The development and role of chemical solutions: an IRAC perspective

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EPPO/IOBC/FAO/NEPPO
Joint International Symposium on management of *Tuta absoluta* (tomato borer)
Agadir (Morocco), November 16-18, 2011

CropLife INTERNATIONAL

IRAC

About IRAC

- **Insecticide Resistance Action Committee (IRAC)**
  - Formed in 1984 – now in its 27th year and still growing
  - Specialist technical expert group of the agrochemical industry
  - Association with CropLife International (Formal part of CLI´s Stewardship Committee since June 2010)
  - Provides a coordinated industry response to the development of resistance in insect and mite pests
  - Around 70 industry representatives and specialist members in different working groups
  - 7 Country / Regional Groups with a further 70-80 representatives




Definition

Resistance – is a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to manufacturer label recommendation

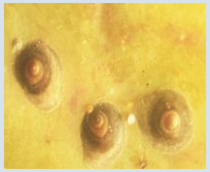
An old story

Melander AL (1914)

Can insects become resistant to sprays?

Journal of Economic Entomology **7**, 167

1908 – *Quadraspidiotus perniciosus*



First resistance observation

Compound: Lime sulphur

Insecticide Resistance Action Committee

Global resistance issues

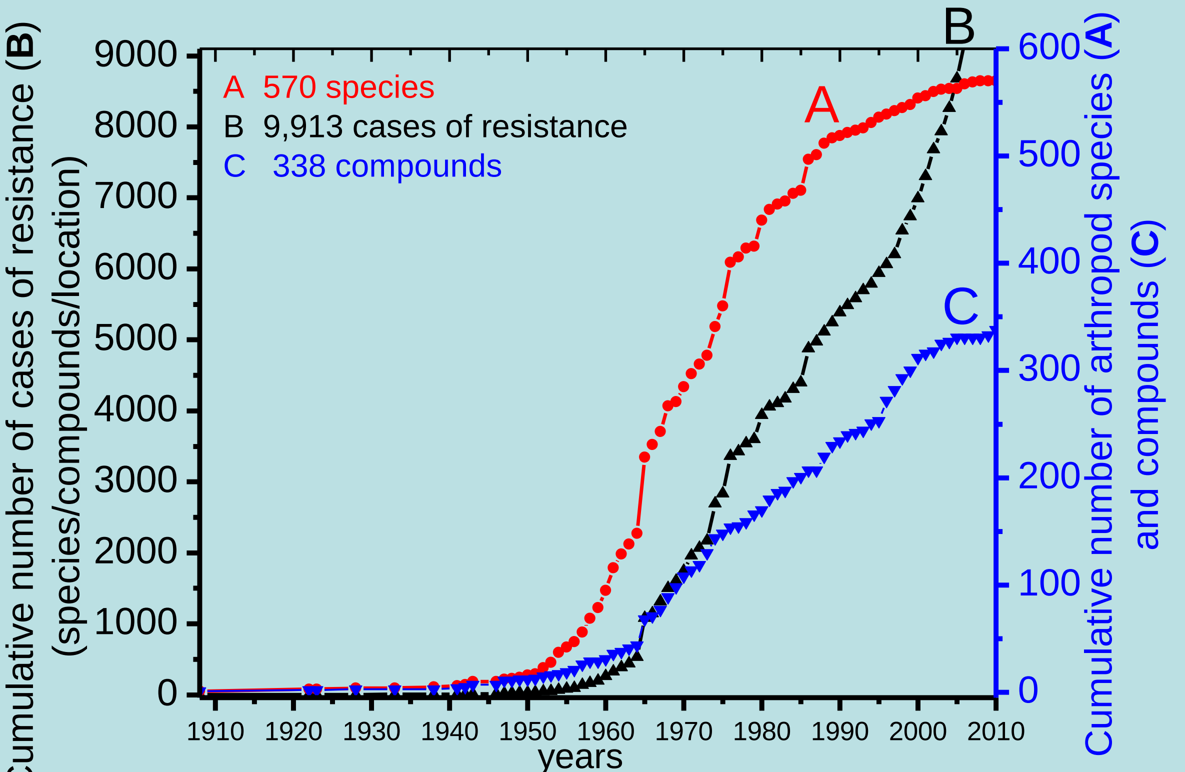


Fig 1. Evolution of arthropod insecticide resistance from 1908 to 2011. (species, compounds and total number of cases).

IRAC Mission

- Facilitate communication and education on insecticide and acaricide resistance
- Promote development of resistance management strategies to maintain efficacy and support sustainable agriculture and improved public health
  - Pool expertise
  - Cross-industry advocacy and lobbying group
  - Industry commitment to product stewardship and sustainability
  - Foster communication and education on IRM
    - Mode of action classification
    - eTools on website (e.g. eMethods)
    - Wide range of educational material (posters, bochures, IRM guidelines)

IRAC INTERNATIONAL

Companies

- BASF The Chemical Company
- Bayer CropScience
- BELCHIM Crop Protection
- CHEMINOVA
- Chemtura
- Dow AgroSciences
- DuPont
- FMC
- MAKHTESHIM AGAN
- MONSANTO imagine
- NIHON NOHYAKU CO.,LTD.
- Nufarm
- SUMITOMO CHEMICAL
- syngenta
- VESTERGAARD FRANDSEN DISEASE CONTROL TEXTILES

EXECUTIVE Committee

- Crop Protection
- Public Health
- Plant Biotechnology

15 Companies

11 International Working Groups

Working Groups

- Steering Group
- Public Health
- Biotechnology
- Methods
- Mode of Action
- Comm./Education
- R. Database (MSU)
- Oilseed Rape*
- Sucking Pest
- Lepidoptera
- Diamide

*Coleoptera (decision pending)

Country/Regional Groups

- IRAC Spain
- IRAC US
- IRAC S.E. Asia
- IRAC Australia
- IRAC Brazil
- IRAC India
- IRAC S. Africa

CropLife INTERNATIONAL

IRAC

Insecticide Resistance Action Committee

www.irac-online.org

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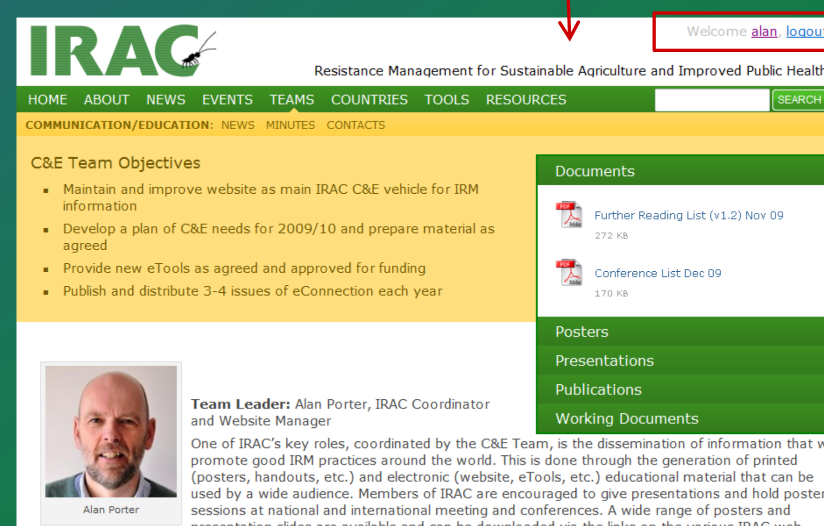
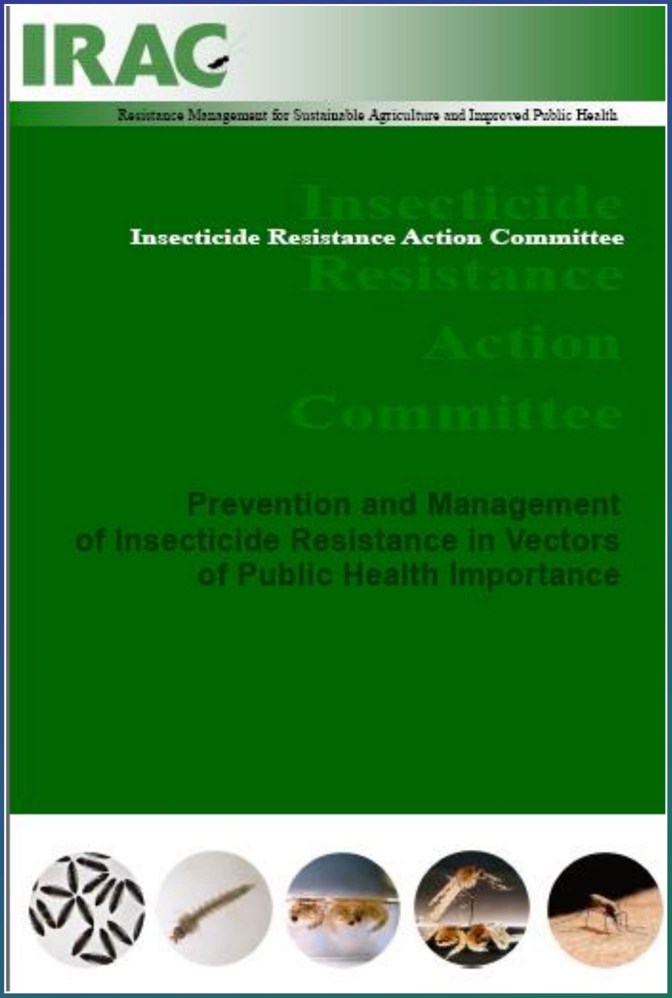
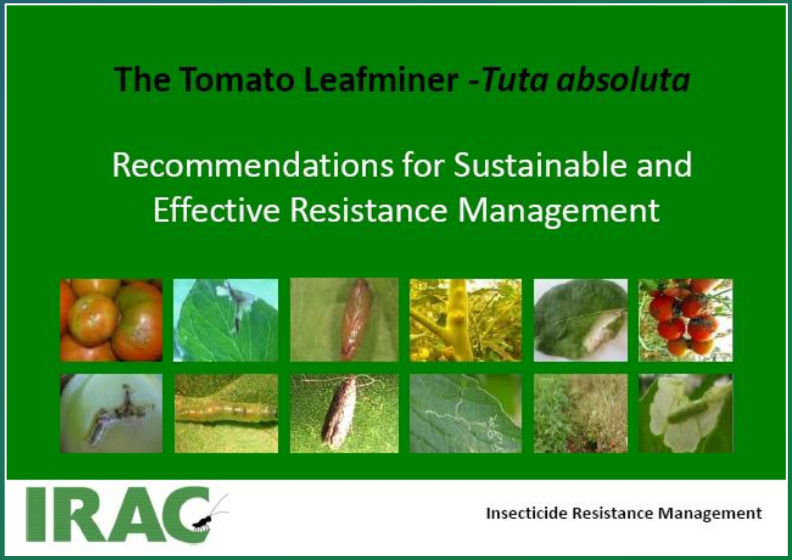


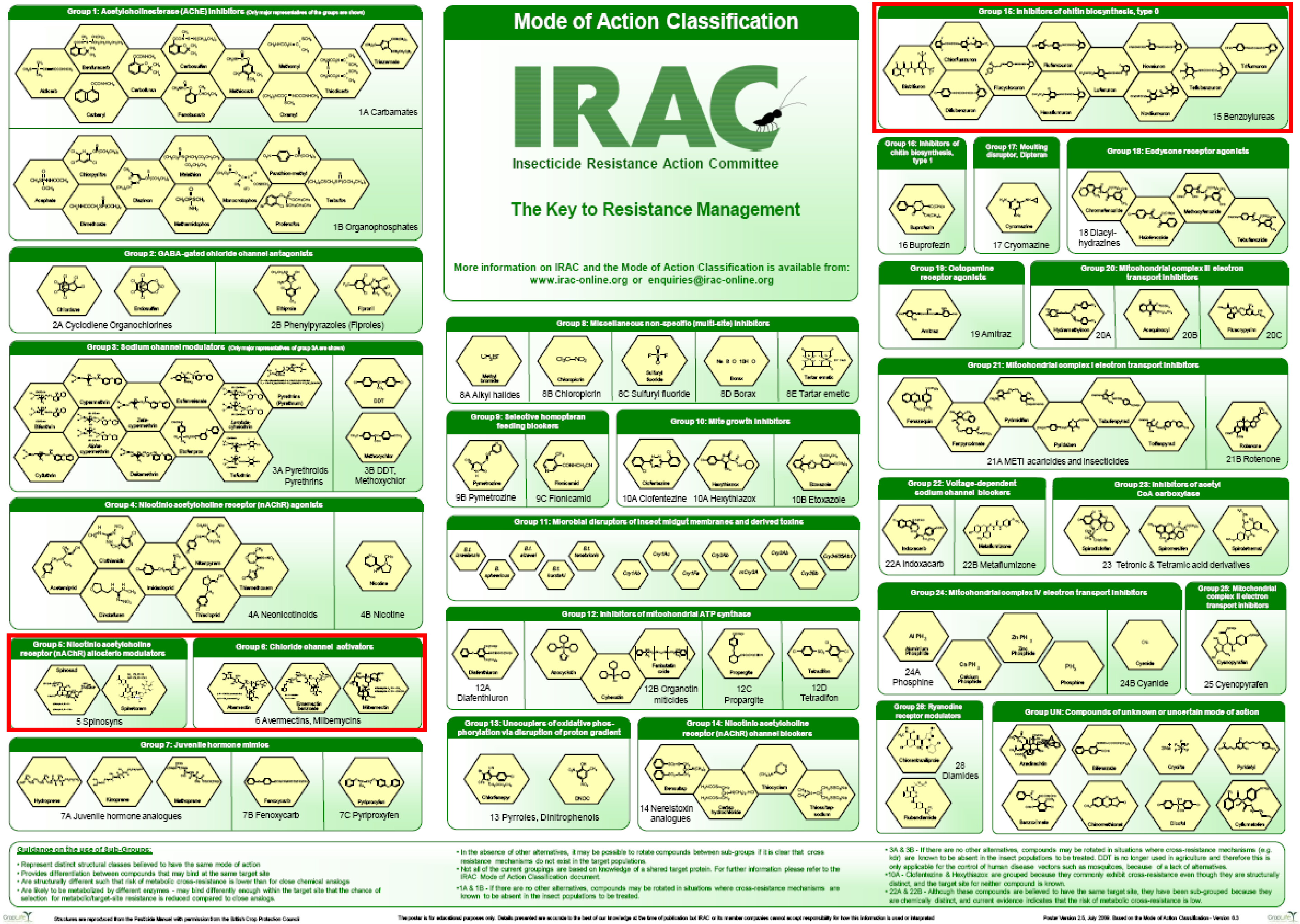
IRAC educational material

Insecticide Resistance Action Committee

Vector manual - 72 page Booklet – 4,000 copies

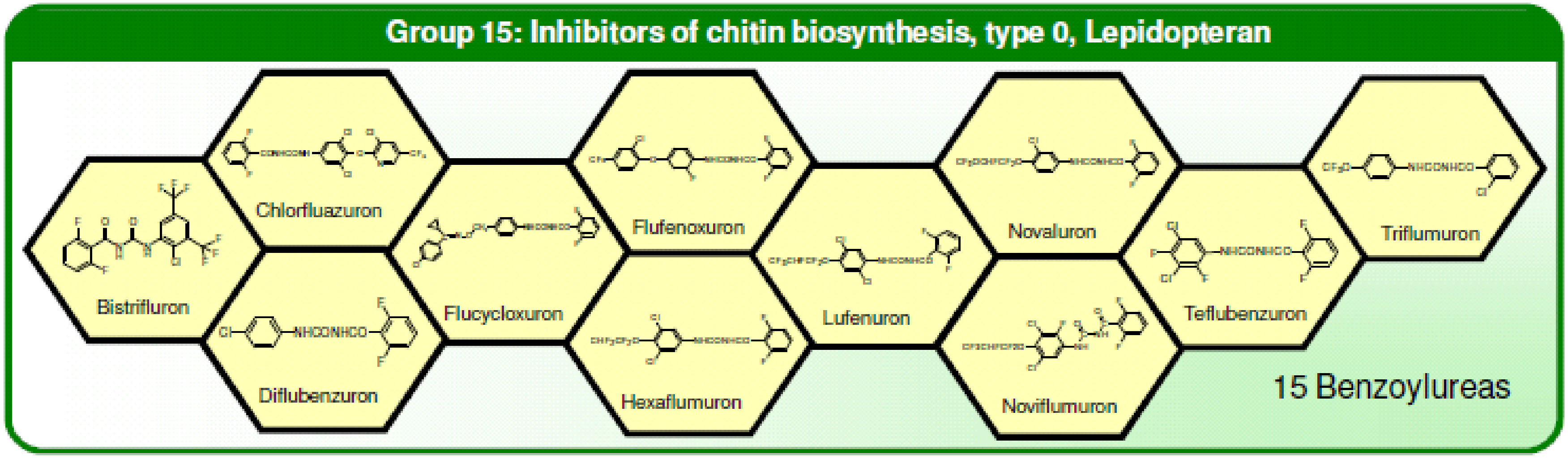


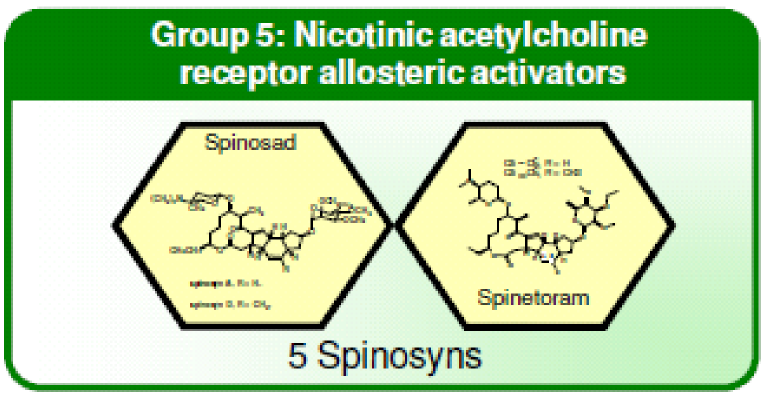


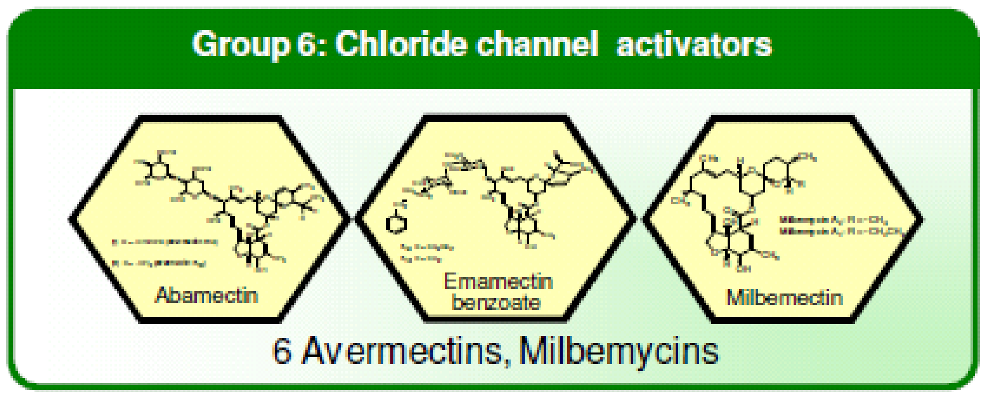

Mode of Action Classification
IRAC
Insecticide Resistance Action Committee
The Key to Resistance Management
More information on IRAC and the Mode of Action Classification is available from:
www.irac-online.org or enquiries@irac-online.org
Group 1: Acetylcholinesterase (AChE) inhibitors
1A Carbamates
1B Organophosphates
Group 2: GABA-gated chloride channel antagonists
2A Cyclodiene Organochlorines
2B Phenylpyrazoles (Fiproles)
Group 3: Sodium channel modulators
3A Pyrethroids Pyrethrins
3B DDT, Methoxychlor
Group 4: Nicotinic acetylcholine receptor (nAChR) agonists
4A Neonicotinoids
4B Nicotine
Group 5: Nicotinic acetylcholine receptor (nAChR) allosteric modulators
5 Spinosyns
Group 6: Chloride channel activators
6 Avermectins, Milbemycins
Group 7: Juvenile hormone mimics
7A Juvenile hormone analogues
7B Fenoxycarb
7C Pyriproxyfen
Group 8: Miscellaneous non-specific (multi-site) inhibitors
8A Alkyl halides
8B Chloropicrin
8C Sulfuryl fluoride
8D Borax
8E Tartar emetic
Group 9: Selective homopteran feeding blockers
9B Pymetrozine
9C Flonicamid
Group 10: Mite growth inhibitors
10A Clofentezine
10A Hexythiazox
10B Etoxazole
Group 11: Microbial disruptors of insect midgut membranes and derived toxins
Group 12: Inhibitors of mitochondrial ATP synthase
12A Diafenthiuron
12B Organotin miticides
12C Propargite
12D Tetradifon
Group 13: Uncouplers of oxidative phosphorylation via disruption of proton gradient
13 Pyrroles, Dinitrophenols
Group 14: Nicotinic acetylcholine receptor (nAChR) channel blockers
14 Nereistoxin analogues
Group 15: Inhibitors of chitin biosynthesis, type 0
15 Benzoylureas
Group 16: Inhibitors of chitin biosynthesis, type 1
16 Buprofezin
Group 17: Moulting disruptor, Dipteran
17 Cyromazine
Group 18: Ecdysone receptor agonists
18 Diacyl-hydrazines
Group 19: Octopamine receptor agonists
19 Amitraz
Group 20: Mitochondrial complex III electron transport inhibitors
20A
20B
20C
Group 21: Mitochondrial complex I electron transport inhibitors
21A METI acaricides and insecticides
21B Rotenone
Group 22: Voltage-dependent sodium channel blockers
22A Indoxacarb
22B Metaflumizone
Group 23: Inhibitors of acetyl CoA carboxylase
23 Tetronic & Tetramic acid derivatives
Group 24: Mitochondrial complex IV electron transport inhibitors
24A Phosphine
24B Cyanide
Group 25: Mitochondrial complex II electron transport inhibitors
25 Cyenopyrafen
Group 28: Ryanodine receptor modulators
28 Diamides
Group UN: Compounds of unknown or uncertain mode of action
Guidance on the use of Sub-Groups:

Insecticide Resistance Action Committee

Examples taken from the IRAC MoA poster







Modes of action

- **Disruption of Insect Neural Function**
  - Groups 1, 2, 3, 4, 5, 6, 9, 14, 19, 22, 28
- **Disruption of Developmental Processes**
  - Groups 7, 10, 15, 16, 17, 18, 23
- **Disruption of Respiratory Function**
  - Groups 12, 13, 20, 21, 24, 25
- **Disrupt Insect Gut function (Bt's)**
  - Group 11
- **Nonspecific / Uncertain / Unknown MoA**
  - Groups 8, UN

Those marked in red = 70% market share

Mode of action classification

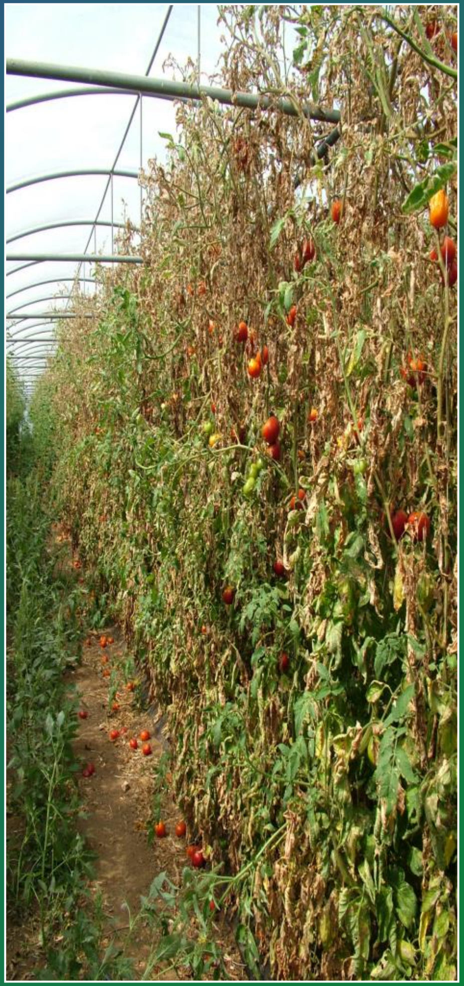
- Resistance development in insects is generally for the entire class of chemistry
- One important tool for Insecticide Resistance Management (IRM) is the rotation or alternation of insecticides with different resistance mechanisms
  - most common / simplest approach – different modes of action
- IRAC classifies insecticides by mode of action
  - MoA Scheme
  - Version 7.0
  - MoA labeling mandatory in some countries

Tuta absoluta, a serious pest

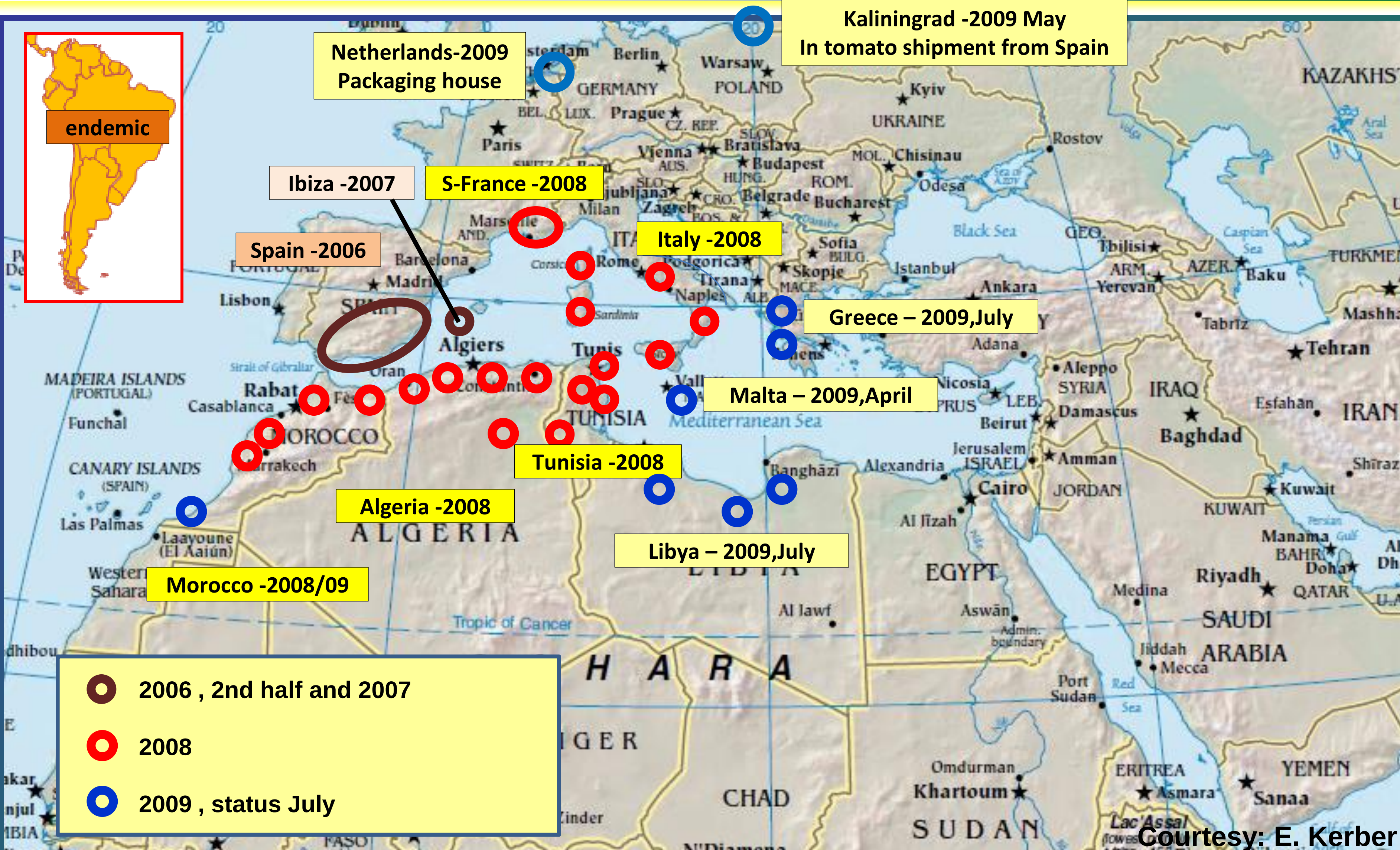
Tuta absoluta **is a lepidopteran leafminer and the crop damage is much higher compared with dipteran leafminers such as *Liriomyza*. *Liriomyza* may cause a yield decrease of 10-20 % , whereas *Tuta* will destroy the tomato plantations by 90–100 %!**

In South America, *Tuta* developed resistance against several Insecticide modes of action.

In Brazil, the whole tomato industry moved 1,500 km to the south years ago, because the *Tuta* problem was not managable any more by any control measures (incl. Insecticides, hygiene measures and biological control).



Tuta absoluta on the move



Tuta absoluta –
The Tomato Leafminer / Tomato Borer / Tomato Pinworm

Recommendations for Sustainable and Effective Resistance Management










IRAC

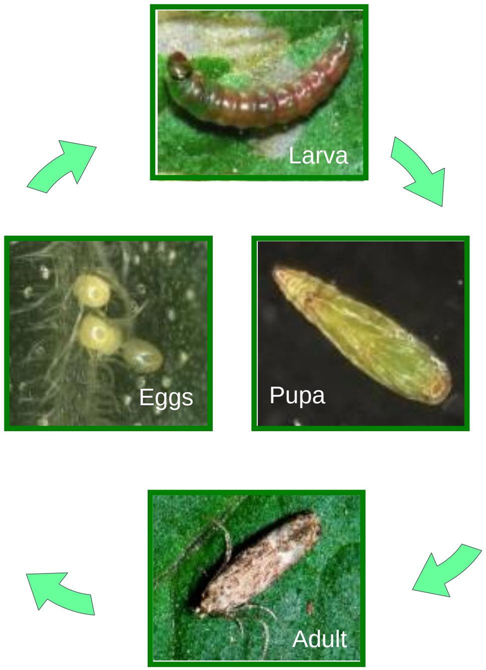
Insecticide Resistance Management

Damage and Symptoms

Infestation of tomato plants occurs throughout the entire crop cycle. Feeding damage is caused by all larval instars and throughout the whole plant. On leaves, the larvae feed on the mesophyll tissue, forming irregular leaf mines which may later become necrotic. Larvae can form extensive galleries in the stems which affect the development of the plants. Fruits are also attacked by the larvae, and the entryways are used by secondary pathogens, leading to fruit rot. The extent of infestation is partly dependent on the variety. Potential yield loss in tomatoes (quantity and quality) is significant and can reach up to 100% if the pest is not managed.

Insect Description and Life Cycle

Life Cycle



Larval Developmental Time (days) at different temperatures

14° C	76 days
20° C	40 days
27° C	24 days

Modified from Barrientos et al. (1998)

Tuta absoluta is a micro-lepidopteran insect. The adults are silvery brown, 5-7 mm long. The total life cycle is completed in an average of 24-38 days, with the exception of winter months, when the cycle could be extended to more than 60 days. The minimal temperature for biological activity is 4° C.

After copulation, females lay up to 300 individual small (0.35 mm long) cylindrical creamy yellow eggs, which are often found alongside the rachis. Freshly hatched larvae are light yellow or green and only 0.5 mm in length. As they mature, larvae develop a darker green color and a characteristic dark band posterior to the head capsule. Four larval instars develop. Larvae do not enter diapause when food is available. Pupation may take place in the soil, on the leaf surface, within mines or in packaging material. A cocoon is built if pupation does not take place in the soil. 10-12 generations can be produced each year. *Tuta absoluta* can overwinter as eggs, pupae or adults depending on environmental conditions. Under open-field conditions *Tuta* is usually found up till 1000 m above sea level.

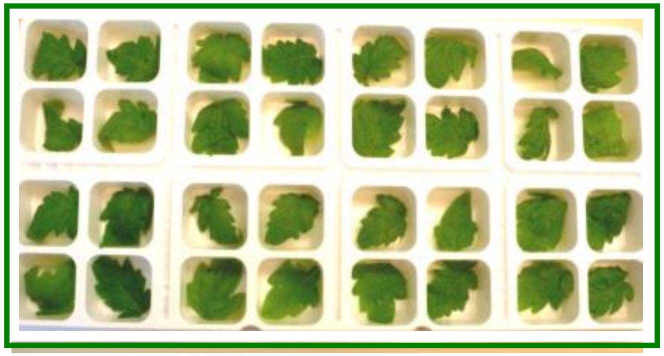
High Risk of Insecticide Resistance Development in *Tuta absoluta*

Risk for Insecticide Resistance Development: Pests like *Tuta absoluta*, with high reproduction capacity and short generation cycle, are at higher risk of developing resistance to insecticides. This risk increases significantly when management of the pest relies exclusively on chemical control with a limited number of effective insecticides available. This situation usually leads to an increase in the frequency of use and thus, increased selection pressure for resistance. In fact, field populations of *T. absoluta* resistant to a range of mode of action groups are already known from Latin American countries, where it has been a key pest of tomato for decades.

IRAC´s aim is to facilitate networking between the industry and the scientific / advisory community, to promote resistance monitoring , and to advance the development and use of resistance management strategies, in order to ensure a longer effective life of the available insecticide portfolio, including new product classes not yet widely used.

Evaluation of Insecticide Susceptibility – IRAC Method No. 22

Evaluation of Insecticide Susceptibility: IRAC has a standard "leaf-dip" larval bioassay method to assess susceptibility of field populations to insecticides. Please, refer to IRAC method No. 022 on the IRAC Website (http://www.irac-online.org/teams/methods).



link (http://www.youtube.com/watch?v=BoF6h9szXQc)

Insecticide Resistance Management (IRM): The recommendations for sustaining the effectiveness of available insecticides is centred on integration of as many pest management tools as possible, use of insecticides only when needed and based on established thresholds, and rotation of effective insecticides with different modes of action (MoA).

Insecticide MoA groups for the control of *Tuta absoluta*

Group	Mode of Action	Chemical Class	Common Names (e.g.)
1B	Acetylcholinesterase (AChE) inhibitors	Organophosphates	Chlorpyrifos, Methamidophos
3A	Sodium channel modulators	Pyrethroids	Bifenthrin, Cyfluthrin, *beta*-Cyfluthrin, *gamma*-Cyhalothrin, *lambda*-Cyhalothrin, Cypermethrin, *alpha*-Cypermethrin, *beta*-Cypermethrin, *zeta*-Cypermethrin, Delthamethrin, Esfenvalerate, Etofenprox, *tau*-Fluvalinate, Fenpropathrin, Permethrin
5	Nicotinic acetylcholine receptor (nAChR) allosteric modulators	Spinosyns	Spinetoram, Spinosad
6	Chloride channel activators	Avermectins, Milbemycins	Abamectin, Emamectin-benzoate
11	Microbial disruptors of insect midgut membranes and derived toxins	-	*Bacillus thuringiensis aizawai, Bacillus thuringiensis kurstaki*
13	Uncouplers of oxidative phosphorylation via disruption of the proton gradient	Pyrroles	Chlorfenapyr
14	Nicotinic acetylcholine receptor (nAChR) channel blockers	Nereistoxin analogues	e.g. Cartap
15	Inhibitors of chitin biosynthesis, type 0	Benzoylureas	Diflubenzuron, Flufenoxuron Lufenuron, Novaluron,Noviflumuron, Teflubenzuron, Triflumuron,
18	Ecdysone receptor agonists	Diacylhydrazines	Chromafenozide, Methoxyfenozide, Tebufenozide
22A	Voltage-dependent sodium channel blockers	Oxadiazine	Indoxacarb
22B	Voltage-dependent sodium channel blockers	Semi-carbazone	Metaflumizone
28	Ryanodine receptor modulators	Diamides	Chlorantraniliprole, Flubendiamide
UN	Compounds of unknown or uncertain MoA	Tetranortriterpenoid	Azadirachtin

Insecticide resistance in *Tuta absoluta*

- 12 different insecticide modes of action are available
  - 7 neuronal targets, 3 development targets, 1 each respiration & gut
- For all chemical classes resistance in lepidopteran pests is known
- For at least 6 of them resistance in *Tuta* is already described
- All resistance reports are based on populations from South America
- A concerted survey on the resistance status of EU populations is missing yet (local activities, e.g. Spain)
- In some countries farmer´s control practices rely on a few compounds
- Several modes of action available are suitable for resistance management purposes due to full susceptibility of *Tuta absoluta*

Tuta absoluta is a high risk pest regarding resistance development

- Resistance = Selection
- Selection = Repeated treatment with same MoA

- Factors contributing to an increased selection:

➔ Short life-cycle (many generations per year)

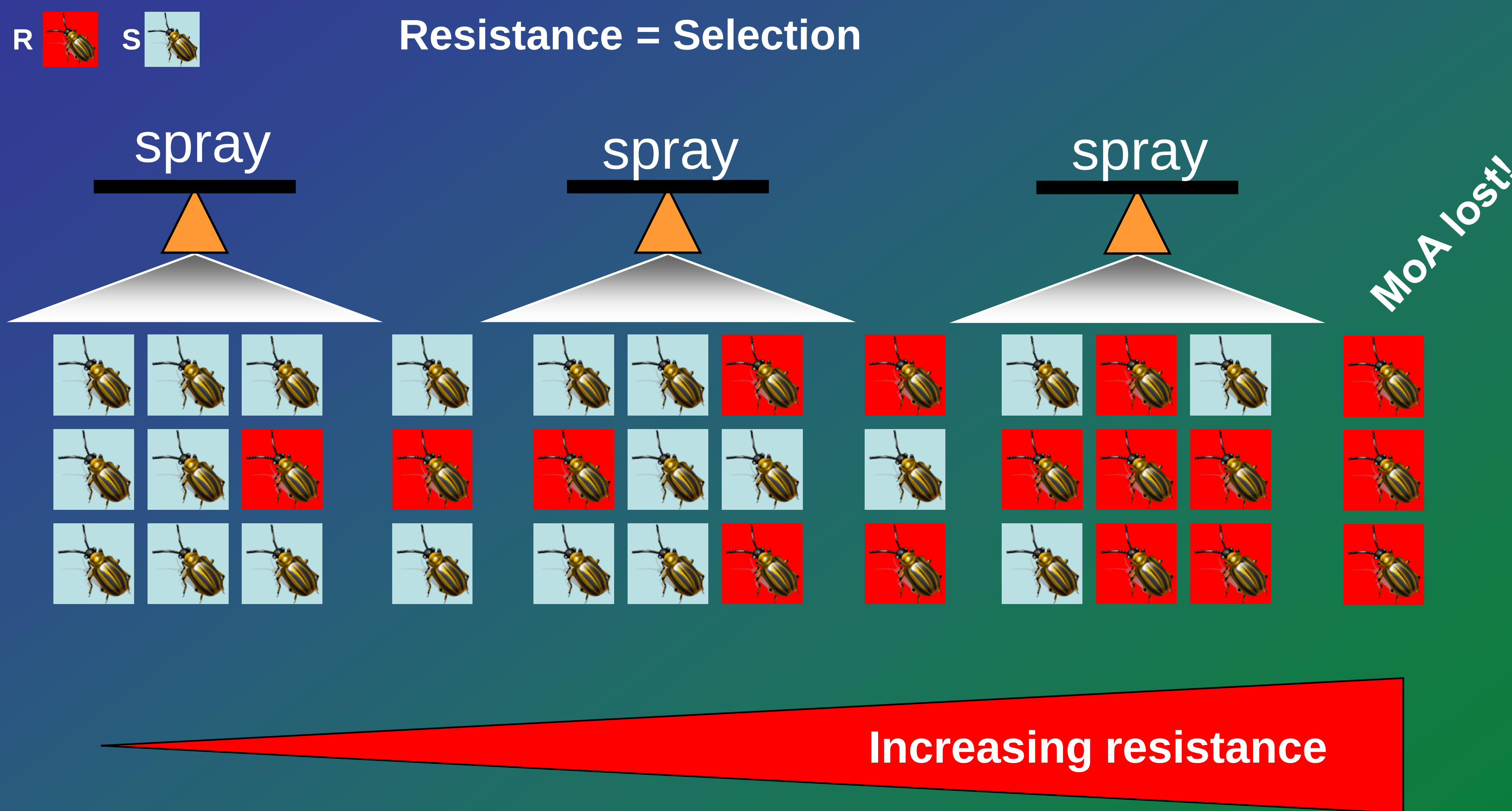
➔ High fecundity

➔ High spraying frequency

➔ Decreasing recommended rates

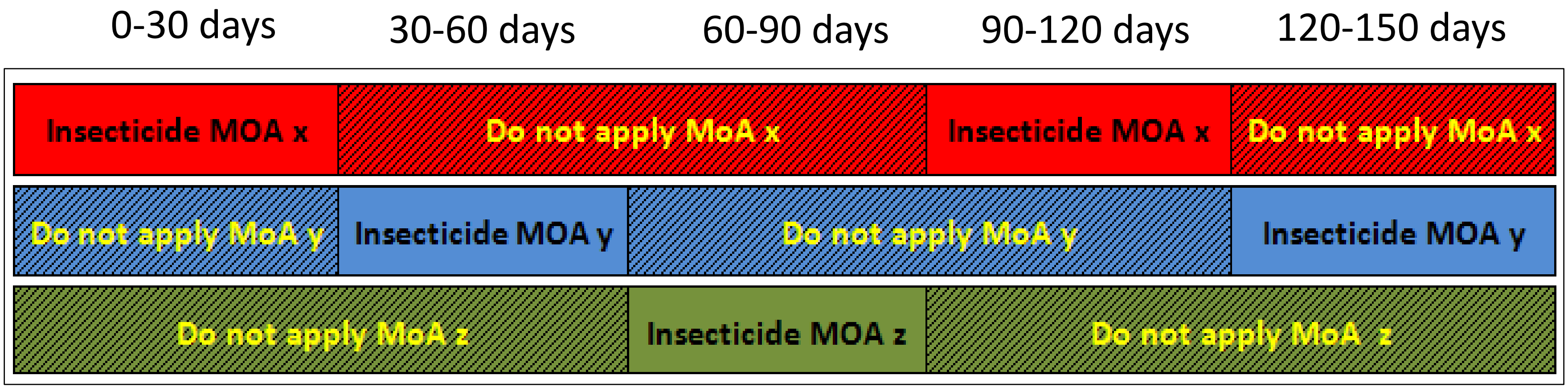
➔ Isolated populations (greenhouses)

Resistance development



Mode of Action Window Approach

<u>Example:</u> Insecticide Mode of Action (MoA)
“Window” Approach – 150 day cropping cycle



Sequence of Mode of Action (MoA) Windows throughout the season

Notes:

- **Within a “window” (MoA x, y, or z in the diagram above) more than one application of the same MoA or different MoA’s can be applied if necessary and depending on label advice, as long as these MoA’s are not re-applied for 60 days as indicated above.**
- **Following the “window rotation scheme”, example above, use as many effective MoA groups as locally registered/available and always follow product labels for specific directions of use.**
- **For a comprehensive list of existing insecticides classified by MoA group visit the IRAC website (http://www.irac-online.org/teams/mode-of-action).**

The Tomato Leafminer, *Tuta absoluta*

Recommendations for Sustainable and Effective Resistance Management

Insecticide Resistance Action Committee

www.irac-online.org

Tuta absoluta, an Aggressive Pest with High Risk of Insecticide Resistance Development

Tuta absoluta **(Meyrick) (Lepidoptera: Gelechiidae)** is a pest of great economic importance in a number of countries. Its primary host is tomato, although potato, aubergine, common bean, and various wild solanaceous plants are also suitable hosts. *T. absoluta* is characterized by high reproduction potential. Each female may lay up to 300 eggs and 10-12 generations can be produced each year. In tomato, it attacks all plant parts and crop developmental stages, although the larvae prefer apical buds, tender new leaflets, flowers, and green fruits and can cause up to 100% crop destruction.

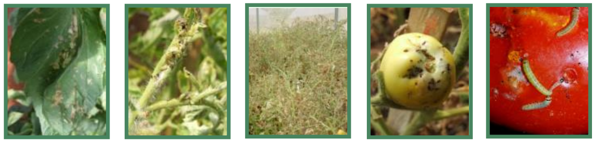
This pest is crossing borders and devastating tomato production in protected and open fields. Originally from Latin America, *T. absoluta* has recently spread to Europe, North Africa and the Middle East. Given its aggressive nature and crop destruction potential, it has quickly become a key pest of concern in these new geographies.

Risk for Insecticide Resistance Development: Pests like *Tuta absoluta*, with high reproduction capacity and short generation cycle, are at higher risk of developing resistance to insecticides. This risk increases significantly when management of the pest relies exclusively on chemical control with a limited number of effective insecticides available. This situation usually leads to increase in the frequency of use and thus, increase in the selection pressure. In fact, field populations of *T. absoluta* resistant to a range of mode of action groups are already known from L. America countries, where this has been a key pest for decades.

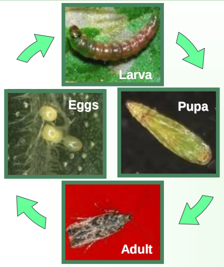
Local Evaluation of Insecticidal Efficacy: T. *absoluta* populations in Europe, Middle East and N. Africa were most likely imported from L. America and thus, may already express high level of resistance to one or multiple mode of action groups. It is therefore essential to first evaluate the efficacy of each insecticide for the control of *Tuta absoluta* in each geography before specific recommendations are made for their use within IPM (Integrated Pest Management) and IRM (Insecticide Resistance Management) programs.

Damage and Symptoms

Infestation of tomato plants occurs throughout the entire crop cycle. Feeding damage is caused by all larval instars and throughout the whole plant. On leaves, the larvae feed on the mesophyll tissue, forming irregular leaf mines which may later become necrotic. Larvae can form extensive galleries in the stems which alter the general development of the plants. Fruits are also attacked by the larvae, forming galleries which represent open areas for invasion by secondary pathogens, leading to fruit rot. Potential yield loss (quantity & quality) is significant and if the pest is not managed, can reach 100% in tomatoes.



Insect Description and Life Cycle



Modified from Barrientos et al. (1998)

Larval Developmental Time at Different Temperatures	
14°C	76 days
20°C	40 das
27°C	24 days

Tuta absoluta is a micro lepidopteran insect. The adults are silvery brown, 5-7 mm long. The total life cycle is completed in an average of 24-40 days, with the exception of winter months, when the cycle could be extended to more than 60 days. The minimal temperature for biological activity is 9°C.

After copulation, females lay individual small (0.35 mm long) cylindrical creamy yellow eggs. Recently hatched larvae are light yellow or green and only 0.5 mm in length. As they mature, larvae develop a darker green color and a characteristic dark band posterior to the head capsule. Four larval instars develop. Larvae do not enter diapause when food is available. Pupation may take place in the soil, on the leaf surface or within mines. *Tuta absoluta* can overwinter as eggs, pupae or adults depending on environmental conditions.

Key Management Strategy Integration of Control Measures

The basis for an effective and sustainable management of *Tuta absoluta* is the integration of preventive sanitary measures with effective non-chemical and chemical tools.

Key Management Tactics

- Use pest-free transplants
- Prior to transplanting, install yellow sticky traps
- Monitor pest using delta pheromone indicator traps
- Between planting cycles, cultivate the soil and cover with plastic mulch or perform solarisation
- Allow a minimum of 6 weeks from crop destruction to next crop planting
- Seal greenhouse structure with high quality nets (screen size ≤ 9x6 cm^2)
- Inspect the crop regularly to detect the first signs of damage
- For massive trapping, use water + oil traps (20-40 traps/ ha)
- Constantly, remove and destroy attacked plant parts and all plant refuse
- Control weeds to prevent multiplication in alternative host
- Establish populations of effective biological control agents (*e.g. Nesidiocoris tenuis*)
- Use locally established thresholds to trigger insecticide applications
- Select insecticides based on known local effectiveness and selectivity
- Rotate insecticides by mode of action group (MoA), using a window approach
- Use only insecticides registered for control of *T. absoluta*
- Always follow the directions for use on the label of each product

Insecticide Resistance Management

Resistance status in L. America vs. Europe, N. Africa, and Middle East: In L. America, high level and widespread resistance is known to exist in field populations of *T. absoluta* mainly to organophosphates (MoA group 1B), synthetic pyrethroids (MoA group 3), and benzoylureas (MoA group 15). However, resistance has also developed to newer classes of insecticides. Because it is likely that resistant populations from L. America may have spread to Europe, N. Africa and the Middle East, it is urgent that regional technical experts understand the susceptibility profile of *T. absoluta* field populations to the available insecticides so that local recommendations can be made.

Evaluation of Insecticide Susceptibility: IRAC has a standard "leaf-dip" larval bioassay method to assess susceptibility of field populations to insecticides. Please, refer to IRAC method No. 022 on the IRAC Website (http://www.irac-online.org/teams/methods).

Insecticide Resistance Management (IRM): The recommendations for sustaining the effectiveness of available insecticides is centred on integration of as many pest management tools as possible, use of insecticides only when needed and based on established thresholds, and rotation of effective insecticides with different modes of action.

Mode of Action (MoA) Window Approach:

- The basic rule for adequate rotation of insecticides by MoA is to avoid treating consecutive generations of the target pest with insecticides in the same MoA group, by using a scheme of " MoA treatment windows".
- A treatment window is here defined as a period of 30 consecutive days, based on the minimum duration of single generation of *T. absoluta*.
- Multiple applications of the same MoA may be possible within a particular window (follow label for maximum number of applications within a window and per crop cycle).
- After a first MoA window of 30 days is completed and if additional insecticide applications are needed based on established thresholds, a different and effective MoA should be selected for use in the next 30 days (second MoA window). Similarly, a third MoA window should use yet another MoA for the subsequent 30 days etc.
- The proposed scheme seeks to minimize the selection of resistance to any given MoA group by ensuring that the same insecticide MoA group will not be re-applied for at least 60 days after a window closes, a wise measure given the potential of a longer life cycle based on temperature fluctuations throughout the growing season.
- This scheme requires a minimum of three effective insecticide MoA groups but ideally more MoA groups should be included, if locally registered and effective against *T. absoluta*.

Example: Insecticide Mode of Action (MoA) "Window" Approach – 150 day cropping cycle

0-30 days	30-60 days	60-90 days	90-120 days	120-150 days
Insecticide MOA x	Do not apply MoA x	Do not apply MoA x	Insecticide MOA x	Do not apply MoA x
Do not apply MoA y	Insecticide MOA y	Do not apply MoA y	Do not apply MoA y	Insecticide MOA y
Do not apply MoA z	Do not apply MoA z	Insecticide MOA z	Do not apply MoA z	Do not apply MoA z

Sequence of Mode of Action (MoA) Windows throughout the season →

Note: For a comprehensive list of existing insecticides classified by MoA group visit the IRAC website (http://www.irac-online.org/teams/mode-of-action). In the "window rotation scheme", use as many effective MoA groups as locally registered/available and always follow product labels for specific directions of use.

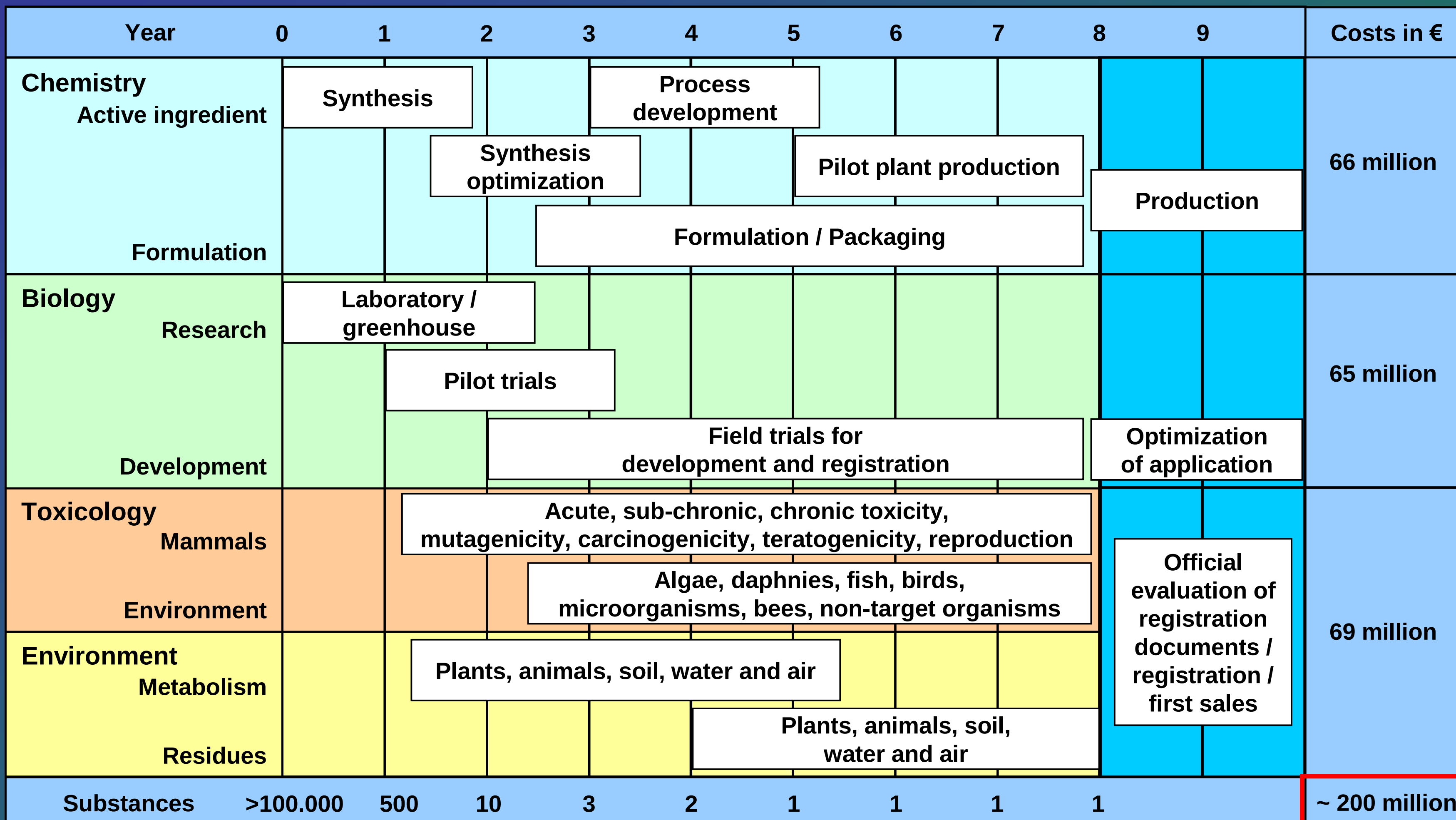
Designed & produced by the IRAC Lepidoptera Working Group. Also refer to IRAC Spain brochure "Prevención de resistencias en *Tuta absoluta* (April 2009) http://www.irac-online.org/irac_spain

May 2010, Poster Version 1.0 For further information visit the IRAC website: www.irac-online.org
Photographs courtesy: Bayer CropScience, DuPont Crop Protection & ● M Shepard, GR.Carner, & PAC Ooi, Insects & their Natural Enemies Associated with Vegetables & Soybean in SE Asia, Bugwood.org

Why effective IRM is essential

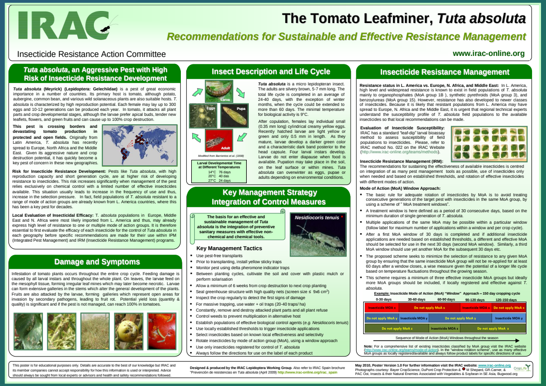
- Sustaining effective commercial life of current insecticides requires intelligent use of presently available compounds
  - Insecticide Resistance Management (IRM)
- For any crop / pest situation, effective IRM requires the availability of a broad range of modes of action and alternative control measures
- IRM is made much more difficult by loss of modes of action through resistance development caused by misuse or overuse of insecticides
- **We cannot always rely on having a steady stream of new modes of action to circumvent resistance problems…….**

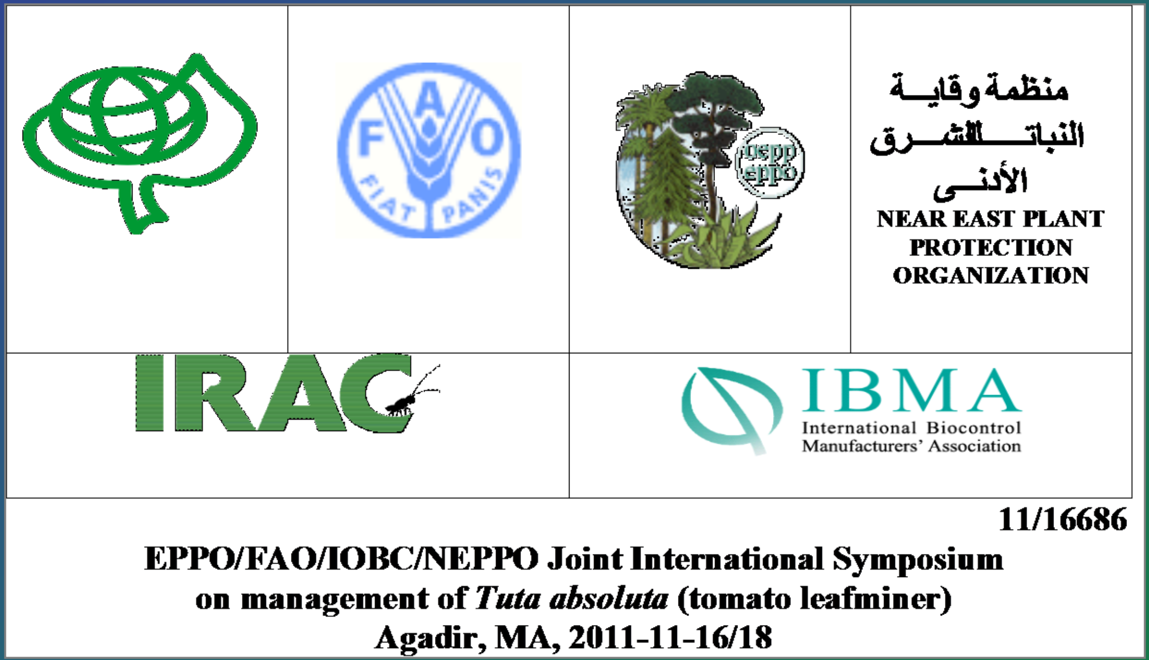
Development of an insecticide

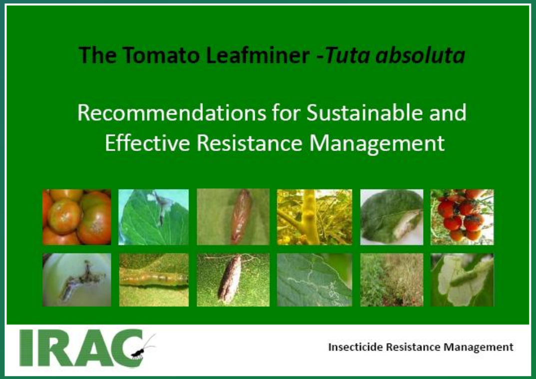


IRAC and *Tuta absoluta*

- ❑ Poster (>200 downloads!)
- ❑ Bioassay method
- ❑ Video (YouTube)
- ❑ Brochure







Thanks for your attention