Bt, Baculovirus, EPN, Telonomus remus		No SIT, yes bio-radiation			Dos Santos et al 2009; Polanczyk et al 2000; Van lenteren & Bueno 2003
Spodoptera exigua	beet armyworm	Lepidoptera: Noctuidae	Global except S-Am	Solanaceae, Ornemantals, Cucurbitaceae, Rosaceae		Bt, NPV		SIT and bio-radiation		1	Debolt & Wright 1976
Duponchelia fovealis	Southern European marshland pyralid	Lepidoptera: Crambidae	MEA, S US, CAN (ONT), EU,	Ornementals, Solenaceae, Ornemantals, Cucurbitaceae, Rosaceae		Bt, EPN, Trichogramma, Soil mites		no data			
Liriomyza spp.	Leafminers	Diptera: Agriomyzidae	Global	Solenaceae, Ornemantals, Cucurbitaceae		Diglyphus	short male longevity	SIT and bio-radiation			Kaspi & Parrella 2006; Walker 2012

Pest scientific name	Common name pest	Taxonomical group	Distribution	Host	Vector Y/N	Established BC	Comments	SIT existing	Mass rearing	Economic importance	References
Storage pests											
Cadra figulilela	Dried fruit moth	Lepidoptera: Pyralidae					SIT potential not applied	Bio-radiation	YES		
Corcyra cephalonica	Rice moth	Lepidoptera: Pyralidae					SIT potential not applied	Bio-radiation	YES		
Cadra cautella	Tropical warehouse moth	Lepidoptera: Pyralidae					SIT potential not applied	Bio-radiation	YES		
Ectomyelois ceratoniae	Carob moth	Lepidoptera: Pyralidae		Date			SIT potential not applied	Bio-radiation	YES		
Phthorimaea operculella	potato tuber moth	Lepidoptera: Gelechiidae		Potato, Solanaceae		No commercial baculovirus, parasitoids, SCLP		Bio-radiation	YES		Saour & Makee 2009
Plodia interpunctella	Indian flower moth	Lepidoptera: Pyralidae					SIT potential not applied	Bio-radiation	YES		
Sitotroga cerealella	Angoumois grain moth	Lepidoptera: Gelechiidae		Paddy rice			SIT potential not applied	Bio-radiation	YES		
Animal husbandry											
Aethina tumida	Small hive beetle	Coleoptera: Nitidulidae		Bees	AFB vector	EPN	80 Gy; longevity of 8d	Bio-radiation			Downey et al 2015; Schaefer et al 2010

Targeted candidates for SIT

a. Pest distribution (continent/countries),
b. Host range (major family of confined crops attacked),
c. Biological control methods used and their effectiveness,
d. Vector species yes or no?
e. Reproduction (sexual-arrhenotokous-thelytokous),
f. Plant parts attacked: marketable or non-marketable part,
g. Availability of information on mass rearing,
h. Availability on radiation biology or SIT data.

We took also into account the risk of pests invading new areas and the limitations to the use of the available natural enemies outside of their current range because of regulatory restrictions. Vectors of viruses or pests with a parthenogenetic reproduction were automatically discarded of the list because SIT will amplify the problem in the first case and for the second case SIT will be difficult to implement for species that do not rely on sexual reproduction. We ranked species from 1 to 3 in function of their economic importance based essentially on a, b, c and f criteria (1 = high economic importance; 2 = medium economic importance and 3 = poor economic importance). The final choice of potential candidates has been based on a discussion integrating economic importance and c, g and h criteria.

3 Recommendation on storage pests

The expert group recognized that among the discussed stored product pests the lepidopteran species appear to be suitable candidates for SIT/ inherited sterility. These species are generally easy to mass produce; in fact some are already mass produced as hosts and food for biocontrol agents. In addition, for most species information on the radiation biology is already available. Despite these potential opportunities, this technique has not been taken up widely for stored product pests. The expert group consists of experts on plant pests only and considers the stored products out of their expertise. For a critical review of the potential of SIT against stored product pests in confined areas the current expert group advises to consult other experts. These experts may be found from within the IOBC working group: integrated protection of stored products (https://www.iobc-wprs.org/expert_groups/11_wg_stored_products.html). First questions these experts should consider is: why the potential for SIT/ inherited sterility has not been taken up.

4 Recommendation on apicultural pests

The expert group identified a single species that might be of interest for SIT in apiculture. This species being the small hive beetle *Aethina tumida*. Radiation biology for this species is known from Downey et al 2015 and Schaefer et al 2010. However, the expert group does not consider apiculture as part of their expertise. For a critical review of the potential of SIT against this species the expert group advises to consult experts on apiculture, preferably from an area where this species is present, such as North America (http://www.uoguelph.ca/canpolin/_About/a_research.html for potential contacts).

5 Recommendation on livestock pests

The expert group has considered several species of pest to livestock in confined areas as stables and barns. Although livestock is not within the expertise of the expert group, no potential candidates for

SIT could be identified. All the species that were discussed are either vectors of diseases or are a nuisance. Therefore the release of large numbers of individuals, although sterilized, is considered undesirable.

6 Identified plant pests with SIT potential in confined cropping systems

Through the procedure described above, the expert group identified three groups of pests that show potential for SIT integration.

6.1 Drosophila suzukii

Drosophila suzukii (Diptera: Drosophilidae) is an exotic pest of stone fruits and berries that has recently invaded Europe (Italy, France, Belgium, Austria,…), North America (United states and Canada) and south America (Brazil). This species has now a worldwide distribution (Cini et al. 2012; Asplen et al. 2015). This pest attacks a wide range of soft fruits with preference for blueberry, strawberry and raspberry (Bellamy et al.2013), crops that can be grown in confined cropped systems. The female flies lay eggs under the skin of maturing fruits and the developing larvae feed on the fruit tissues, thereby provoking the fruit to collapse.

This pest is of economic importance because when left uncontrolled the flies can cause complete loss of the harvests. Currently the control relies mostly on the application of chemical insecticides that need to be applied a few days before the fruits are harvested and may cause a threat for the health of human consumers. In addition specific cultural practices such as mass trapping, netting and strict hygiene are being used. Research on natural enemies (predators and parasitoids) is ongoing, but no biological control solutions are readily available (Cuthbertson et al. 2014; Asplen et al. 2015; Renkema et al. 2015; Stacconi et al. 2015).

Radiation biology experiments are ongoing on *D. suzukii* in collaboration with FAO/IAEA, and several universities and research institutes. Artificial rearing diets for laboratory rearing are available in literature (Chabert et al. 2013) and at least two laboratories are conducting research on mass rearing under the Suzukill project that is a multidisciplinary and international research project funded by both the French ANR and the Austrian FWF (https://suzukill.univ-rennes1.fr/).. In addition, the IAEA has had recurrent requests from member countries about developing SIT for *D. suzukii*. The experts group has some reservations about the feasibility of SIT for this pest considering the high fecundity of this pest and the recurrent immigration of flies into the crops that, often, are not completely confined. Therefore, we recommend the involvement of an expert on the modelling of the population dynamics.

6.2 Spodoptera *and* Helicoverpa *group*

The expert group considered the *Spodoptera exigua*, *S. frugiperda* and *Helicoverpa armigera* species together as they share a similar biology. All three species are known as pests of both outdoor and important greenhouse crops such as tomato, peppers and eggplant. Biocontrol of these species relies on egg-parasitoids such as *Trichogramma* sp. or *Telenomus* sp. that are often insufficiently effective because of the short timespan to parasitize the eggs (Jarjees & Merritt, 2004). Also, the commercially available *Bacillus thuringiensis* strains appear to be insufficiently effective (Moar et al 1995; Polanczyk et al 2000; Omoto et al 2015).

For each of these species, SIT for area wide pest management has been developed in the past (Debolt & Wright, 1976; Ocampo, 2001; Carpenter et al., 1983; Carpenter et al., 1985; Carpenter et al., 1986; Carpenter et al., 1992; Hamm & Carpenter 1997; Pransopon et al 2000). However, these were never operational. The reasons why are not clear to the group and need to be looked into. The group does feel there are opportunities for SIT against these pests in confined area's that should be investigated.

Because of the past work on SIT, data on the rearing of these species and the radiation biology is available (Snow et al 1970; Snow et al 1972; Carpenter et al., 1997; Ramos Ocampo & Leon 2002; Merkx-Jacques & Bede 2005; Abbasi et al 2007). This would allow the research to quickly focus on demonstrating efficiency in the confined cropping systems. As the SIT for Lepidoptera usually relies on F1 sterility, a certain degree of damage needs to be tolerated. For fruit crops this tolerance is expected as the caterpillars primarily feed on the leaves, not on the fruits. On the other hand, the F1 sterility will result in increased numbers of sterile eggs in the crop. These eggs will improve the efficiency of egg parasitoids if these were to be combined with the SIT. If crop damage cannot be tolerated, full sterility (95-99%) rather than F_1 sterility can be used, but this reduces the efficiency of the control as high doses are required to reach full sterility.

Because of the similarities in the biology of these three species, a CRP that coordinates the research and allows for exchange of the results is expected to lead to strong synergisms.

6.3 Tuta *and* Neoleucinodes *group*

Tuta absoluta (tomato leaf miner) and *Neoleucinodes elegantalis* (eggplant stem borer or tomato borer) are two emerging pests of Solanaceous crops of South-American origin (EPPO, 2005). *Tuta absoluta* has currently spread eastward into Europe as far as India and northward up to Mexico (Desneux et al. 2010). Following its introduction into Europe, North Africa and the Middle East, *T. absoluta* has already caused extensive economic damage (Tropea Garzia et al. 2012). The impact of the pest includes severe yield loss reaching 100%, increasing tomato prices, bans on the trade of tomato including seedlings, an increase in synthetic insecticide applications, disruption of integrated management programmes of other tomato pests, and an increase in the cost of crop protection. Considering its high biotic potential, its ability to adapt to various climatic conditions and the speed with which it has colonized Europe and North Africa, the potential invasion of African and especially Asian tomato crops by *T. absoluta* will probably impact heavily on the livelihood of local tomato growers and tomato agribusinesses in these regions. *Tuta absoluta* in Europe is currently sufficiently controlled by the predatory mirid bugs *Nesidiocorus tenuis* and *Macrolophus pygmeus* (Molla et al. 2009; Urbaneja et al. 2009). However, these invertebrate biocontrol agents, native to Europe, will not be an option for control when the pest reaches N. America or Asia, which is outside of the natural enemies' native ranges. Control of the pest in South America is currently based largely on chemical control. Therefore, development of a SIT for *Tuta absoluta* could provide a sustainable alternative. Radiation biology data for *T. absoluta* suggest doses of 200–250 Gy could be used to induce inherited sterility in *T. absoluta* males (Cagnotti et al. 2012).

Neoleucinodes elegantalis (tomato borer or eggplant stem borer) is a major pest of tomatoes and other Solanaceous fruit crops (e.g. *Solanum melongena* and *Capsicum* sp.) which occurs in South and Central America (Diaz Montilla et al. 2013). *Neoleucinodes elegantalis* is absent from other regions, but is considered a threat due to the importance of tomato and other Solanaceous fruit crops in many other regions. It has been intercepted several times by the Netherlands (1 interception in 2009 and 3 in 2012) during import inspections of eggplant from Suriname and control of passenger baggage at Schiphol airport. Consequently, it has been added to the EPPO Alert List.

The objective of developing a SIT program for *T. absoluta* and *N. elegantalis* would be twofold; firstly providing a more sustainable control method for currently invaded areas where biocontrol is not yet developed and secondly providing an eradication method for these Solanaceous pests ready to use immediately a new area is invaded.

7 Irradiation

Application of SIT requires an irradiation system. Currently, the available irradiators of a suitable size for research, development and small scale production include both gamma and X irradiators.

Gamma irradiators have the advantage of reliability as the source, whilst constantly decaying, is always present and there is little to go wrong with the simple operating mechanism. Their disadvantages include the stringent regulatory, safety and security requirements for large radioactive sources, the potential risks associated with radiation and the need for periodic replenishment of the source. They can provide high dose rates (up to 200 $Gy.min^{-1}$) but small self-shielded machines can only provide good dose uniformity to small volumes (typically little more than one litre per load). Small research irradiators are cheaper than equivalent X ray systems but the price rises quickly for larger processing volumes.

In contrast, X irradiators can be switched off, making transport easy, the regulatory burden much lighter, the risk associated with the radiation is much lower and there is no source to replenish. But these systems are much more complex requiring sophisticated maintenance and reliable power supply. X irradiators provide lower dose rates than gamma irradiators, typically around 10 $Gy.min^{-1}$ but to a larger volume per load (up to 18 litres) with good dose uniformity. Suitable X irradiators for SIT are still relatively new and so far have not yet shown themselves sufficiently reliable to be adopted in operational programmes. Improved quality control and reliability, rapid service response and availability of spare parts will be critical to the future success of these systems. X irradiators are generally rather more expensive than simple gamma irradiators, but could become more competitive if any unit established a market position. The absence of any radioactive material makes these systems more acceptable to the public.

The limited number of small, self-shielded irradiation units currently available and the cost of new units pose a risk to the development and small scale application of nuclear techniques in this field. For larger scale production irradiation services can be purchased from commercial irradiator operators, but the minimum practical dose from a multipurpose irradiator, the longer exposure times and poor control of dose and dose uniformity make this less satisfactory for SIT.

8 Conclusions and Recommendations

After literature review, knowledge exchange and extensive discussions, the expert group has produced a list of key pests that could be good candidates for SIT in confined cropping systems. Also, the group recommends contacting experts on storage pests and beehive pests to have a better idea of the SIT potential for these groups. The expert group recommends having a co-ordinated research project (CRP) and drafted a proposal for the three groups of pests identified: *Drosophila suzukii*, *Spodoptera*/*Helicoverpa* and *Tuta/Neoleucinodes*. In view of the focus on greenhouse pests the proposed title is “Integration of the SIT with Biocontrol for Greenhouse Insect Pest Management“.

9 References

ABBASI, B.H., K. AHMED, F. KHALIQUE, N. AYUB, H.J. Liu, S.A. RAZA KAZMI and M.N. AFTAB (2007). Rearing the cotton bollworm, *Helicoverpa armigera*, on a tapioca-based artificial diet. Journal of Insect Science 7:35.

ASPLEN, M.K., G. ANFORA, A. BIONDI, D.S. CHOI, D. CHU, K.M. DAANE, P. GIBERT, A.P. GUTIERREZ, K.A. HOELMER and W.D. HUTCHISON (2015). Invasion biology of spotted wing Drosophila (*Drosophila suzukii*): a global perspective and future priorities. Journal of Pest Science 88(3):469-94.

BELLAMY, D.E., M.S. SISTERSON and S.S. WALSE (2013). Quantifying host potentials: indexing postharvest fresh fruits for spotted wing drosophila, *Drosophila suzukii*. PLoS One 8(4):e61227.

BLACKMER, J.L., A.E. EIRAS and C.L. DE SOUZA (2001). Oviposition preference of *Neoleucinodes elegantalis* (Guenée) (Lepidoptera: Crambidae) and rates of parasitism by *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae) on *Lycopersicon esculentum* in São José de Ubá, RJ, Brazil. Neotropical Entomology 30(1):89-95.

CAGNOTTI, C.L., M.M. VISCARRET, M.B. RIQUELME, E.N. BOTTO, L.Z. CARABAJAL, D.F. SEGURA and S.N. LÓPEZ (2012). Effects of X-rays on *Tuta absoluta* for use in inherited sterility programmes. Journal of Pest Science 85(4):413-21.

CARPENTER, J.E. and B.R. WISEMAN (1992). *Spodoptera frugiperda* (Lepidoptera: Noctuidae) development and damage potential as affected by inherited sterility and host plant resistance. Environmental Entomology 21:57-60.

CARPENTER, J.E., HIDRAYANI, N. NELLY and B.G. MULLINIX (1997). Effect of substerilizing doses of radiation on sperm precedence in fall armyworm (Lepidoptera: Noctuidae). Journal of Economic Entomology 90(2):444-8.

CARPENTER, J.E., J.R. YOUNG and A.N. SPARKS (1985). Fall armyworm (Lepidoptera: Noctuidae): field survival of F_1 larvae from partially sterile parents. Florida Entomologist 68(2):290-6.

CARPENTER, J.E., J.R. YOUNG and A.N. SPARKS (1986). Fall armyworm (Lepidoptera: Noctuidae): comparison of inherited deleterious effects in progeny from irradiated males and females. Journal of Economic Entomology 79(1):46-9.

CARPENTER, J.E., J.R. YOUNG, E.F. KNIPLING and A.N. SPARKS (1983). Fall armyworm (Lepidoptera: Noctuidae): inheritance of gamma-induced deleterious effects and potential for pest control. Journal of Economic Entomology 76(2):378-82.

CINI, A., C. IORIATTI and G. ANFORA (2012). A review of the invasion of *Drosophila suzukii* in Europe and a draft research agenda for integrated pest management. Bulletin of Insectology 65(1):149-60.

DEBOLT, J.W. and F.K. WRIGHT (1976). Beet armyworm: inherited sterility produced by irradiation of pupae or adults. Journal of Economic Entomology 69(3):336-8.

DESNEUX, N., E. WAJNBERG, G. BURGIO, S. ARPAIA, K. WYCKHUYS, C. NARVÁEZ-VASQUEZ CA, J. GONZÁLEZ-CABRERA, D. CATALÁN-RUESCAS, E. TABONE, J. FRANDON,J.C. PIZZOL, C. PONCET and A. URBANEJA. 2010. Biological invasion of European tomato crops by Tuta absoluta: ecology, geographic expansion and prospects for biological control. Journal of Pest Science 83, 197–215.

DIAZ MONTILLA, A.E., M.A. SOLIS and T. KONDO. 2013. The fruit borer, Neoleucinodes elegantalis (Guenée) (Lepidoptera: Crambidae), an insect pest of neotropical Solanaceous fruits, In J Peña (Ed.), Potential Invasive Pests of Agricultural Crops, CABI, London.

DOS SANTOS, K.B., MENEGUIM, A.M., DOS SANTOS, R.B., DOS SANTOS, W.J., BOAS, G.V., DUMAS, V., MARTINS, E., PRAÇA, L.B., QUEIROZ, P., BERRY,C. and R. MONNERAT. 2009. Selection and characterization of the *Bacillus thuringiensis* strains toxic to *Spodoptera eridania* (Cramer), *Spodoptera cosmioides* (Walker) and *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae). Biological Control 50(2): 157–163.

DOWNEY, D., S. CHUN and P. FOLLETT (2015). Radiobiology of small hive beetle (Coleoptera: Nitidulidae) and prospects for management using sterile insect releases. Journal of Economic Entomology 108(3):868-72.

EIRAS, A.E. and J.L. BLACKMER (2003). Eclosion time and larval behavior of the tomato fruit borer, *Neoleucinodes elegantalis* (Guenée) (Lepidoptera: Crambidae). Scientia Agricola 60(1):195-7.

EPPO. 2005. Data sheets on quarantine pests: Tuta absoluta. Bulletin OEPP/EPPO Bulletin 35, 434–435.

HAMM, J.J. and J.E. CARPENTER (1997). Compatibility of nuclear polyhedrosis viruses and inherited sterility for control of corn earworm and fall armyworm (Lepidoptera: Noctuidae). Journal of Entomological Science 32:148-53.

JARJEES, E.A. and D.J. MERRITT (2004). The effect of parasitization by *Trichogramma australicum* on *Helicoverpa armigera* host eggs and embryos. Journal of Invertebrate Pathology 2004, 85(1):1-8.

KASPI, R. and M. PARRELLA (2006). Improving the biological control of leafminers (Diptera: Agromyzidae) using the sterile insect technique. Journal of Economic Entomology 99(4):1168-75.

MAKEE, H. and G. SAOUR. 2003. Noninherited sterility in irradiated *Phthorimaea operculella* females. Journal of Applied Entomology 127(9-10): 489–493

MERKX-JACQUES, M. and J.C. Bede (2005). Influence of diet on the larval beet armyworm, *Spodoptera exigua*, glucose oxidase activity. Journal of Insect Science 5: 48.

MOAR, W.J., M. PUSZTAI-CAREY, H. VAN FAASSEN, D. BOSCH, R. FRUTOS, C. RANG, K. LUO and M.J. ADANG (1995). Development of *Bacillus thuringiensis* CryIC Resistance by *Spodoptera exigua* (Hubner) (Lepidoptera: Noctuidae). Appl Environ Microbiol. 61(6): 2086-92.

MOLLÁ, Ó., H. MONTÓN, P. VANACLOCHA, F. BEITIA and A. URBANEJA. 2009. Predation by the mirids Nesidiocoris tenuis and Macrolophus pygmaeus on the tomato borer Tuta absoluta. Proceedings of the IOBC/WPRS Working Group "Integrated Control in Protected Crops", Crete, Greece, 6-11 September 2009. IOBC/WPRS Bulletin 2009 Vol. 49 pp. 209-214

OCAMPO, V.R. (2001). Effect of a substerilizing dose of radiation on the mating competitiveness of male and on the mating propensity of female *Helicoverpa armigera* (Lepidoptera: Noctuidae). Florida Entomologist 84(2):194-8.

OMOTO, C., O. BERNARDI, E. SALMERON, R.J. SORGATTO, P.M. DOURADO, A. CRIVELLARI, R.A. CARVALHO, A. WILLSE, S. MARTINELLI, and G. P. HEAD (2015). Field-evolved resistance to Cry1Ab maize by *Spodoptera frugiperda* in Brazil. Pest Management Science doi: 10.1002/ps.4201.

POLANCZYK, R.A., R.R.F.P.D. SILVA and L.M. FIUZA (2000). Effectiveness of Bacillus thuringiensis strains against *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Brazilian Journal of Microbiology 31(3):164-6.

PRANSOPON, P., M. SUTANTAWONG, P. HORMCHAN and A. WONGPIYASATID (2000). Effects of gamma radiation on mature pupae of the cotton bollworm, *Helicoverpa armigera* (Hübner) and their F1 progeny. Kasetsart Journal, Natural Sciences 34(3):401-7.

RAMOS OCAMPO, V., J.B.D. LEON (2002). *The effects of radiation on the biology and reproduction of Helicoverpa armigera (Lepidoptera: Noctuidae)*, Evaluation of Lepidoptera Population Suppression by Radiation Induced Sterility. IAEA, pp. 29-36.

SAOUR, G. and H. MAKEE (1997). Radiation induced sterility in male potato tuber moth *Phthorimaea operculella* Zeller (Lep., Gelechiidae). Journal of Applied Entomology 121(7):411-5.

SAOUR, G. and H. MAKEE (1999). Effect of gamma irradiation on sperm utilization in twice-mated female *Phthorimaea opercullella* Zeller (Lep., Gelechiidae). Journal of Applied Entomology 123(9):513-7.

SCHÄFER, M.O., RITTER, W., PETTIS, J. and P. NEUMANN. 2010. Small hive beetles, *Aethina tumida*, are vectors of *Paenibacillus larva*. Apidologie 41(1): 14–20.

SNOW, J.W., J.R. YOUNG and R.L. JONES (1970). Competitiveness of sperm in female fall armyworms mating with normal and chemosterilized males. Journal of Economic Entomology 63(6):1799-802.

SNOW, J.W., J.R. YOUNG, W.J. LEWIS and R.L. JONES (1972). Sterilization of adult fall armyworms by gamma irradiation and its effect on competitiveness. Journal of Economic Entomology 65(5):1431-3.

TALEKAR, N.S. (2002). Controlling Eggplant Fruit and Shoot Borer. AVRDC, 02-534. Asian Vegetable Research and Development Center.

TROPEA GARZIA, G., A. SISCARO, L. BIONDI and L. ZAPPALA. 2012. Tuta absoluta, a South American pest of tomato now in the EPPO region: biology, distribution and damage. Bulletin OEPP/EPPO Bulletin 42 (2): 205–210.

URBANEJA, A., H. MONTÓN and O. MOLLÁ. 2009. Suitability of the tomato borer Tuta absoluta as prey for *Macrolophus pygmaeus* and *Nesidiocoris tenuis*. Journal of Applied Entomology 133, 292–296

VAN LENTEREN, J.C. and V.H. BUENO (2003). Augmentative biological control of arthropods in Latin America. BioControl 48(2):123-39.

WALKER, C.S. (2012). The application of sterile insect technique against the tomato leafminer *Liriomyza bryoniae*. Imperial College London.

10 Annexes

Annex 1: List of participants

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Annex 2: Agenda

Monday 14 March [M0E58]

08:00 – 09:00		Registration (Bring passport / ID papers and collect security pass from Gate 1 on arrival)
09:00 – 09:30	Andrew Parker	Welcome Introduction of the participants Selection of meeting chairman and rapporteur Background and objectives of the consultants group meeting
09:30 – 10:00	Bashur Bashur	*The IAEA Programme of Coordinated Research Activities*
10:00 – 10:30		**Coffee break**
10:30 – 11:15	Annabelle Firlej	*Title to be announced*
11:15 – 12:00	Tom Groot	*On augmentative biocontrol and SIT*
12:00 – 13:30		**Lunch**
13:30 – 14:15	Lieselot van der Veken	*Options from biological control for pest control; experiences, prospects and regulatory framework*
14:15 – 15:00	Wang Shaoli	*Occurrence and Control of Insect Pests on greenhouse vegetables in China*
15:00 – 15:30		**Coffee break**
15:30 16:15	David Opatowski	*Feasibility study for the implementation of leafminer (*Liriomyza *spp.) SIT combined with biological control under greenhouse conditions in Israel*
16:15 – 17:00	Discussion of presentations	

Tuesday 15 March [A2172]

08:30 – 10:30 Group discussions.

Suggested topics:

- Discussion of presentations
- Constraints to biocontrol in greenhouses and confined areas
- Poorly controlled pests
- New and invasive pests
- Opportunities for integration of SIT

10:30 – 11:00 **Coffee break**

11:00 – 12:30 Group discussions continued

12:30 – 13:45 **Lunch**

13:45 – 15:15 Group discussions continued

15:15	–	15:45	**Coffee break**
15:45	–	17:00	CRP proposal design

Wednesday 16 March [A2172]

08:30	–	10:30	Identification of areas of research
10:30	–	11:00	**Coffee break**
11:00	–	12:30	Identification of areas of research continued
12:30	–	13:45	**Lunch**
13:45	–	15:15	Group discussions
15:15	–	15:45	**Coffee break**
13:45	–	17:15	Decision on meeting recommendations regarding requirements, scope and objectives for a CRP.
19:30	–		**DINNER**

Thursday 17 March [A2172]

09:00	–	10:30	Drafting of CRP proposal
10:30	–	11:00	**Coffee break**
11:00	–	12:30	Drafting of CRP proposal
12:30	–	13:45	**Lunch**
13:45	–	15:15	Drafting of CRP proposal
15:15	–	15:45	**Coffee break**
15:45	–	17:00	Preparation of logical framework

Friday 18 March [M0E59]

09:00	–	10:30	Identification of potential contract and agreement holders
10:30	–	11:00	**Coffee break**
11:00	–	12:30	Drafting of meeting report
12:30	–	13:45	**Lunch**
13:45	–	15:15	Drafting of meeting report

15:15 – 15:45	**Coffee break**
15:45 – 17:00	Presentation of Meeting Conclusions and Outcome
17:00	End of the meeting

Annex 3: Proposal for a Coordinated Research Project

Title of CRP

Integration of the SIT with Biocontrol for Greenhouse Insect Pest Management

Brief Summary

This CRP will develop and evaluate SIT for insect pests in greenhouses. The CRP will focus on three groups of species that are disruptive to current biocontrol practices, or are expected to become serious pest when invading new areas. The three groups are *Drosophila suzukii*, *Helicoverpa*/ *Spodoptera* spp. and *Tuta absoluta*/*Neoleucinodes elegantalis*. The background information required for SIT, such as mass rearing and radiation biology, has been developed for these greenhouse pests to a variable extent. However, for all of these groups the application in confined areas still needs to be refined and evaluated.

1. Background Situation Analysis (Rationale/Problem)

a. Current situation

Greenhouses and other confined locations provide ideal conditions for the rapid build-up of pest populations as they are largely protected from predators and parasitoids. Many of these pests have been exposed to high insecticide pressure over many generations and resistance has developed in many of them. Biocontrol agents are widely used to combat these pests, but not all are well controlled with biocontrol agents and when a pest gets out of control it has to be controlled with pesticides, which then disrupts other biocontrol and pollination.

The SIT is compatible with biological control and can complement biocontrol for those pests that are otherwise difficult to control, reducing crop losses, pesticide residues in food and risk to workers.

Augmentative biological control has historically focused mainly on crops grown in confined areas. Recently there is more attention for crops grown outside. For SIT the opposite direction can be observed: historically SIT has focused on area wide pest management, but with this CRP SIT will now enter confined areas such as greenhouses.

b. *Drosophila suzukii*:

Drosophila suzukii (Diptera: Drosophilidae) is an exotic pest of stone fruits and berries that has recently invaded Europe (Italy, France, Belgium, Austria,…), North America (United States and Canada) and South America (Brazil). This species now has a worldwide distribution (Cini et al. 2012; Asplen et al. 2015). This pest attacks a wide range of soft fruits with preference for blueberry, strawberry and raspberry (Bellamy et al. 2013), crops that can be grown in confined cropped systems. The female flies lay eggs under the skin of maturing fruits and the developing larvae feed on the fruit tissues thereby causing the fruit to collapse.

This pest is of economic importance because when left uncontrolled the flies can cause complete loss of the harvests. Currently the control relies mostly on the application of chemical insecticides that need to be applied a few days before the fruits are harvested and may cause a threat for the health of human consumers. In addition specific cultural practices such as mass trapping, netting and strict hygiene are being used. Research on natural enemies (predators and parasitoids) is ongoing, but no biological control solutions are readily available (Cuthbertson et al. 2014; Asplen et al. 2015; Renkema et al. 2015; Stacconi et al. 2015).

Radiation biology experiments are ongoing on *D. suzukii* in collaboration with FAO/IAEA, and several universities and research institutes. Artificial rearing diets for laboratory rearing are available in the literature (Chabert et al. 2013) and at least two laboratories are conducting research on mass rearing under the Suzukill project that is a multidisciplinary and international research project funded by both the French ANR and the Austrian FWF (https://suzukill.univ-rennes1.fr/). In addition, the FAO/IAEA has had recurrent requests from member countries about developing conventional SIT for *D. suzukii*.

c. *Spodoptera* and *Helicoverpa* group

Spodoptera exigua, *S. frugiperda* and *Helicoverpa armigera* (Lepidoptera: Noctuidae) share a similar biology. All three species are known as pest of both outdoor crops and of important greenhouse crops such as tomato, peppers and eggplant. Biocontrol of these species relying on egg-parasitoids such as *Trichogramma* sp. (Hymenoptera: Trichogrammatidae) or *Telenomus* sp. (Hymenoptera: Scelionidae) are often insufficiently effective because of the short timespan to parasitize the eggs (Jarjees & Merritt, 2004). Also, the commercially available *Bacillus thuringiensis* strains appear to be insufficiently effective (Moar et al 1995; Polanczyk et al 2000; Omoto et al 2015).

For each of these species, SIT for area wide pest management has been developed in the past (Debolt & Wright, 1976; Ocampo, 2001; Carpenter et al., 1983, 1985, 1986, 1992; Hamm & Carpenter 1997; Pransopon et al 2000). However, these were never operationalized.

Because of the past work on SIT, data on the rearing of these species and the radiation biology is available (Snow et al 1970; Snow et al 1972; Carpenter et al., 1997; Ramos Ocampo & Leon 2002; Merkx-Jacques & Bede 2005; Abbasi et al 2007). This will allow the research to quickly focus on demonstrating efficiency in greenhouses. Because the SIT for Lepidoptera normally relies on F_1 sterility, a certain degree of damage needs to be tolerated. For fruit crops this tolerance is expected as the caterpillars primarily feed on the leaves, not on the fruits. On the other hand, the F_1 sterility will result in increased numbers of sterile eggs in the crop. These eggs will improve the efficiency of egg parasitoids if these were to be combined with the SIT. If crop damage is not tolerable, full sterility can be considered but the high doses necessary reduce the efficacy of the control.

Because of the similarities in the biology of these three species, a CRP that coordinates the research and allows for exchange of the results is expected to lead to strong synergisms.

d. *Tuta* and *Neoleucinodes* group

Tuta absoluta (tomato leaf miner) (Lepidoptera: Gelechiidae) and *Neoleucinodes elegantalis* (eggplant stem borer or tomato borer) (Lepidoptera: Crambidae) are two emerging pests of Solanaceous crops of South-American origin (EPPO, 2005). *Tuta absoluta* has currently spread eastward through Europe as far as India and northward up to Mexico (Desneux et al. 2010). Following its introduction into Europe, North Africa and the Middle East, *T. absoluta* has already caused extensive economic damage (Tropea Garzia et al. 2012). The impact of the pest includes severe yield loss reaching 100%, increasing tomato prices, bans on the trade of tomato including seedlings, an increase in synthetic insecticide applications, disruption of integrated management programmes of other tomato pests, and an increase in the cost of crop protection. Considering its high biotic potential, its ability to adapt to various climatic conditions and the speed with which it has colonized Europe and North Africa, the potential invasion of African and especially Asian tomato crops by *T. absoluta* will probably impact heavily on the livelihood of local tomato growers and tomato agribusinesses in these regions (BBC 2016). *Tuta absoluta* in Europe is currently sufficiently controlled by the predatory mirid bugs *Nesidiocorus tenuis* and *Macrolophus pygmeus* (Heteroptera: Miridae) (Molla *et al.* 2009; Urbaneja *et al.* 2009). However, these invertebrate biocontrol agents, native to Europe, will not be a control option when the pest reaches North America or Asia, which are outside of the natural enemies' native ranges. Control of the pest in South America is currently based largely on chemical control. Therefore, development of SIT for *Tuta absoluta* could provide a sustainable alternative. Radiation biology data for *T. absoluta* suggest doses of 200–250 Gy could be used to induce inherited sterility in *T. absoluta* males (Cagnotti *et al*. 2012).

Neoleucinodes elegantalis (tomato borer or eggplant stem borer) is a major pest of tomatoes and other Solanaceous fruit crops (e.g. *Solanum melongena* and *Capsicum sp*.) which occurs in South and Central America (Diaz Montilla *et al.* 2013). *N. elegantalis* is absent from other regions, but is considered a threat due to the importance of tomato and other Solanaceous fruit crops in many other regions. It has been intercepted several times by the Netherlands (1 interception in 2009 and 3 in 2012) during import inspections of eggplant from Suriname and control of passenger baggage at Schiphol airport. Consequently, it has been added to the EPPO Alert List.

The objective of developing a SIT program for *T. absoluta* and *N. elegantalis* is twofold; firstly providing a more sustainable control method for currently invaded areas where biocontrol is not yet developed and secondly provide an eradication method for these Solanaceous pests in the event they invade new areas.

2. Overall Objective

The overall objective is to advance development and implementation of SIT for integration with other biocontrol in greenhouses.

3. Specific Research Objective (Purpose)

- To adapt SIT and inherited sterility for *Spodoptera*/*Helicoverpa* species for confined cropping systems
- To develop SIT for *Drosophila suzukii*
- To develop SIT and inherited sterility for *Tuta absoluta* and *Neoleucinodes elegantalis*

4. Expected Research Outputs

1. Survey on factors inhibiting the adoption of SIT and inherited sterility for *Spodoptera/Helicoverpa* group
2. Feasibility study on SIT and inherited sterility for *Spodoptera/Helicoverpa* group in confined cropping systems
3. Radiation biology for *D. suzukii*
4. Sexing system for *D. suzukii*
5. Mass rearing for *D. suzukii*
6. Feasibility study for *D. suzukii* in confined cropping systems
7. Radiation biology *T. absoluta* and *N. elegantalis*

8. Sexing system for *T. absoluta* and *N. elegantalis*
9. Mass rearing for *T. absoluta* and *N. elegantalis*
10. Feasibility study for *T. absoluta* and *N. elegantalis* in confined cropping systems

5. Expected Research Outcomes

Outcome 1: SIT and inherited sterility techniques for the targeted pest species ready for implementation in confined cropping systems

Outcome 2: SIT and inherited sterility techniques for the targeted pest species adopted in confined cropping systems

6. Relationship to Sub-programme objective and other Agency Programmes and Sub-programmes

- IPCS develops and promotes the use of nuclear techniques for the control of insect pests.

7. Action Plan (Activities)

Activity 1. Submit CRP proposal.

Activity 2. Announce project to MS and amongst established entomologists, biocontrol and pest control specialists and commercial glasshouse growers.

Activity 3. Organize first RCM to plan, coordinate and review research activities

Activity 4. Carry out R&D.

Activity 5. Second RCM to analyse data and draft technical protocols as required

Activity 6. Hold workshop on "Insect mass rearing", in conjunction with second RCM.

Activity 7. Continue R&D.

Activity 8. Review the CRP after its third year.

Activity 9. Convene third RCM to evaluate and standardize protocols.

Activity 10. Hold workshop on "Irradiation and dosimetry", in conjunction with third RCM.

Activity 11. Continue R&D.

Activity 12. Hold final RCM to review data and reach consensus.

Activity 13. Evaluate the CRP and submit evaluation report.

Activity 14. Summarize and publish advances of CRP in a series of joint publications (special issue of a scientific journal).

8. Inputs

1. Duration: 5 years.
2. Number of RCMs: 4.
3. Contracts and agreements:
   Technical contract: 1 (1 year)
   Agreement holders: 9.
   Research contract holders: 9.

4. Workshops:
   Insect mass rearing for pests of confined cropping systems (*D. suzukii*) and irradiation protocols (with 2nd RCM)
   Insect mass rearing for pests of confined cropping systems (Lepidoptera) and irradiation protocols (with 3rd RCM)
5. Publication of results (special journal issue).
6. Staff travel of SS to RCMs

9. Assumptions

- Continued relevance of SIT for *Drosophila suzukii*, *Tuta absoluta, Neoleucinodes elegantalis* and *Spodoptera/Helicoverpa* species.

10. Foreseen Participants

Countries with significant greenhouse industries

Developed countries with capabilities for SIT or greenhouse crop research

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Developing countries with capabilities for SIT or greenhouse crop research

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11. Links to Technical Cooperation Projects

There are no links to current TC projects.

12. Logical Framework

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
Overall Objective: To advance development and implementation of SIT and inherited sterility for integration with other biocontrol for greenhouse and other confined arthropod pests	N/A	N/A	Non-SIT biocontrol is not sufficiently controlling the targeted pests in confined cropping systems
Specific Objective: 1. To adapt inherited sterility or SIT for *Spodoptera*/*Helicoverpa* species for confined cropping systems 2. To develop SIT for *Drosophila suzukii* 3. To develop inherited sterility or SIT for *Tuta absoluta* and *Neoleucinodes elegantalis*	Techniques advanced Network established	Reports and publications of techniques Number, expertise and geographic distribution of applicants	Regulatory requirements permit the use of inherited sterility Suitable participants apply to join the CRP with a broad range of expertise User community is engaged Radiation services and insects colonies are available
Outcomes: 1. SIT and inherited sterility techniques for the targeted pest species ready for implementation in confined cropping systems			R&D has resulted in a functional SIT package for some of the targeted species

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
2. SIT and inherited sterility techniques for the targeted pest species adopted in confined cropping systems	Crop losses	National statistics	Growers are willing to adopt the developed technology Growers acceptance of limited crop damage from F_1 sterility No other sustainable control method will become available
Outputs:			
1. Survey on factors inhibiting the adoption of inherited sterility for *Spodoptera/Helicoverpa* group	Survey conducted	RCM report	Industry engagement
2. Feasibility study on inherited sterility and SIT for *Spodoptera/Helicoverpa* group in confined cropping systems	Research conducted	Research reports	Viable opportunities are identified New techniques are appropriate
3. Radiation biology for *D. suzukii*	Protocols	RCM report	Techniques developed
4. Sexing system for *D. suzukii*	Protocols	RCM report	
5. Mass rearing for *D. suzukii*	Manuscripts drafted	Manuscripts submitted	Manuscripts accepted
6. Feasibility study for *D. suzukii* in confined cropping systems	New facts and refined understanding	Papers published, contract reports, CRP review	End users engaged
7. Radiation biology *T. absoluta* and *N. elegantalis*	Protocols	RCM report	Techniques developed
8. Sexing system for *T. absoluta* and *N. elegantalis*	Test conducted	Test reports	End users engaged
9. Mass rearing for *T. absoluta* and *N. elegantalis*	Manuscripts drafted	Manuscripts submitted	Manuscripts accepted
10. Feasibility study for *T. absoluta* and *N. elegantalis* in confined cropping systems	New facts and refined understanding	Papers published, contract reports, CRP review	End users engaged

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
	Recommendations for future work	RCM report	Validation will not be completed within the CRP period New opportunities identified as a result of the CRP Project is still relevant at the end of the CRP
Activities: 1. Submit CRP proposal. 2. Announce project to MS and amongst established entomologists, biocontrol and pest control specialists and commercial glasshouse growers 3. Organize first RCM to plan, coordinate and review research activities 4. Carry out R&D. 5. Second RCM to analyse data and draft technical protocols as required 6. Hold workshop on "*Insect mass rearing for pests of confined cropping systems* (D. suzukii) *and irradiation protocols*", in conjunction with second RCM. 7. Continue R&D. 8. Review the CRP after its third year.			Project is approved

Project Design Elements	Verifiable Indicators	Means of Verification	Important Assumptions
9. Convene third RCM to evaluate and standardize protocols. 10. Hold workshop on *"Insect mass rearing for pests of confined cropping systems (Lepidoptera) and irradiation protocols"*, in conjunction with third RCM. 11. Continue R&D. 12. Hold final RCM to review data and reach consensus. 13. Evaluate the CRP and submit evaluation report. 14. Summarize and publish advances of CRP in a series of joint publications (journal special issue).			

13. References

ABBASI, B.H., K. AHMED, F. KHALIQUE, N. AYUB, H.J. Liu, S.A. RAZA KAZMI and M.N. AFTAB (2007). Rearing the cotton bollworm, *Helicoverpa armigera*, on a tapioca-based artificial diet. Journal of Insect Science 7:35.

ASPLEN, M.K., G. ANFORA, A. BIONDI, D.S. CHOI, D. CHU, K.M. DAANE, P. GIBERT, A.P. GUTIERREZ, K.A. HOELMER and W.D. HUTCHISON (2015). Invasion biology of spotted wing Drosophila (*Drosophila suzukii*): a global perspective and future priorities. Journal of Pest Science 88(3):469-94.

BBC (2016) Nigeria's Kaduna state declares 'tomato emergency'. http://www.bbc.com/news/world-africa-36369015

BELLAMY, D.E., M.S. SISTERSON and S.S. WALSE (2013). Quantifying host potentials: indexing postharvest fresh fruits for spotted wing drosophila, *Drosophila suzukii*. PLoS One 8(4):e61227.

BLACKMER, J.L., A.E. EIRAS and C.L. DE SOUZA (2001). Oviposition preference of *Neoleucinodes elegantalis* (Guenée) (Lepidoptera: Crambidae) and rates of parasitism by *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae) on *Lycopersicon esculentum* in São José de Ubá, RJ, Brazil. Neotropical Entomology 30(1):89-95.

CAGNOTTI, C.L., M.M. VISCARRET, M.B. RIQUELME, E.N. BOTTO, L.Z. CARABAJAL, D.F. SEGURA and S.N. LÓPEZ (2012). Effects of X-rays on *Tuta absoluta* for use in inherited sterility programmes. Journal of Pest Science 85(4):413-21.

CARPENTER, J.E. and B.R. WISEMAN (1992). *Spodoptera frugiperda* (Lepidoptera: Noctuidae) development and damage potential as affected by inherited sterility and host plant resistance. Environmental Entomology 21:57-60.

CARPENTER, J.E., HIDRAYANI, N. NELLY and B.G. MULLINIX (1997). Effect of substerilizing doses of radiation on sperm precedence in fall armyworm (Lepidoptera: Noctuidae). Journal of Economic Entomology 90(2):444-8.

CARPENTER, J.E., J.R. YOUNG and A.N. SPARKS (1985). Fall armyworm (Lepidoptera: Noctuidae): field survival of F_1 larvae from partially sterile parents. Florida Entomologist 68(2):290-6.

CARPENTER, J.E., J.R. YOUNG and A.N. SPARKS (1986). Fall armyworm (Lepidoptera: Noctuidae): comparison of inherited deleterious effects in progeny from irradiated males and females. Journal of Economic Entomology 79(1):46-9.

CARPENTER, J.E., J.R. YOUNG, E.F. KNIPLING and A.N. SPARKS (1983). Fall armyworm (Lepidoptera: Noctuidae): inheritance of gamma-induced deleterious effects and potential for pest control. Journal of Economic Entomology 76(2):378-82.

CINI, A., C. IORIATTI and G. ANFORA (2012). A review of the invasion of *Drosophila suzukii* in Europe and a draft research agenda for integrated pest management. Bulletin of Insectology 65(1):149-60.

DEBOLT, J.W. and F.K. WRIGHT (1976). Beet armyworm: inherited sterility produced by irradiation of pupae or adults. Journal of Economic Entomology 69(3):336-8.

DESNEUX, N., E. WAJNBERG, G. BURGIO, S. ARPAIA, K. WYCKHUYS, C. NARVÁEZ-VASQUEZ CA, J. GONZÁLEZ-CABRERA, D. CATALÁN-RUESCAS, E. TABONE, J. FRANDON,J.C. PIZZOL, C. PONCET and A. URBANEJA. 2010. Biological invasion of European tomato crops by Tuta absoluta: ecology, geographic expansion and prospects for biological control. Journal of Pest Science 83, 197–215.

DIAZ MONTILLA, A.E., M.A. SOLIS and T. KONDO. 2013. The fruit borer, Neoleucinodes elegantalis (Guenée) (Lepidoptera: Crambidae), an insect pest of neotropical Solanaceous fruits, In J Peña (Ed.), Potential Invasive Pests of Agricultural Crops, CABI, London.

DOS SANTOS, K.B., MENEGUIM, A.M., DOS SANTOS, R.B., DOS SANTOS, W.J., BOAS, G.V., DUMAS, V., MARTINS, E., PRAÇA, L.B., QUEIROZ, P., BERRY,C. and R. MONNERAT. 2009. Selection and characterization of the *Bacillus thuringiensis* strains toxic to *Spodoptera eridania* (Cramer), *Spodoptera cosmioides* (Walker) and *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae). Biological Control 50(2): 157–163.

DOWNEY, D., S. CHUN and P. FOLLETT (2015). Radiobiology of small hive beetle (Coleoptera: Nitidulidae) and prospects for management using sterile insect releases. Journal of Economic Entomology 108(3):868-72.

EIRAS, A.E. and J.L. BLACKMER (2003). Eclosion time and larval behavior of the tomato fruit borer, *Neoleucinodes elegantalis* (Guenée) (Lepidoptera: Crambidae). Scientia Agricola 60(1):195-7.

EPPO. 2005. Data sheets on quarantine pests: Tuta absoluta. Bulletin OEPP/EPPO Bulletin 35, 434–435.

HAMM, J.J. and J.E. CARPENTER (1997). Compatibility of nuclear polyhedrosis viruses and inherited sterility for control of corn earworm and fall armyworm (Lepidoptera: Noctuidae). Journal of Entomological Science 32:148-53.

JARJEES, E.A. and D.J. MERRITT (2004). The effect of parasitization by *Trichogramma australicum* on *Helicoverpa armigera* host eggs and embryos. Journal of Invertebrate Pathology 2004, 85(1):1-8.

KASPI, R. and M. PARRELLA (2006). Improving the biological control of leafminers (Diptera: Agromyzidae) using the sterile insect technique. Journal of Economic Entomology 99(4):1168-75.

MAKEE, H. and G. SAOUR. 2003. Noninherited sterility in irradiated *Phthorimaea operculella* females. Journal of Applied Entomology 127(9-10): 489–493

MERKX-JACQUES, M. and J.C. Bede (2005). Influence of diet on the larval beet armyworm, *Spodoptera exigua*, glucose oxidase activity. Journal of Insect Science 5: 48.

MOAR, W.J., M. PUSZTAI-CAREY, H. VAN FAASSEN, D. BOSCH, R. FRUTOS, C. RANG, K. LUO and M.J. ADANG (1995). Development of *Bacillus thuringiensis* CryIC Resistance by

Spodoptera exigua (Hubner) (Lepidoptera: Noctuidae). Appl Environ Microbiol. 61(6): 2086-92.

MOLLÁ, Ó., H. MONTÓN, P. VANACLOCHA, F. BEITIA and A. URBANEJA. 2009. Predation by the mirids Nesidiocoris tenuis and Macrolophus pygmaeus on the tomato borer Tuta absoluta. Proceedings of the IOBC/WPRS Working Group "Integrated Control in Protected Crops", Crete, Greece, 6-11 September 2009. IOBC/WPRS Bulletin 2009 Vol. 49 pp. 209-214

OCAMPO, V.R. (2001). Effect of a substerilizing dose of radiation on the mating competitiveness of male and on the mating propensity of female *Helicoverpa armigera* (Lepidoptera: Noctuidae). Florida Entomologist 84(2):194-8.

OMOTO, C., O. BERNARDI, E. SALMERON, R.J. SORGATTO, P.M. DOURADO, A. CRIVELLARI, R.A. CARVALHO, A. WILLSE, S. MARTINELLI, and G. P. HEAD (2015). Field-evolved resistance to Cry1Ab maize by *Spodoptera frugiperda* in Brazil. Pest Management Science doi: 10.1002/ps.4201.

POLANCZYK, R.A., R.R.F.P.D. SILVA and L.M. FIUZA (2000). Effectiveness of Bacillus thuringiensis strains against *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Brazilian Journal of Microbiology 31(3):164-6.

PRANSOPON, P., M. SUTANTAWONG, P. HORMCHAN and A. WONGPIYASATID (2000). Effects of gamma radiation on mature pupae of the cotton bollworm, *Helicoverpa armigera* (Hübner) and their F1 progeny. Kasetsart Journal, Natural Sciences 34(3):401-7.

RAMOS OCAMPO, V., J.B.D. LEON (2002). *The effects of radiation on the biology and reproduction of Helicoverpa armigera (Lepidoptera: Noctuidae)*, Evaluation of Lepidoptera Population Suppression by Radiation Induced Sterility. IAEA, pp. 29-36.

SAOUR, G. and H. MAKEE (1997). Radiation induced sterility in male potato tuber moth *Phthorimaea operculella* Zeller (Lep., Gelechiidae). Journal of Applied Entomology 121(7):411-5.

SAOUR, G. and H. MAKEE (1999). Effect of gamma irradiation on sperm utilization in twice-mated female *Phthorimaea opercullella* Zeller (Lep., Gelechiidae). Journal of Applied Entomology 123(9):513-7.

SCHÄFER, M.O., RITTER, W., PETTIS, J. and P. NEUMANN. 2010. Small hive beetles, *Aethina tumida*, are vectors of *Paenibacillus larva*. Apidologie 41(1): 14–20.

SNOW, J.W., J.R. YOUNG and R.L. JONES (1970). Competitiveness of sperm in female fall armyworms mating with normal and chemosterilized males. Journal of Economic Entomology 63(6):1799-802.

SNOW, J.W., J.R. YOUNG, W.J. LEWIS and R.L. JONES (1972). Sterilization of adult fall armyworms by gamma irradiation and its effect on competitiveness. Journal of Economic Entomology 65(5):1431-3.

TALEKAR, N.S. (2002). Controlling Eggplant Fruit and Shoot Borer. AVRDC, 02-534. Asian Vegetable Research and Development Center.

TROPEA GARZIA, G., A. SISCARO, L. BIONDI and L. ZAPPALA. 2012. Tuta absoluta, a South American pest of tomato now in the EPPO region: biology, distribution and damage. Bulletin OEPP/EPPO Bulletin 42 (2): 205–210.

URBANEJA, A., H. MONTÓN and O. MOLLÁ. 2009. Suitability of the tomato borer Tuta absoluta as prey for *Macrolophus pygmaeus* and *Nesidiocoris tenuis*. Journal of Applied Entomology 133, 292–296

VAN LENTEREN, J.C. and V.H. BUENO (2003). Augmentative biological control of arthropods in Latin America. BioControl 48(2):123-39.

WALKER, C.S. (2012). The application of sterile insect technique against the tomato leafminer *Liriomyza bryoniae*. Imperial College London.

Annex 4 Presentations

BERRIES PEST MANAGEMENT IN QUEBEC

Annabelle Firlej, Ph.D.
Institut de recherche et de développement en Agro-environnement

PLAN

- Very short review of professional background and of past research
- Review of recent research on *Drosophila suzukii*

EDUCATIONAL BACKGROUND

- Master of Biology (University of Quebec at Montreal)
  - Selection of an artificial diet and artificial egg laying for a Miridae predator of Tetranychus urticae Koch (Firlej et al. 2002)

- Ph.D. of Biology (University of Quebec at Montreal)
  - Interaction between the parasitoid *Dinocampus coccinellae* and *Harmonia axyridis* Pallas and *Coleomegilla maculata* lengi Timberlake (Firlej et al. 2005, 2007, 2010, 2012)

EDUCATIONAL BACKGROUND

- Post-doctoral study (FQRNT funded, University of Montreal)
  - Impact of climate change (CO_2) on interaction between aphids and parasitoids
  - Studying impact of climate change (temperature) on development rate of aphids
  - Development of molecular gut content analysis for studying control of soybean aphid by carabid beetles (Firlej et al. 2012 ; 2013)

IRDA

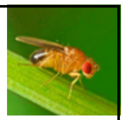
Entomology
Plant pathology
Weed management
Water management
Air Quality
Effluent Management……

- Applied research
- Experimental orchard
- 90ha of organic certified crops
- High tunnel for small fruits
- Grant from Ministry of agriculture with project oriented to specific problematic

PROJECTS

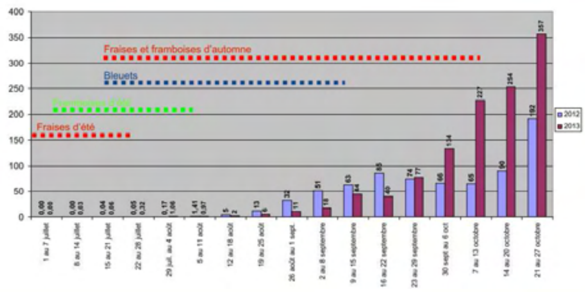
1. Improving pesticide application method for cranberry production (2 years-2014-2015)
2. Selection of low-risk insecticides to control the cranberry weevil in cranberry farm (2 years-2015-2016)
3. Improved molecular identification technique of pests to meet the diagnostic needs of the agricultural sector in the context of climate change (2 years-2016-2018)
4. Creation of integrated fruit production poster for small-fruit (1 year-2016)
5. Adaptation of phytosanitary measures for pests and diseases of fruit crops in regard to climate change impacts (3 years-2016-2019)

SWD IN QUEBEC



- Arrival in 2010: strawberry, raspberry, blueberry…
- Sanitation and short interval between harvest
- Insecticides: max of 10 applications in some crops (Exirel, Success 480 SC, Entrust SC, Delegate WG, Imidan 70WP instapak, Mako, Malathion 85 E)
- Harvest 3 days after insecticide application
  - ➢ Health concern
  - ➢ Damage uncontrolled
  - ➢ Few alternative methods
  - ➢ Growers discouraged
  - ➢ Sector really open to new solution

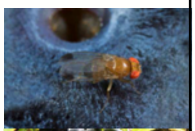
SEASONAL ABUNDANCE OF SWD



(Courtesy of C. Lacroix)

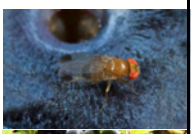
PROJECTS ON *DROSOPHILA SUZUKII*

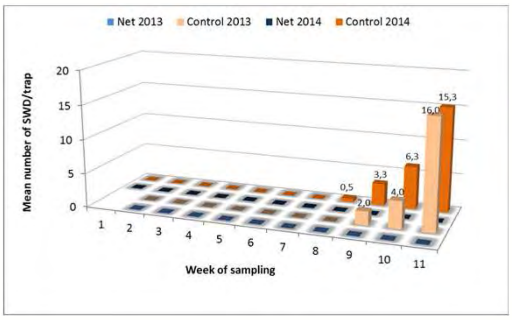
1. Net exclusion to control the SWD (2 years-2013-2014)
2. Baits for SWD mass-trapping (1 year-2014)
3. The sterile insect release as a control method for SWD (3 years-2014-2017, with 1 year extension)
4. Repellents against SWD in raspberry fall (2 years-2016-2017)
5. Study of the link between the populations of spotted wing drosophila, damage and yield losses (2 years-2016-2018)
6. Litterature review on SWD (1 year-2016)



PROJECTS

1. Net exclusion to control the SWD (2 years-2013-2014)





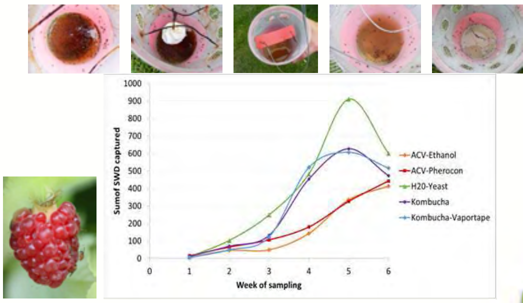
No effect on other pests and diseases
No effect on sugar rate
No effect on yield
But method not yet adopted

(Cormier et al. 2015)

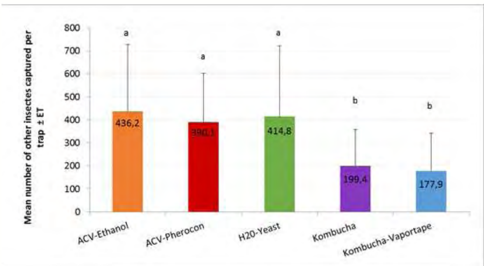
PROJECTS ON *DROSOPHILA SUZUKII*

1. Net exclusion to control the SWD (2 years-2013-2014)
2. Baits for SWD mass-trapping (1 year-2014)

SELECTION OF BAITS FOR SWD MASS TRAPPING



SELECTION OF BAITS FOR SWD MASS TRAPPING



Unfortunately project of mass trapping refused by ministry…

PROJECTS ON *DROSOPHILA SUZUKII*

1. Net exclusion to control the SWD (2 years-2013-2014)
2. Baits for SWD mass-trapping (1 year-2014)
3. The sterile insect release as a control method for SWD (3 years-2014-2017, with 1 year extension)

- Since 2005 project on onion fly SIT in Quebec
- About 30 millions of flies released each year
- Facilities: company Phytodata

SIT APPLIED TO SWD

- Objectives:

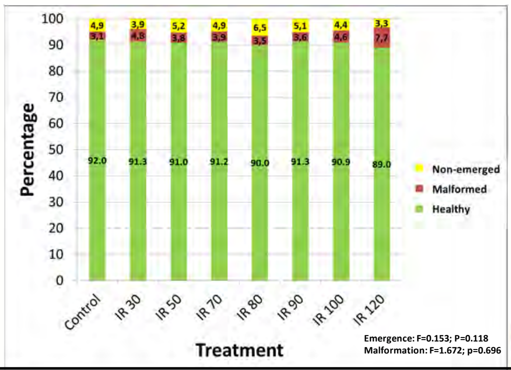
1. Developing dose-response
   - Emergence, malformation
   - Longevity
   - Egg hatching
   - Fertility
2. Competitivity of irradiated male
   - Are-they able to mate the same number of females than wild strain?
   - How much time a female will wait to mate another time after an irradiated male?
   - Which male the female will choose?
   - Field cage experiment

Université de Montréal
Canada
IAEA
COLLÈGE MONTMORENCY

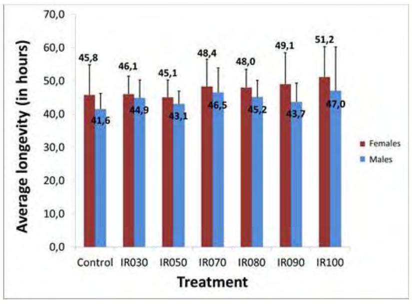
DOSE-RESPONSE

- 0, 30, 50, 70, 80, 90, 100 and 120 Gy
- Five day-old pupae
- >10 000 pupae

EMERGENCE-MALFORMATION

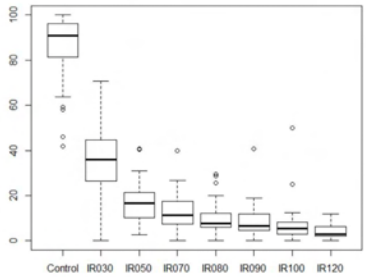


LONGEVITY



Flies fed only with water, statistics to be done…

EGG HATCHING



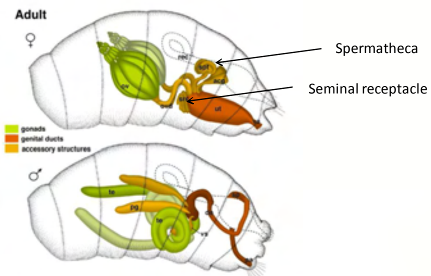
Discussion about testing higher doses

STERILITY

Treatment	Mean number of eggs/day		
Irradiated females + unirradiated males			
0 Gy	39,29	±	32,06
030 Gy	1,72	±	2,01
050 Gy	0,03	±	0,10
070 Gy	0,01	±	0,07
080 Gy	0,72	±	2,63
090 Gy	0,16	±	0,70
100 Gy	0,00	±	0,00
Virgin females	11,26	±	18,91
Irradiated males + unirradiated females			
0 Gy	39,29	±	32,06
050 Gy	35,89	±	31,15
070 Gy	41,27	±	28,40
080 Gy	38,22	±	29,35
090 Gy	42,40	±	32,21

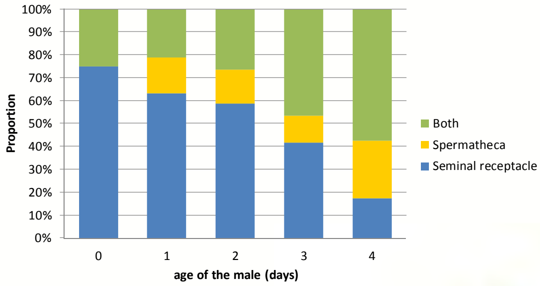
<u>To be done:</u>
1-Developing dose-response
Complete doses
Survival of F1 larvae
2-Evaluation of irradiated male competitivity

PRE-TEST FOR NEXT EXPERIMENTS

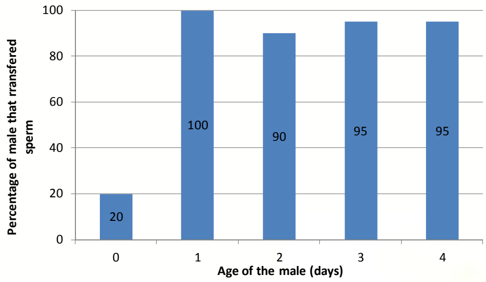


(Drawing: Volker Hartenstein, 1993)

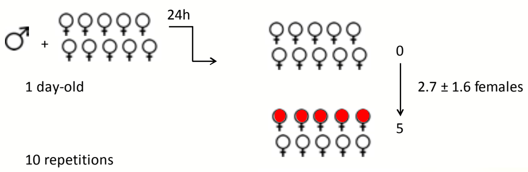
WHERE THE FEMALE STOCK SPERM?

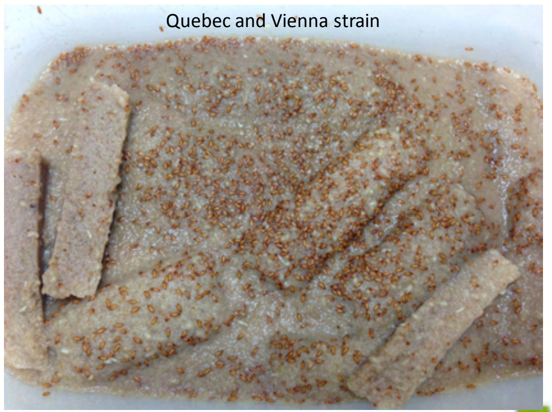


WHEN THE MALE IS ABLE TO MATE?

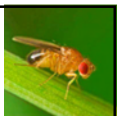


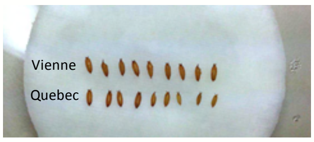
HOW MUCH FEMALES A MALE CAN INSEMINATE?

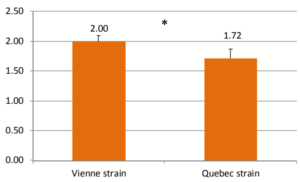




PUPAL WEIGHT







Switch to Quebec strain?

PROJECTS ON *DROSOPHILA SUZUKII*

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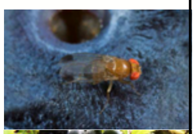
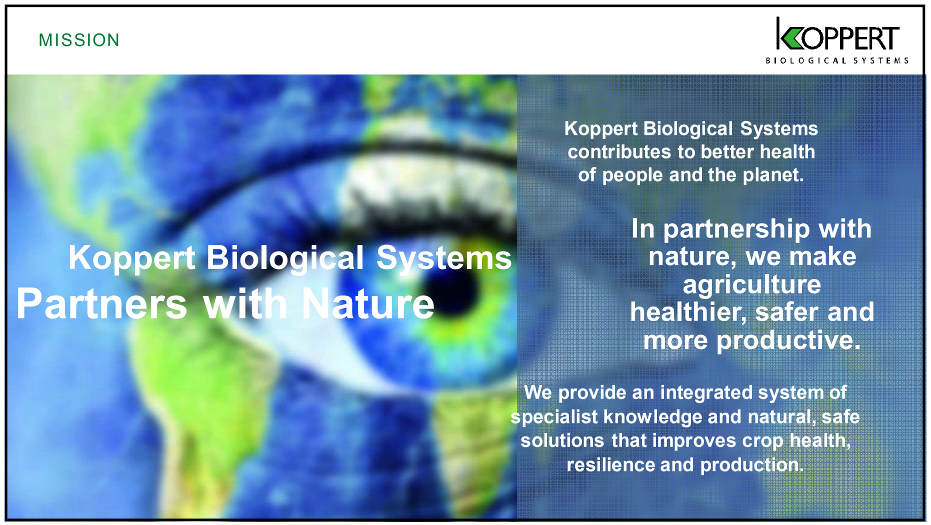


QUESTIONS??


KOPPERT
BIOLOGICAL SYSTEMS
On augmentative biocontrol and SIT
Tom Groot, Manager R&D Entomology


OUTLINE OF MY TALK
KOPPERT
BIOLOGICAL SYSTEMS
• Current position: Koppert
• PhD work: University of Amsterdam
• In between: de Groene Vlieg


ABOUT KOPPERT
KOPPERT
BIOLOGICAL SYSTEMS
• Founded 1967
• Family company
• Head office: Berkel en Rodenrijs
• 250 people in NL, 1100 globally
• Products are sold in >120 countries

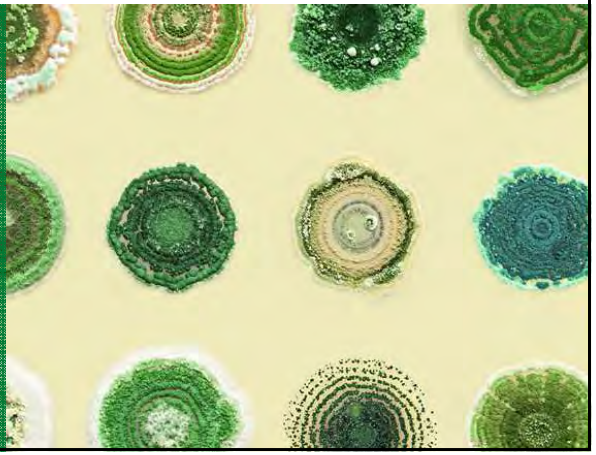

MISSION
KOPPERT
BIOLOGICAL SYSTEMS
Koppert Biological Systems
Partners with Nature
Koppert Biological Systems contributes to better health of people and the planet.
In partnership with nature, we make agriculture healthier, safer and more productive.
We provide an integrated system of specialist knowledge and natural, safe solutions that improves crop health, resilience and production.

3 MAIN AREAS

1: Microbiology

Natugro:

- Beneficial micro-organisms
  - Fungi
  - Bacteria
- Biostimulants
  - Amino, humic & vulvic acids
  - Seaweed extracts
  - Vitamins

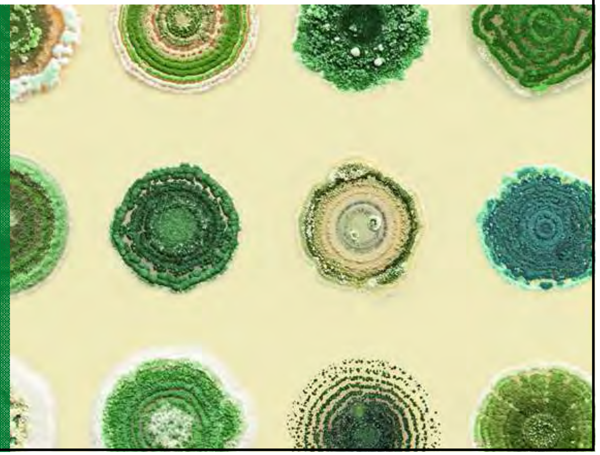


3 MAIN AREAS

1: Microbiology

(micro)biological biocontrol

- Entomopahthogenic nematodes
- Entomopathogenic fungi



3 MAIN AREAS

2: Pollination

- Mostly by bumblebees
- Main production and R&D in Slovakia
- Local production with local species
- Have paved the way for biocontrol

3 MAIN AREAS

3: Macrobials/ Entomology

Production

- Major product group of Koppert
- Production mostly in NL
- Sales worldwide: logistics!
- Wide range of beneficials
  - Predory mites
  - Predatory insects
  - parasitoids
- And their prey/ hosts!

cost efficiency + reliability + quality

3 MAIN AREAS

KOPPERT BIOLOGICAL SYSTEMS

3: Macrobials/ Entomology

R&D Entomology

- In NL 8 researchers and 5 assistants
- (field) research in Spain, France, Brazil, Mexico, VS, …
- 2016: Move to brand new R&D centre

3 MAIN AREAS

KOPPERT BIOLOGICAL SYSTEMS

3: Macrobials/ Entomology

R&D Entomology

- Customer Sales
  - New biocontrol agents
  - New uses of existing BA
  - New application methods
- Customer Production
  - Rearing methods for new species
  - New rearing technologies
  - Including logistics
  - Assist with troubles

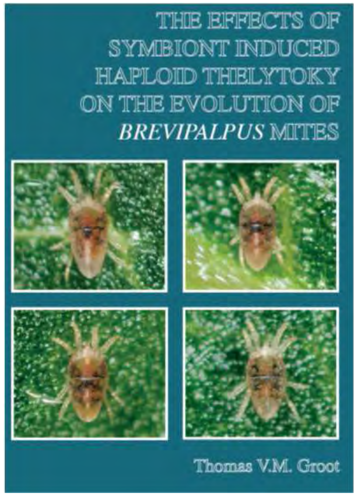
KOPPERT BIOLOGICAL SYSTEMS

PhD work

University of Amsterdam

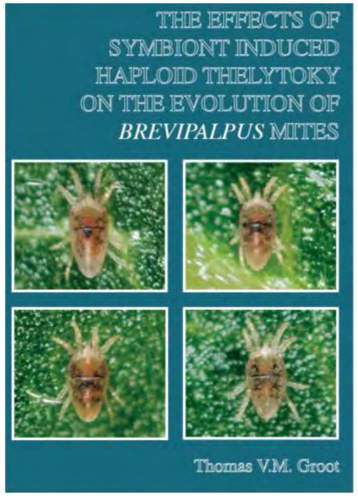
Supervisor:
Hans Breeuwer

Promotores
Steph Menken
Maus Sabelis



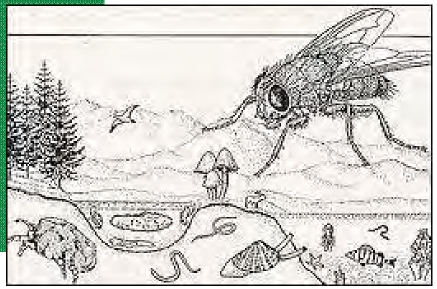
KOPPERT BIOLOGICAL SYSTEMS

THE EFFECTS OF SYMBIONT INDUCED HAPLOID THELYTOKY ON THE EVOLUTION OF BREVIPALPUS MITES



MITES

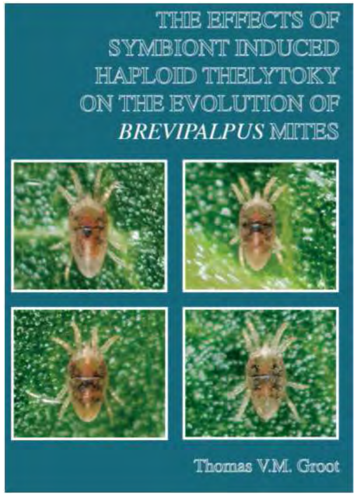
- Related to the spiders
- Small
- Very divers
- Receive not enough attention!



BREVIPALPUS MITES

- False spider mites
- Herbivores, highly polyphagous
- (sub-)tropical
- Small
- Generation 1 month
- Pest: direct and virus vector

THE EFFECTS OF SYMBIONT INDUCED HAPLOID THELYTOKY ON THE EVOLUTION OF BREVIPALPUS MITES

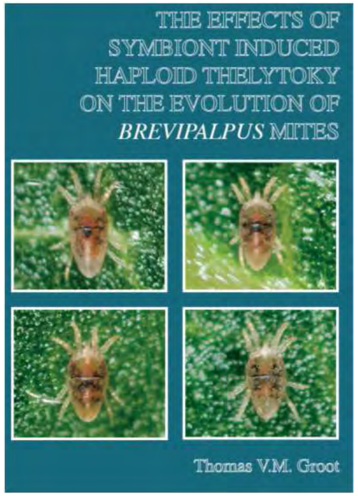


THELYTOKY

Thelytoky = virgin (asexual) reproduction producing females

NO thelytoky: virgin producing a son!

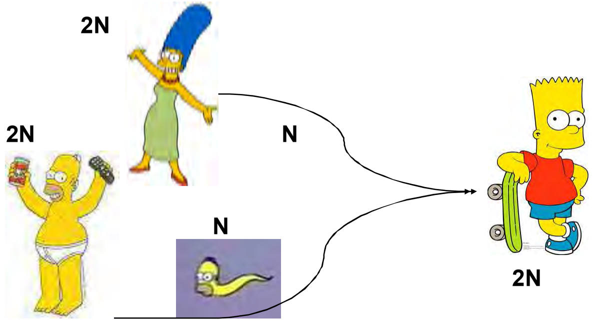
THE EFFECTS OF
SYMBIONT INDUCED
HAPLOID THELYTOKY
ON THE EVOLUTION OF
BREVIPALPUS MITES



KOPPERT BIOLOGICAL SYSTEMS

HAPLOID

Most animal species are diploid; a copy of each gene from each parent.



KOPPERT BIOLOGICAL SYSTEMS

HAPLOÏDE

Diploïd: 2N

Polyploïd: >2N

Haploïd: N

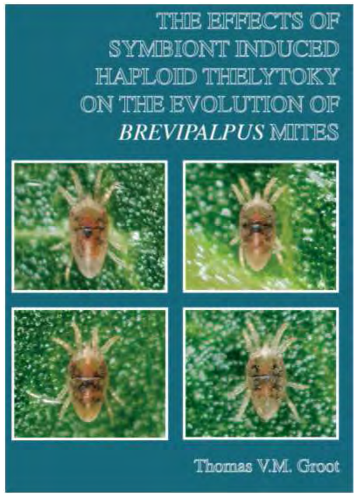
Males of some insect and mite species are haploid

Females are always diploid or poly-ploid

Except for Brevipalpus!!!

KOPPERT BIOLOGICAL SYSTEMS

THE EFFECTS OF
SYMBIONT INDUCED
HAPLOID THELYTOKY
ON THE EVOLUTION OF
BREVIPALPUS MITES

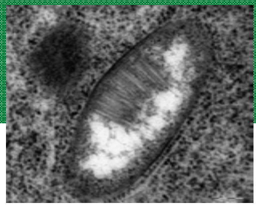


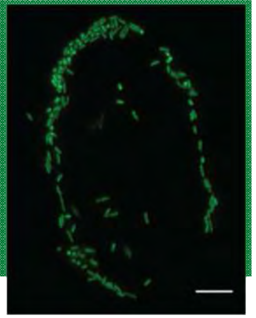
KOPPERT BIOLOGICAL SYSTEMS

SYMBIONT

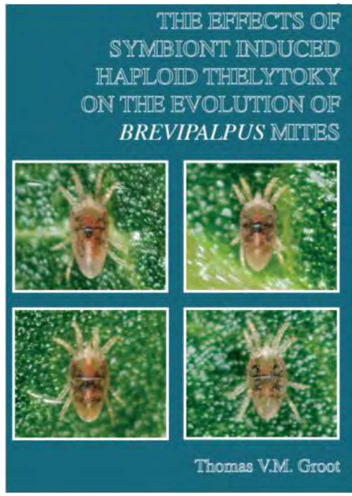
Symbiont van *Brevipalpus*: *Cardinium*

- Intracellular bacterium
- discvered in 2001
- 7 % of all insects and mite infected

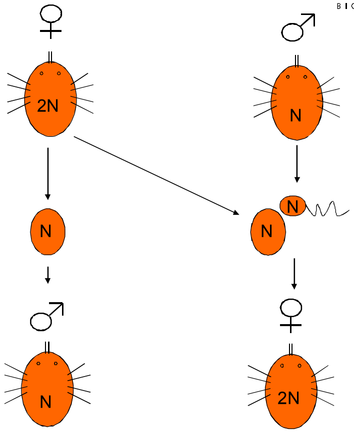




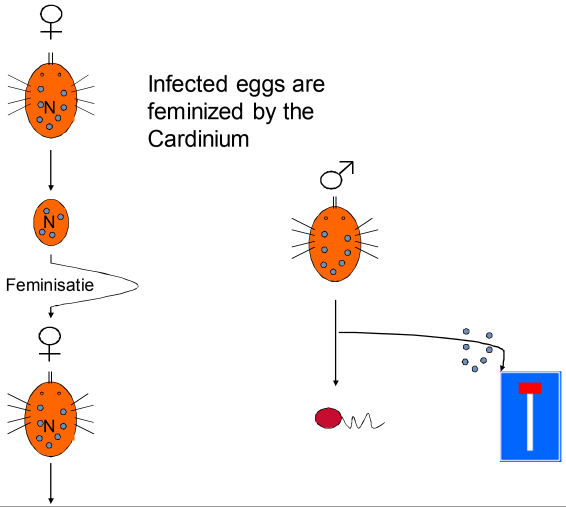
DE **EFFECTEN** VAN **SYMBIONT GEÏNDUCEERDE HAPLOÏDE THELYTOKIE** OP DE **EVOLUTIE** VAN ***BREVIPALPUS*** **MIJTEN**



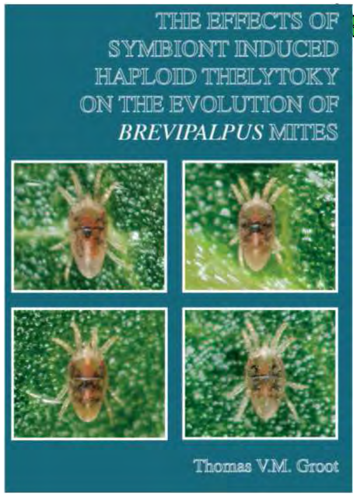
Uninfected *Brevipalpus* mites are arrhenotokous/ haplo-diploid



Infected eggs are feminized by the Cardinium



DE **EFFECTEN** VAN **SYMBIONT GEÏNDUCEERDE HAPLOÏDE THELYTOKIE** OP DE **EVOLUTIE** VAN ***BREVIPALPUS*** **MIJTEN**



EFFECTS

Asexual reproduction: Mother and daughters are all identical

Sexual reproduction: every individual inherits a unique combination of paternal genes: VARIATION!

MAIN CONCLUSIONS

Despite asexuality, remarkable amount of variation

Symbionts are capable of horizontal transfer

Different species became asexual at different times

Occasional males behave functional, but fail te transmit their genes

WHY MOVE FROM ACEDEMIA TO COMPANY?

Preference for applied work: far more rewarding if the work evidently helps people

Don't like / good at bureaucracy

Don't like the pleading for money

Sterile Insect Technique against onion fly

T.V.M. Groot, M. Loosjes & T.C. Everaarts

de groene vlieg

de Groene Vlieg: the Green Fly

Founded in 1980

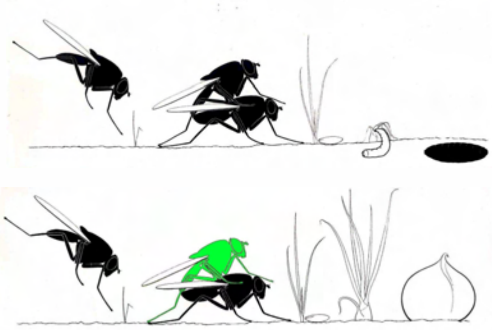
Main products

- SIT against onion fly (*Delia antiqua*)
- Supervised control of carrot fly (*Psila rosae*)
- Soil sampling for plant parasitic nematodes

Currently 100 employees

Onion fly biology

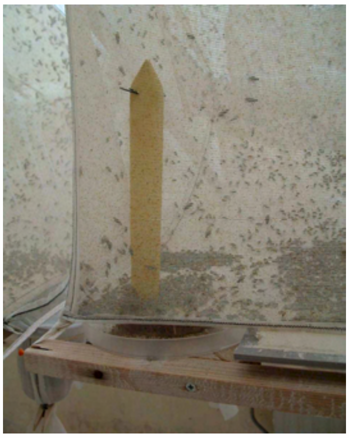
- 2 to 3 generations
  - First flight: May - 1/2 June
  - Second flight: ½ July - August
  - Third flight: ….
  - Diapauses as pupae in soil
- Host plants
  - Onions
  - Leek



Onion seedlings are eaten …

… as are larger plants…

…and damage can be quite severe.



Producing sterile flies

- Total production: 1.000.000.000
- Produced all year round
- In summer: weekly batches taken from storage
- Sterilization as pupae
- Released on the fields as flies
- All sterile flies are color marked
- No sexing strain; max. 10-15 generations from wild!

Monitoring the fly population in the field

mark - recapture
- sterile flies are marked
- various colours

mark - **recapture**
- at least one set of traps / field
- traps are emptied once per week
- catches are processed immediately

Monitoring the fly population in the field

mark - recapture provides information on:
- Size of fertile population
- Ratio of fertile : sterile flies
- Age structure of the sterile fly population
- Recapture rate
- Effect of additional spray

Monitoring the fly population in the field

- The information enables to asses the risk on damage on each seperate field and respond quickly

how many flies are required?
additional spraying?

Current situation

- In the last few years strong expansion to new area's within the Netherlands. For 2016 about 9.500 hectares
- Total area: 25.000 hectares
- Chemical alternative: seedtreatment with Mundial
  - Easy and effective
  - Also effect on thrips
  - Seed treatment is no IPM
  - Does leave a residu in harvested onion

A unique way of working…

- Each filed is treated separately
- Fully paid for by the growers; no subsidies!
- Price depending on size of the field and the crop
- Contracts per year
- Requires a good participation rate
  - To prevent contamination from non-participating fields
  - For efficiency in the logistics of fieldwork

Augmentative SIT?

FAO/IAEA Consultants' Group Meeting: Integration of the SIT with Biocontrol for Greenhouse and Other Confined Pest Insects.

Options for biological pest control; experiences, regulatory framework, prospects

14–18 March 2016, Vienna, Austria.

Dr. Lieselot Van der Veken

Biological nematode control: an agro-ecosystem approach

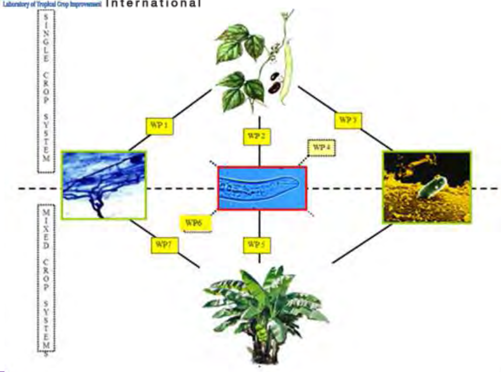
- Potential of multipurpose intercrops for the management of pathogenic nematodes and beneficial arbuscular fungi and root nodulating rhizobacteria in banana-based cropping systems

6/8/2016

General objective

Better understanding of the different biotic components in a mixed banana production system to develop more efficient integrated nematode management

Biological nematode control: an agro-ecosystem approach



6/8/2016

Biological nematode control: an agro-ecosystem approach

Conclusions

Nematode susceptibility: cultivar specific.

AMF compatibility: majority of the IC's had intermediate compatibility

Rhizobial compatibility: very specific; few functional symbiosis were observed

Interactions:

- No effect of AMF or rhizobia in non/poor nematode hosts: marigold/sunn hemp
- AMF suppressed nematodes in intermediate/ good nematode hosts: sweet potato/ sorgho-Sudangrass
- Dual inoculation (AMF and rhizobia) suppressed nematodes in intermediate nematode host soybean
- Single or dual inoculation (AMF or/and rhizobia) suppressed nematodes in intermediate nematode host common bean

Common bean (and sorgho-Sudangrass) as potential intercrops

IC_{AMF} did not result in plant growth promotion, did not provide significant extra nematode suppression in mixed systems

Biobest Group

- Worldwide authority in pollination and biological pest control for protected crops since 1987
- Leading Brand
- N° 2 in a fast expanding market:
  - Geographically
  - Applications
  - Products
- 8 production units
- +350 employees
- Broad, reliable product offering:
  - Biological Pollination
  - Biological Control
  - Monitoring & Scouting
  - Accessories
  - Greenlab

Our Network

8

What is IBMA?

- International Biocontrol Manufacturers Association
- •Established in 1995, this year 20th anniversary
- •Over 230 members
- •Global (European focused) Association
- •Strong growth from 10 original founding members
- •Diverse membership
- •SME's to multinationals
- •Organic and biocontrol only to IPM and conventional
- •Principally involved in agriculture and horticulture

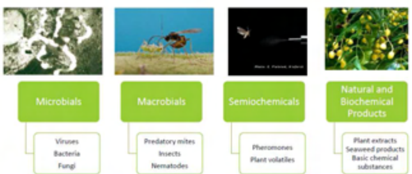
IBMA INTERNATIONAL BIOCONTROL MANUFACTURERS ASSOCIATION

Mission statement

- Raise awareness, both among decision makers and consumers, concerning the benefits of the biocontrol products.
- Ensure Biocontrol is at the forefront thinking. It is not just something that it is nice to do but a priority. (SUD)

IBMA INTERNATIONAL BIOCONTROL MANUFACTURERS ASSOCIATION

4 professional groups according to product categories

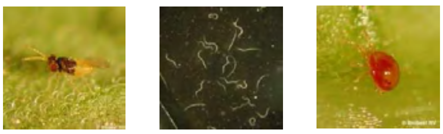


IBMA INTERNATIONAL BIOCONTROL MANUFACTURERS ASSOCIATION

IBCAs: Scope

- Professional group head of the Invertebrate Biological Control Agents (IBCA's)

include insects, entomopathogenic nematodes and predatory mites



PG IBCA organisation

Steering Group:

- Chair: Lieselot Van der Veken, Biobest
- Vice Chair: Phil Walker, BCP
- Johannette Klapwijk, Koppert
- Enric Vila, Agrobio
- Samuel Critchley, Syngenta BL, Invivo
- Patrick Frettinger, BASF

Objectives

- **Main group topics:**
  - Promote IBCA's as sustainable solutions for crop protection in a wide range of crop
  - Promote reasonable and harmonized regulation of IBCA's
  - Provide input to the EC on regulations relevant to IBCA's, such as Invasive Alien Species, Access & Benefit Sharing
  - Address scientific issues together with experts to anticipate future regulation
  - Support national groups on IBCA regulation and other issues

Position papers

Position Paper on Regulation of Invertebrate Biological Control Agents

Invertebrate Biocontrol Agents (IBCAs) are key elements in IPM systems in agricultural ecosystems and especially greenhouses. They offer a safe alternative for the use of pesticides and are effective also in cases where chemical pest control fails because of resistance. As pests are often non-native local natural enemies are not always able to control them and the introduction of exotic species may be required. Although there are hardly any examples of IBCAs causing problems for the environment, we do have the obligation to assess the risks of releasing a species in a new environment prior to its release.

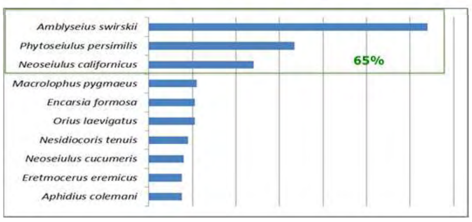
Different countries do have regulations for the import and release of IBCAs. However, requirements are currently not standardised and not always appropriate. IBMA therefore has the following recommendations for the implementation of regulation on the release of IBCAs:

1. We refer to studies already conducted by IOBC, ERBIC and REBECA on evaluating risks of the release of IBCAs (references IPPC, REBECA final reports, Van Lenteren, 2003 and Loomans and Bigler (2006)).
2. A Risk Assessment should be primarily based on available scientific knowledge. Before starting Risk Assessment tests, all relevant available data should therefore be collected in a dossier and submitted to competent national authorities.
3. We recognise EPPO Standard 6.2 on safe use of Biological Control as being the guideline for data requirements for such a dossier.
4. In case that not all assessment criteria are covered by literature data, additional experiments need to be conducted by the applicant in conference with national authorities.

IBCAs for key greenhouse pests EU

IBCAs for key greenhouse pests

Predatory mites most important IBCA's



Top-10 of biocontrol agents used in greenhouses (turnover) (J. Klapwijk)

IBCA Regulation history:

- **1996** FAO ISPM 3 (IPPC)
- **1997** EPPO / CABI on Safety and Efficacy of Biological Control in EU: endorsment ISPM 3
- **1999** EPPO Guidelines for the first import of exotic BCAs for research under contained conditions
- **2000** EPPO Guidelines for import and release of exotic BCAs
- **2002** EPPO positive list with IBCAs widely used in the EPPO region
- **1998-2002** ERBIC; detailed criteria for RA and IBCA ranking (safety)
- **2003** OECD Guidance for information requirements for IBCAs
- **2003** IOBC/WPRS Commission for the Harmonisation of Regulation of IBCA's
- **2005** FAO: revised version of ISPM 3
- **2006** Bigler *et al.* 2006: book as framework for ERA of IBCAs
- **2006-2008**: REBECA (EU Policy Support Action)

(Ehlers, 2011)

REBECA project (EU 2006-2008)

- Need for balanced and appropriate EU regulatory systems for import and release of BCA's
  - IBCA's : EPPO guidelines
    - Human health risk: usually limited
    - Environmental risks of exotic species (CBD)

How to evaluate IBCAs environmental risk?

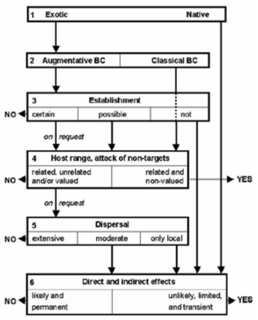
Identify risks of introducing exotic natural enemy

- **Establishment** and/or **dispersal** in non-target habitat
- Non-target **host range**
- (In) direct effects on **non-target organisms**

Determine likelihood and magnitude of each of the risks
Quantify risk and apply cost-benefit analysis (also for other control methods!!!)

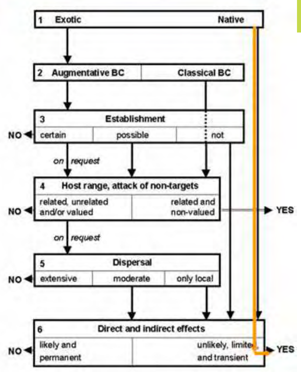
(Van Lenteren, 2006)

Stepwise risk assessment : from 5 to 1 sheme



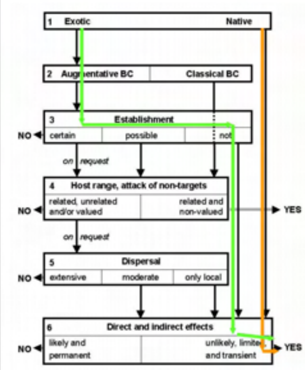
- Clearly good or bad species are discovered early in evaluation (saves money and time)
- Only doubtful species go through whole evaluation
- Scheme can be used for quick scan or comprehensive evaluation
  - We tested 150 commercially available species with this sheme

Van Lenteren, 2006



Native natural enemy:
all natives (34 spp.): safe

Van Lenteren, 2006

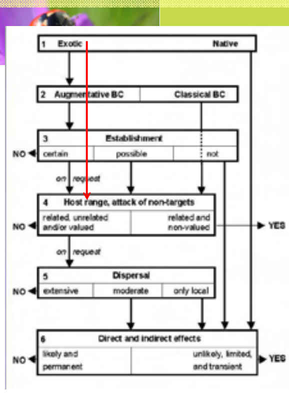


Native natural enemy
all natives: safe

Exotic natural enemy for greenhouse use

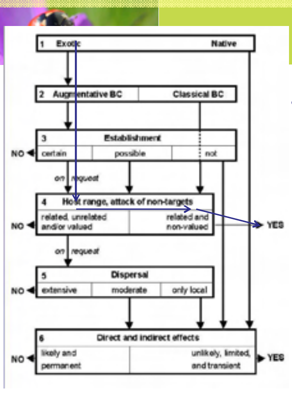
If establishment impossible, usually safe
If establishment possible: more work!
SIT

Van Lenteren, 2006



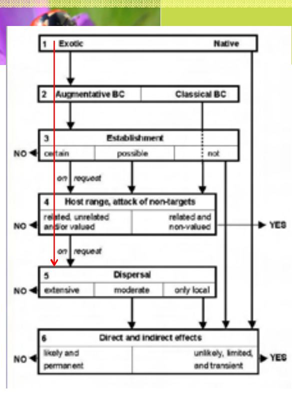
- **Exotic species for augmentative biological control that are likely to establish are detected very early in the evaluation process, and will be excluded from release without further studies**

Van Lenteren, 2006



- Exotic species that attack only related spp. and do not attack valued non-targets are also detected early in the evaluation without the need to study dispersal and direct/indirect non-target effects; they can be released

Van Lenteren, 2006



Exotic species that attack related and unrelated non-targets and/or valued non-targets will be excluded from release without the study of dispersal and(in)direct non-target effects

Van Lenteren, 2006

Conclusions application hierarchical screening

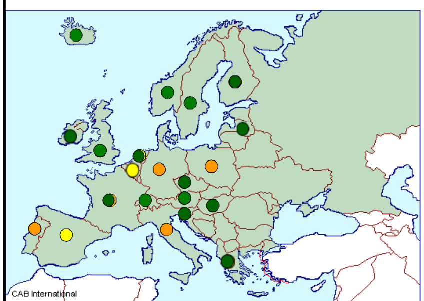
- All native species (34) considered safe for release

- Compared to earlier risk analyses: prevent unnecessary studies, quicker, cheaper, simpler

EPPO PM6(3) " positive list"

- http://archives.eppo.int/EPPOStandards/biocontrol_web/bio_list.htm

Status of national regulation in European countries:



- Implemented (15)
- In preparation (2)
- No regulation

International Regulation

- ISPM 3 (ISPM 2 PRA)
- NAPPO region: NAPPO application: US, CAN and MEX (exotic species disgarded)
- Rest of the world : country specific

Regulatory framework

ISPM 3: ***GUIDELINES FOR THE EXPORT, SHIPMENT, IMPORT AND RELEASE OF BIOLOGICAL CONTROL AGENTS AND OTHER BENEFICIAL ORGANISMS***

(2005)

SCOPE

This standard1 provides guidelines for risk management related to the export, shipment, import and release of biological control agents and other beneficial organisms. It lists the related responsibilities of contracting parties to the IPPC ('contracting parties'), National Plant Protection Organizations (NPPOs) or other responsible authorities, importers and exporters (as described in the standard). The standard addresses biological control agents capable of self-replication (including parasitoids, predators, parasites, nematodes, phytophagous organisms, and pathogens such as fungi, bacteria and viruses), as well as sterile insects* and other beneficial organisms (such as mycorrhizae and pollinators), and includes those packaged or formulated as commercial products. Provisions are also included for import for research in quarantine facilities of non-indigenous biological control agents and other beneficial organisms.

The scope of this standard does not include living modified organisms, issues related to registration of biopesticides, or microbial agents intended for vertebrate pest control.

- *an insect that, as a result of an appropriate treatment, is unable to produce viable offspring

6/8/2016

Prospects

- Harmonized IBCA regulation within an ecological zone context (relevant a/biotic parameters limiting species distribution)

- Use EPPO list as a positive list with safe IBCA's
- Risk categories: ranking according to risk:
  - *Develop tools based on these categories: the safer the category, the lesser assessment required*
    - *For specialist parasitoids less data required as for generalist predators*

- Expected vs perceived risk
- Quick scan 150 species: 80 approved directly, 15 after assessment

Regulatory framework

- Depending on SIT technique

Irradiation

- ISPM 3 (ISPM 2 PRA)
- No establishment if QC guarantees sterility

Molecular

- ISPM 11 (GMO)
- No establishment if QC guarantees sterility
- Acceptance in EU?

6/8/2016

Important crop pests: potential SIT?

Technical feasability for SIT?

- sexual reproduction
- mass rearing
- adecuate sterilisation by irradiation
- good fitness after irradiation
- no remating after mating sterile male
- island population criteria met in confined conditions

Important crop pests: potential SIT?

Key greenhouse pests in EU-N Am

Pest scientific name	Common name pest	Taxonomical group	Crop
Aculops	Tomato russet mite		Tomato
Caterpillars			Tomato
Drosophila suzukii		Diptera	Soft Fruits
Scirtorhips mangiferae (blueberry - leaf thrips)		Thysanoptera	Soft Fruits
Echinotrhips			Cut flowers
Mealybugs			Tomato, sweet pepper, ..
Bemisia tabaci		Hemiptera : Aleyrodidae	Several
Trialeuroides vaporarium		Hemiptera : Aleyrodidae	Several
Leafhoppers			Sweet peppers
Frankliniella occidentalis		Thysanoptera	Soft fruits, Sweet peppers, cut flowers,
Nezara sp		Heteroptera	
Lygus spp		Heteroptera	cucumber

Important crop pests: potential SIT?

- Currently absent in EU, big pests in other continents eg L-Am, Asia

Tomato psyllid (*Bactericera cockerelli*)

Pepper weevil (*Anthonomus eugenii*)

Eggplant stem borer (*Neoleucinodes elegantalis*)

Citrus psyllid/ huanglongbing (*Diaphorina citri*)

THANK YOU FOR YOUR ATTENTION

Occurrence and Control of Insect Pests on Greenhouse Vegetables in China

Shaoli Wang

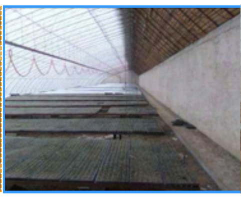
March 14, 2016

Outline

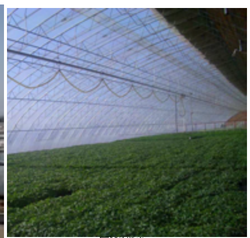
- Greenhouse in China
- Vegetable Ecosystem in greenhouse in China
- Main insects and their control in greenhouse in China
- Integration of SIT and biological method in China

Greenhouse in China

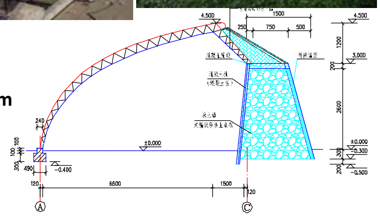
- Modernized greenhouse (Left)
- Solar greenhouse—widely used(Middle) 8-30°C
- Plastic shed—widely used(Right)

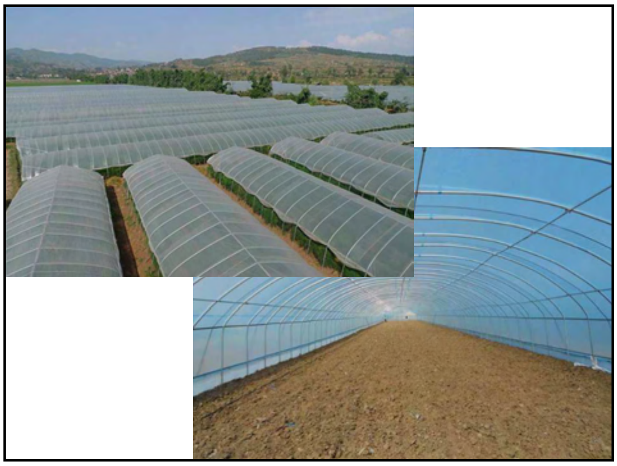







Height: 4-6m
Thickness of back wall: 8m





Importance of developing the protected cultivation in China

- **Meeting the requirement of few kinds of vegetables in Northern China, even though this still needs much improvement**
- **achieve the vegetable supply throughout the year**
- **Some kinds of fruit trees and flowers**
- **The protected cultivation reaches 4 million hm^2 in China.**

Vegetables in the greenhouse in China

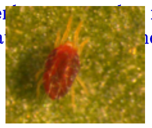
Vegetable ecosystem in greenhouse in China

1. The ecosystem is unstable due to the short-term growing periods and the crop changes frequently.
2. The temperature changes drastically in the greenhouse ranging from 8 degree to 30 degree, especially in the early spring and late autumn.
3. The humidity in the greenhouse is very high, resulting in the plant disease.
4. The control of natural enemy on the greenhouse insect is relatively weak due to the unstable ecosystem, environment and the insecticide spray.

Characteristics of vegetable insect in greenhouse in China

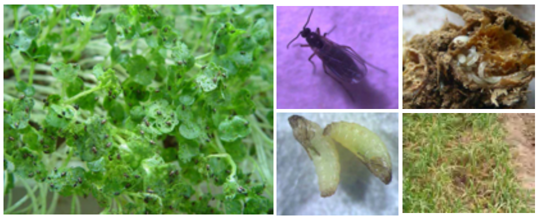
(1) The occurrence of the insect pests becomes more serious

- Cultivation pattern is complicated. There are solar greenhouse, plastic shed and sunshade screen et al. making the complexity of the insect pests;
- The expansion of the greenhouse is helpful for the over-wintering or over-summering of some insect pests.
- The expansion of greenhouse and intensive cultivation adequate the insects.



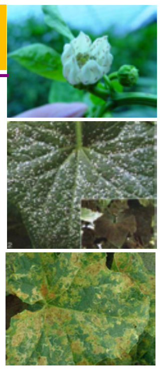
(2)Secondary pests become the main pests

- **Stripped flea beetle is the most important insect on vegetables in Southern China and it becomes more and more serious in Northern China currently.**
- **The root maggot becomes a key factor impressing the production of onion and garlic in northern China.**



(3) Invasive insect pests become more serious

- Leaf miners of *Liriomyza sativae* and *Liriomyza huidobrensis* were found in Hainan, Guangdong in 1994
- Sweetpotato whitefly, *Bemisia tabaci* B biotype was found in Beijing, Hebei, Guangdong at the end of last century.
- West flower thrips, *Frankliniella occidentalis*, was found in Beijing in 2003
- *Bemisia tabaci* Q biotype was found in Beijing in 2003
- American serpentine leaf miner, *Liriomyza trifolii* appeared in South China in 2006



(4) Controlling difficulties for the small insects and intermittent outbreak of some pests

- Small insects including whiteflies, leaf miners, thrips, spider mites and the aphids occur in the protected cultivation throughout the year and the population increases rapidly.
- Beet armyworm, *Spodoptera exigua* is an important insect pest with the characteristics of intermittent outbreak in some areas.

(5) Insecticide resistance of some insects is prominent

- Insects in greenhouse undergoes higher selection pressure against insecticides than those on other crops due to the frequent insecticide spray.
- Few insecticides for the vegetable insects can be used.
- Diamondback moth, beet armyworm, whitefly, west flower thripsm and the two spotted spider mite are the ... nst ins...

Main insects in greenhouse in China

Whitefly
Greenhouse whitefly (*Trialeurodes vaporariorum)*
Sweetpotato whitefly (*Bemisia tabaci*)

Thrips
Onion thrips (*Thrips tabaci*); Thrips palmi
Western flower thrips (*Frankliniella occidentalis)*

Aphid
melon aphid (*Aphis gossypii*); Green peach aphid (*Myzus persicae)*

Leafminer
Pea leafminer (*Liriomyza huidobrensis); *Vegetable leafminer (*Liriomyza sativae)*

Mites
Broad mite (*Polyphagotarsonemus latus*); *Tetranychus* spider mite(*T. urticae* and *T. truncatus)*

Melon fly
melon fruit fly (Bactrocera cucurbitae); Oriental Fruit Fly (*Bactrocera dorsalis*)

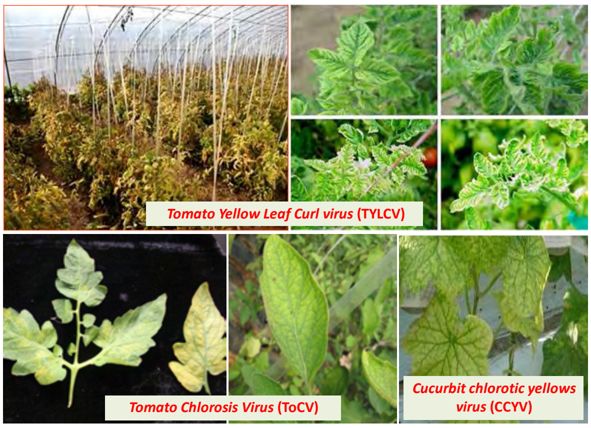
Other important insects

Whiteflies

There are four life stages: egg, nymphal instars, pupal stage, and the adult.

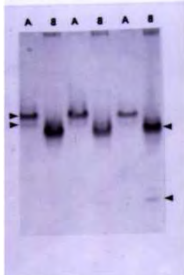
Sweetpotato whitefly
Bemisia tabaci

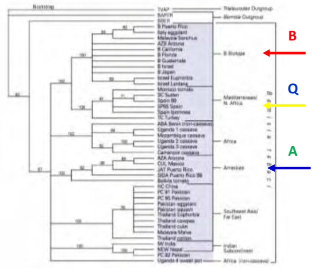
It can cause great damage to a broad range of plants (over 600) by direct feeding, excretion of honeydew.



Biotype (Cryptic species)

Costa & Brown (1990): A, B, Q et al were identified using the pattern of esterase, mt COI genes and other methods





B biotype

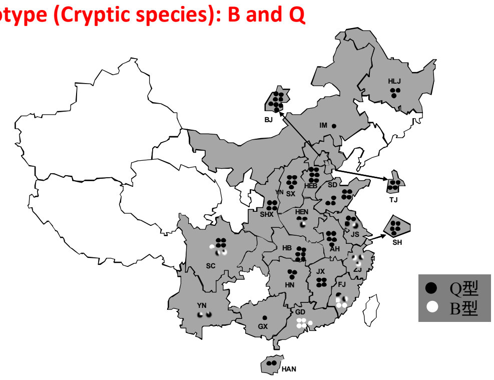
- Mid 1980s to 1990s: Major geographical expansion in B-biotype
- B-biotype become predominant due to wide host range, resistance to insecticides and/or other characteristics.
- B-biotype is generally resistant to pyrethroids, but resistance to newer insecticide groups still patchy.

Q biotype

- Q-biotype was formerly restricted to Mediterranean, where resistance to a broad range of insecticides (neonicotinoids, IGRs, pyrethroids) is now widespread
- Q-biotype currently common over much of the Mediterranean, but not ubiquitous (B-biotypes still occur).
- Q-biotype (plus multiple resistance) are now being transported on ornamentals to other parts of the world (e.g. USA, northern Europe, Japan, and China)

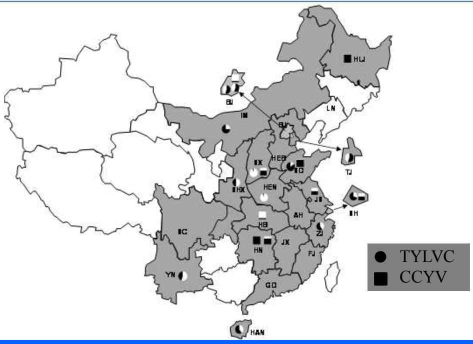
- From 2004 to 2007, B biotype predominated in most parts of China.
- Q biotype and B biotype coexist in mid-east parts of China. In some places, Q biotype replaced B biotype completely.

Biotype (Cryptic species): B and Q

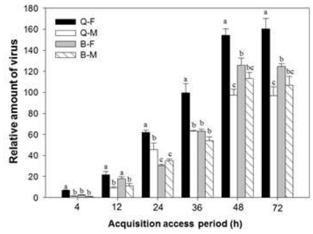


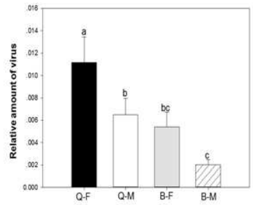
In 2014, 76 populations (Q), 10 populations (B), 7 populations (B+Q)

Rates of *B. tabaci* carrying TYLCV and CCYV



In 2014, 13 populations (of 22) collected from 11 locations were proved to have YLCV; 9 populations (of 21) from 15 locations carried CCYV。





Transmission of TYLCV DNA by males and females of B and Q *Bemisia tabaci*

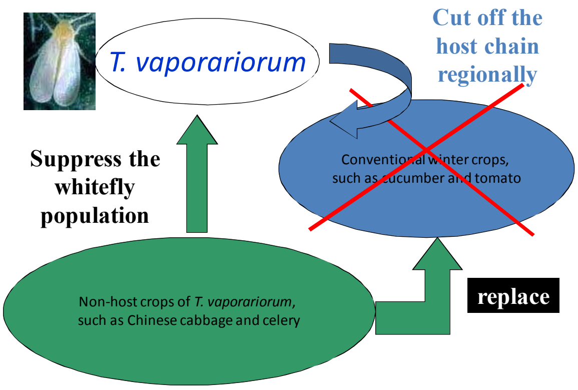
Higher resistance of Q biotype of *B. tabaci* against different insecticides than B

Insecticides	Biotype	SE(SE)	LC_{50}(mg/L)	95% FL	Q/B
Abamectin	B	1.85(0.200)	0.0870	0.0630~0.120	
	Q	2.10(0.196)	0.0970	0.0740~0.127	1.12
Acetamiprid	B	3.47(0.358)	3.22	2.44~4.24	
	Q	1.49(0.157)	22.1	15.8~30.1	6.87
Thiamethoxam	B	1.06(0.112)	17.8	9.78~32.5	
	Q	0.602(0.0840)	54.9	19.2~157	3.08
Cyantraniliprole	B	1.58(0.111)	6.23	4.89~7.94	
	Q	1.12(0.145)	93.9	50.1~175	15.1
Chlorantraniliprole	B	1.13(0.245)	561	176~1788	
	Q	1.65(0.185)	4564	3071~6786	8.14
Buprofezin	B	1.98(0.148)	1476	1192~1827	
	Q	1.85(0.157)	5155	3639~7302	3.49
Pyriproxyfen	B	2.36(0.211)	1434	1125~1829	
	Q	1.58(0.183)	8810	5828~13319	6.14
Spirotetramat	B	1.51(0.209)	2450	1628~3687	
	Q	>16000	—	—	>6.53

Xie et al., 2014

Biological differences of *B. tabaci* B and Q biotypes

- **Adaptability**: The adaptabilities, growth and development, of biotypes B and Q on the host plants are obviously different.
- **Susceptibility to insecticides**: The *B. tabaci* Q biotype has higher tolerance or resistance to many insecticides than B, especially the neonicotinoid insecticides.
- **Efficacy and characteristics of virus transmission**: The Q biotype has the stronger transmission efficacy than B for Tomato Yellow Leaf Curl Virus(TYLCV) and Tomato chlorosis virus (ToCV).



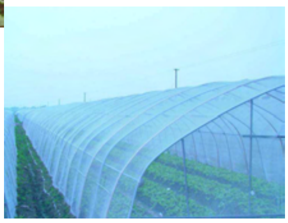
Insect-free greenhouse (insect-proof + sticky cards)

Different Vegetable Seedlings shouldn't bred together.

Healthy and clean seedlings: healthy seedlings needed to slow down the basic population of the insect pests

Yellow Sticky card

NET



PARASITES

Encarsia formosa

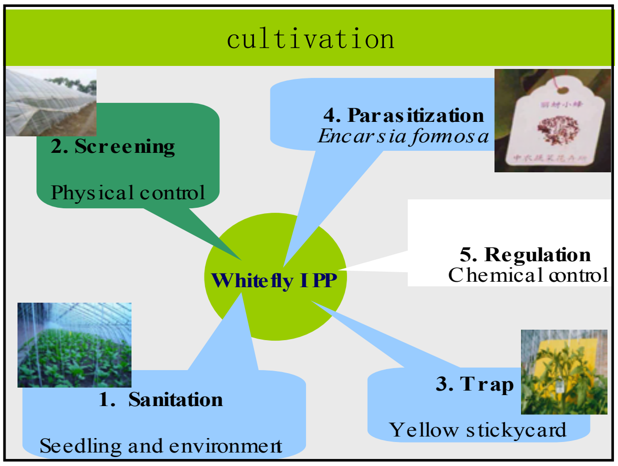
PREDATORES

Delphastus pusillus

Orius spp.

Natural enemy release: **1000-2000 pupae/667m², repeat it every 7-10 and 5-7 times each season**

Insecticide applications: use for the higher insect populations, spray or fumigation using smoke generator (250-400g/667m2).



Thrips


Egg


First nymph


Second nymph


Pupa

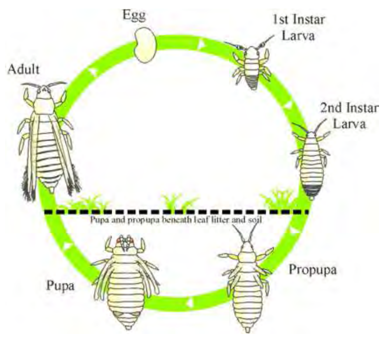

Adult (female)


Adult (male)

- Order Thysanoptera
- around 5,000 species have been described
- generally tiny, 1 mm long or less
- having a single mandible (jaw) used for rasping
- feed on plants and vector of some important virus

Western Flower thrip, Frankliniella occidentalis **is an important invasive insect in China.**

***Tomato spotted wilt virus*, TSWV is transmitted by this thrip and causes giant economical losses.**



Life cycle of thrips

Adult female thrips insert eggs into plant tissues.

The late 2nd instars crawl down into the soil to pupate.

BIOLOGICAL CONTROL

PREDATORS: PIRAT BUGS. (*Orius spp.*)

PREDATORY MITES

BIOLOGICAL CONTROL

Minute Flower Bug (*Orius tristicolor*), and two predatory mites, *Amblyseius cucumeris* and *Hypoaspis miles.* Minute pirate bugs are polyphagous and will also feed on aphids, mites, and small caterpillars. *Orius* are released at a rate of 2000 to 4000 per acre, while *N. cucumeris* are released at a rate of 10 to 50 mites per plant for each of 2 to 3 weeks.

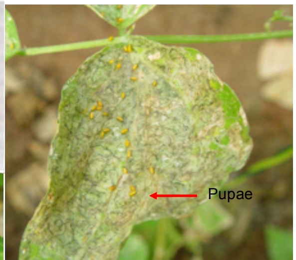
These mites will also feed on spider mite eggs, pollen, and fungi. *Hypoaspis miles* are soil-inhabiting predators that feed on thrips prepupae and pupae in the soil. A commercially available parasite of greenhouse thrips is *Thripobius semileteus.*

CHEMICAL CONTROL

Root irrigation using imidacloprid or thiamethoxam (3000-4000x) after the seedling transplantation with 30ml/plant.

Spinetoram, abamectin, thiamethoxam, emamectin benzoate are the candidates using in the greenhouse currently.

Leaf miner



Liriomyza sativae

BIOLOGICAL CONTROL The parasites *Diglyphus* spp. is commercially available to control leafminers and may be useful in greenhouse situations, especially if greenhouses are screened to exclude adult leafminer movement into greenhouses.

Aphid

Control methods for aphids

1) *Cultural control.* clean the weed and make the seedlings clean and healthy
2) *Seedlings with mesh.* White or silver grey 40-50 mesh are used to cover the seedling beds to minimize the aphids and its vectored virus disease.
3) *Preventing aphid with the plastic film.* Silver grey mesh is used to cover the door and window, ventilation opening, in case of the aphid flying into the greenhouse. Silver strip is hung in the field.
4) *Sticky card.* Yellow sticky cards are hung in the field with the upper margin similar with the plant.
5) *Chemical control.* Chemical control. ①Root irrigation; ②Partial control; ③Spray control; ④Smoking method

Spider mite

DAMAGE Mites suck cell contents from leaves, initially stippling leaves with a fine pale green mottling. As feeding continues, the stippling increases and leaves turn yellow with bronzed or brown areas; damaged leaves frequently fall.



CULTURAL CONTROL

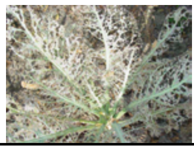
Because spider mites feed on a large variety of plants, keep production areas free of weeds, which can serve hosts to the mites. Carefully inspect plants being brought into a new crop to ensure that they are free of mites.


BIOLOGICAL CONTROL

Many different species of predatory mites are available for control of the mites. *Phytoseiulus persimilis* is a commercially available predator of two spotted spider mite, and it has been used to control mite populations in greenhouses and field situations. It can reproduce faster than its prey, yet best results can be obtained when it is released into the crop before the spider mite populations have built up.

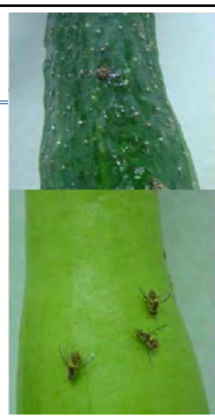
Lepidoptera moth

Sex pheromone trap

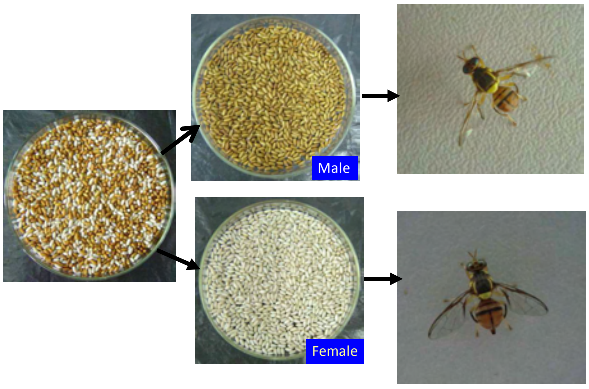



Potential of Integration of SIT and biological method in China

♀ ♂



Jiahua Chen and Qinge Ji *Fujian Agriculture and Forestry University*



Genetic sexing *strain*

Melon fly (*Bactrocera cucurbitae*)

Protein hydrolyzate and other attractants are used in the field.

Spotted wing drosophila

Leaf miner

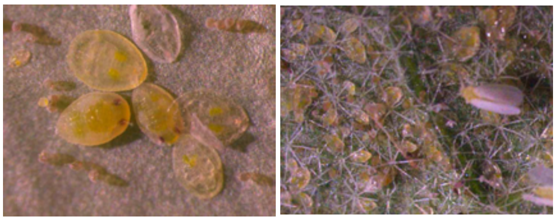
It's possible to control through the integration of biological and SIT techniques, even though there are many steps to go.

(1) bisexual reproduction

(2) It's possible to realize the mass-rearing through artificial food

Bemisia tabaci

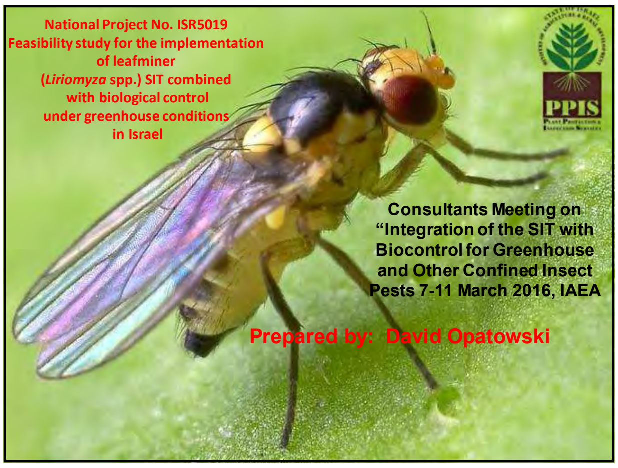
- **Parthenogenesis is a key factor influencing the effective applications of SIT techniques**
- **No artificial food, restricting the mass rearing**



Constraints to the integration of biological control and SIT

- **No SIT techniques have been developed for most other important insects in greenhouse up to now**
- **The mass-rearing of the parasitoids or predators are limited in China**
- **The environment in greenhouse is not helpful for the population establishment of the natural enemies**
- **The oriental fruit fly and the melon fly has the SIT techniques, but their parasitoids are still in the laboratory**
- **The control effects of integration of biological control and SIT technique needs to be evaluated.**


Thank you for your attention！



Counterparts

- PPIS

National Contributors

- Bio-Bee Sde Eliyahu Ltd.

Liriomyza bryoniae

- Major species in Israel
- Highly polyphagous pest of vegetables and flower crops, widely distributed throughout Asia, Europe and Africa
- A worldwide pest, is not considered a quarantine pest in any country but Ireland, therefore SIT could be useful for many countries.

TC Objective

Develop / enhance biological control for leaf miners using SIT

Output 1:
Develop/ improve mass rearing technologies for leaf miner flies

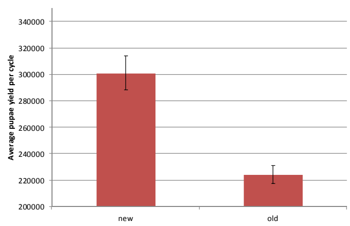
Activities:
Improve the modular system for mass-production of the fly at Bio-Bee

Improve current mass production technique of the leaf miner Liriomyza bryoniae

Develop novel mass rearing technique for leaf miners based on artificial diet

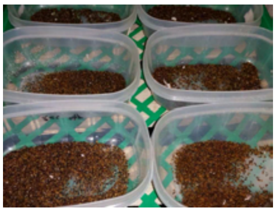
Results

- An upgraded mass rearing system for leafminers was acheived.



New vs. old production facility: Yield improvement, of **over 30%**, was achieved by the newly developed prototyped greenhouse for leaf miners mass rearing.





- Preleminary studies were carried out on artificial diets.

- However, an artifical diet for *Liriomyza* has yet to be acheived

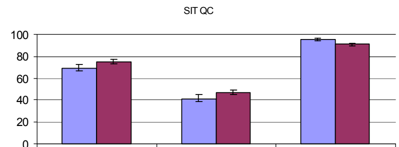
Output 2:
Determine Irradiation dosage for the leaf miner flies

Activities:
Age of the pupae when irradiated
Handling (reduced-oxygen etc.)
Optimal dose for sterilization
Quality of sterilized vs. normal flies:

- Emergence and flight ability
- Longevity under stress
- Dispersal
- Mating performance (competitiveness)
- Survival in the field

Results

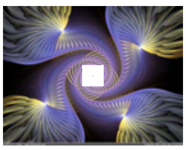
Sterilized leaf miners were tested for emergence rate, sterility and flight capacity according to the medfly QC protocols.



	Emergence rate	Male %	Flight %
CONTROL	69.4	41	95.50425555
SIT	75.25	46.9	90.88051765

Findings

- Optimum stage for irradiation: Late pupae (close to eclosion)
- Keep under hypoxia conditions
- Optimum dosage 170Gy
- Ensures efficient sterilizion while maintaining a high quality of emerging adult leafminers



- Output 3:
- Emergence and release technologies
  - Irradiation performed under hypoxia and pupae released in aired plastic containers

- **Output 4:**
- **Perform pilot tests assessing the effect of releasing sterile leafminers in greenhouses**

Activity: SIT pilot tests for SIT efficacy

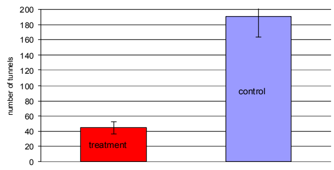
Pupae of *L.bryoniae* were dispersed on tomato plants in a greenhouse.

Preliminary test with a ratio 1:2 fertile:sterile flies was rejected (40% decrease).

Test replicates received a ratio of 1:5 fertile:sterile flies.

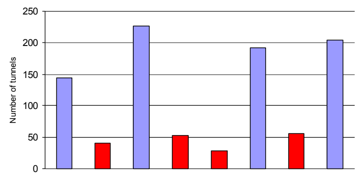
Observations were carried out throughout the infestation stage and proved ,early on, the efficiency of the sterile flies in reducing the amount of tunnels on the leaves.

Significant decrease of over 75% in infestation (based on tunnel count) was recorded.



Average number of tunnels per plant (8 tents, 17 plants per tent, F test p<<0.001)

12 days after introducing *L. bryoniae* to the tomato plants, the total numbers of visible tunnels were counted.



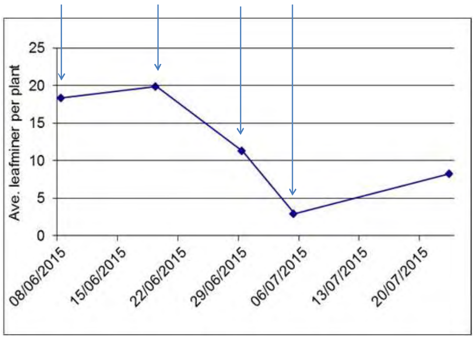
Average number of visible tunnels per plant: Red bars- treatment tents, blue-control tents.

Activity :
Test the efficiency of a supposed synergism between the leaf miner's natural enemy, *Diglyphus isaea* and the sterile flies

Commercial tomato greenhouse (2000 m^2) test

- **Treated before, during and after with the biological control agent, *Diglyphus isaea***
- **At ten day intervals 160,000 sterile *Liriomyza bryoniae* flies (at a ratio of 1:5 fertile/sterile) were released during a 5 week period**
- **An over 80% reduction in leafminer population proving that the method can work on a commercial scale.**

Four releases of sterile flies



Constraints identified from project

- **Artificial diet for *Liriomyza*** (conflict between natural enemy rearing and sterile fly production)**.**
- **A technique to distinguish between leafminers' gender, while in larval or pupal stage.** (♀ leaf stings – nutrition and sterile egg laying)

Other Issues for consideration on the use of SIT in confined areas (1)

- **Production numbers** would have to be much higher than equivalent, if available, natural enemies.
- If a natural enemy is available will need to perform **equivalency tests** N/E vs. SIT and also synergy.

Other Issues for consideration on the use of SIT in confined areas (2)

- **Commercial viability** vs. traditionally (sprays) will also need to be taken into account.
- Perhaps better to concentrate on **pests that have no efficient natural enemies** – **BUT** then mass rearing knowledge is likely to be lacking.