ERASMUS + BLENDED
INTENSIVE PROGRAMME

AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS

VISEU, PORTUGAL, 16 - 22 JUNE 2024

Politécnico de Viseu
eunice EUROPEAN UNIVERSITY

Funded by
the European Union

Food webs in biological pest control

Lucia Zappalà

Dept. of Agriculture, Food and Environment (Di3A)
University of Catania (Italy)

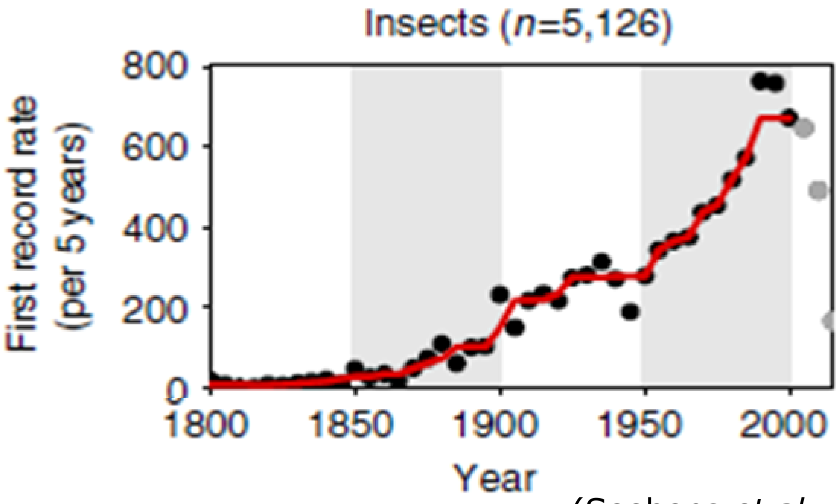
27 May 2024

Challenges of modern agriculture

Food and Agriculture Organization of the United Nations | SUSTAINABLE DEVELOPMENT GOALS

Exotic species invasion

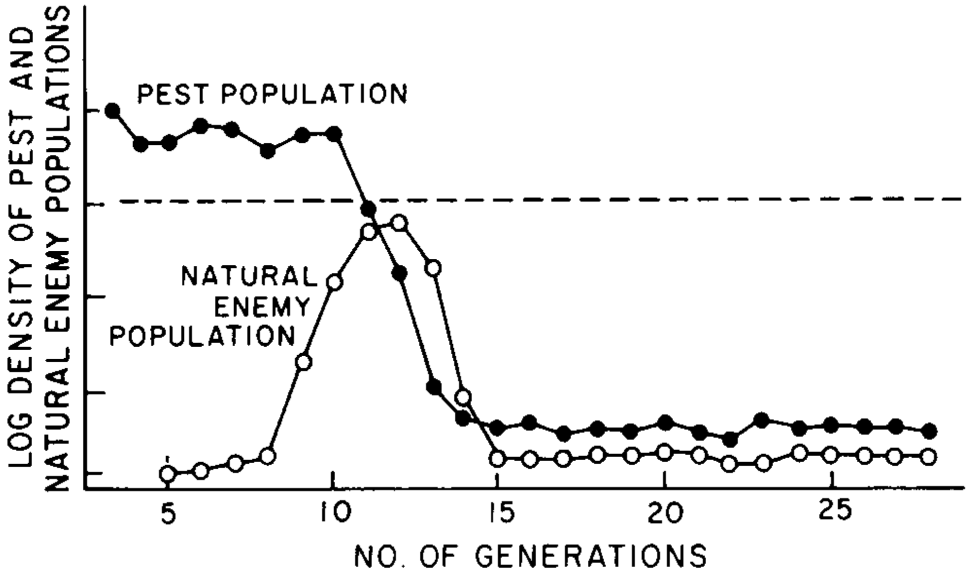
- **Increasing trend**
- Global **ecological and economical challenge** because invasive organisms may alter species communities and ecosystem services provided



(Seebens *et al.*, 2017)

Exotic species invasion

- Higher **competitiveness** compared to native species
- Favorable climatic conditions (global warming)
- No effect of diseases and natural enemies (**enemy release hypothesis**)
  - The number of natural enemy species is reduced (*apparent enemy reduction*)
  - The effect of these enemies on the invader is lower (*realized enemy release*)

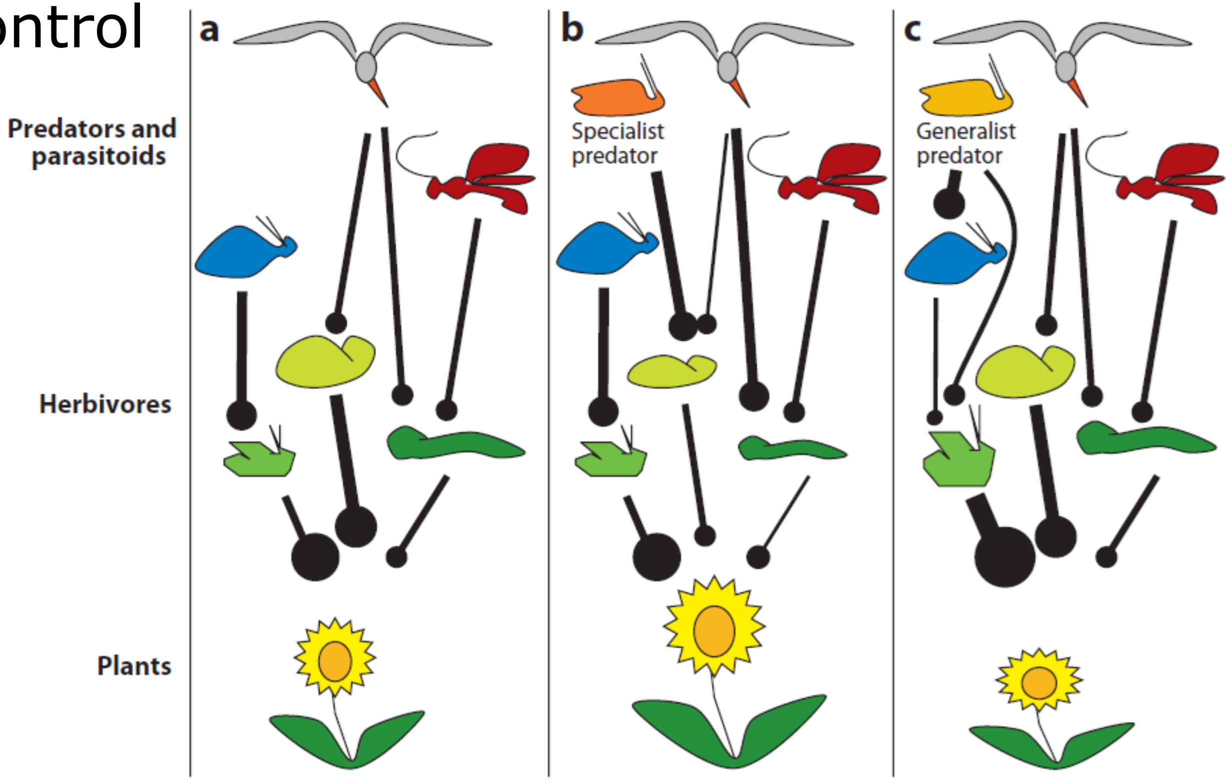


Exotic species invasion

- The **enemy release hypothesis** essentially forms the theoretical rationale for classical biological control
- Knowledge of **biotic limiting factors** in the introduced range is crucial in research on biological invasions and in the implementation of any effective control strategy

Natural enemy diversity and biocontrol

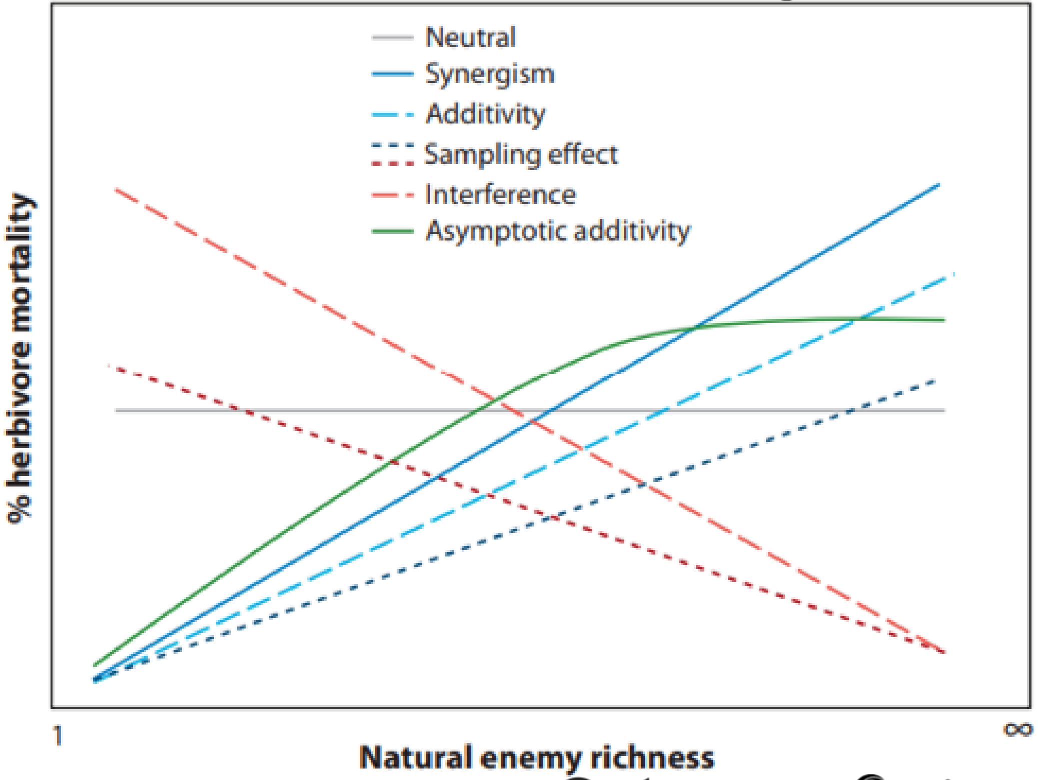
- Biocontrol traditionally mainly focused on specific natural enemies for each pest control
- However, pest-enemy interactions are often embedded in rich communities of multiple interacting pests and natural enemies with effects on the efficacy of biological pest control



(Letourneau *et al.*, 2009)

Natural enemy diversity and biocontrol

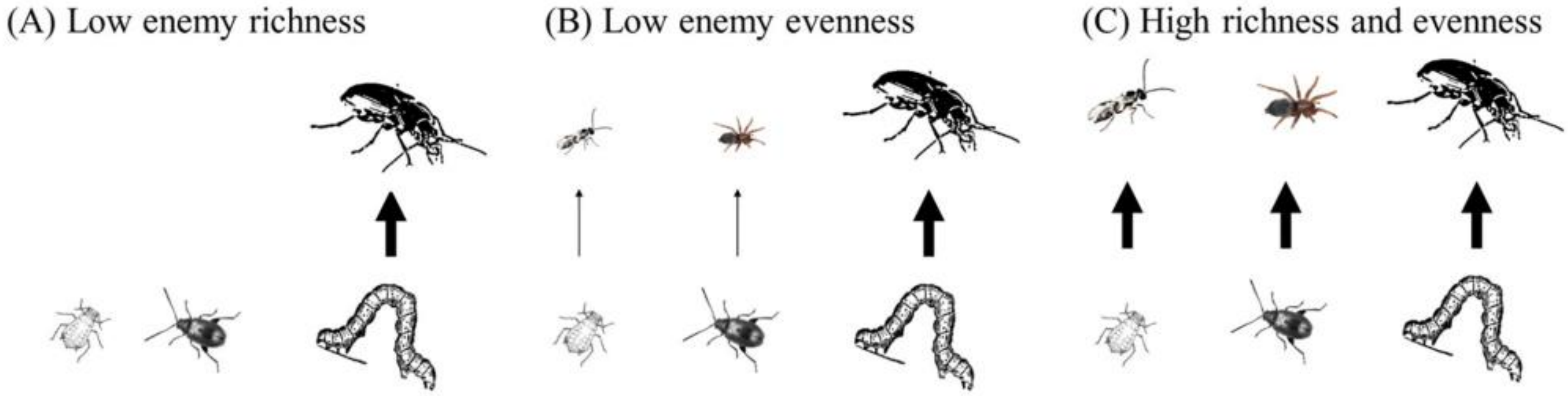
- Effects of natural enemy diversity on herbivore populations depend on whether the interaction among natural enemy species is
  - Positive
  - Neutral
  - Antagonistic



(Letourneau *et al.*, 2009)

Natural enemy diversity and biocontrol

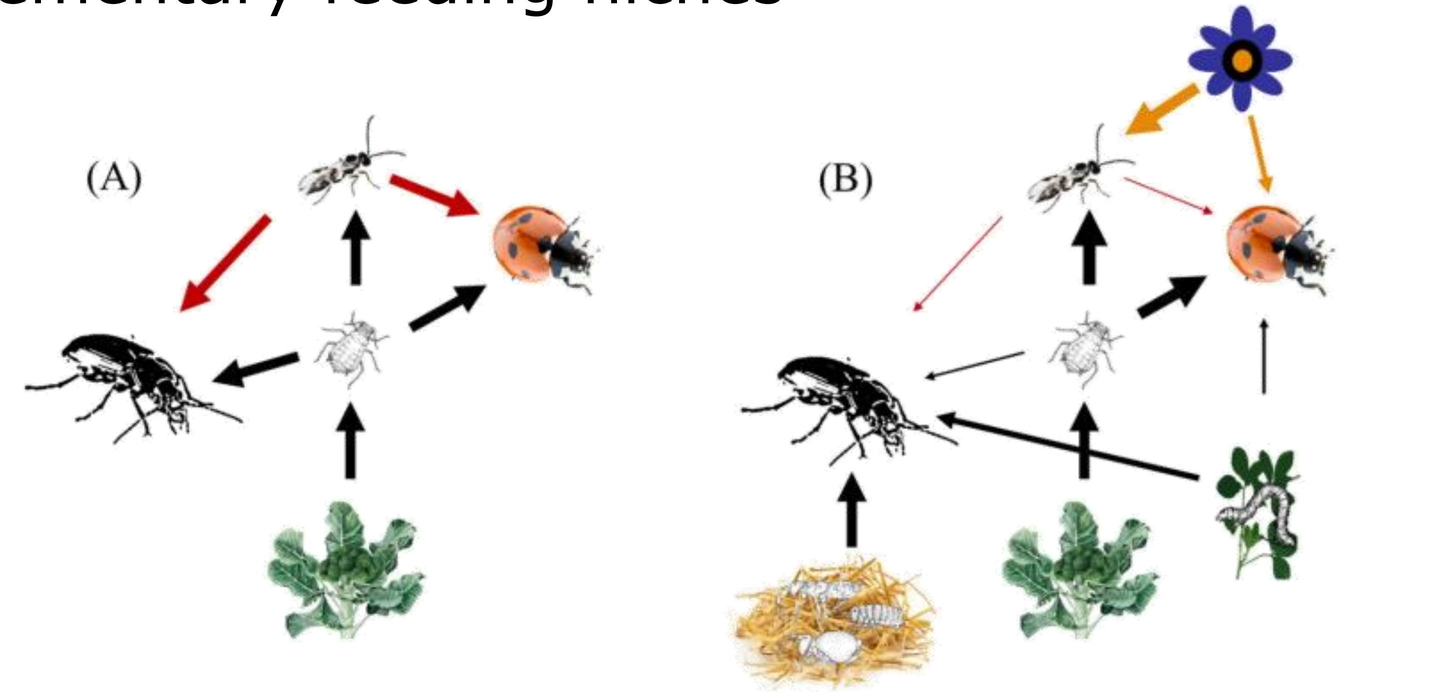
- Natural enemy biodiversity
  - number of species attacking pests (species richness)
  - their relative abundances (species evenness)
- Only natural enemy communities with high richness and evenness exert strong suppression on all pests



(Snyder, 2019)

Natural enemy diversity and biocontrol

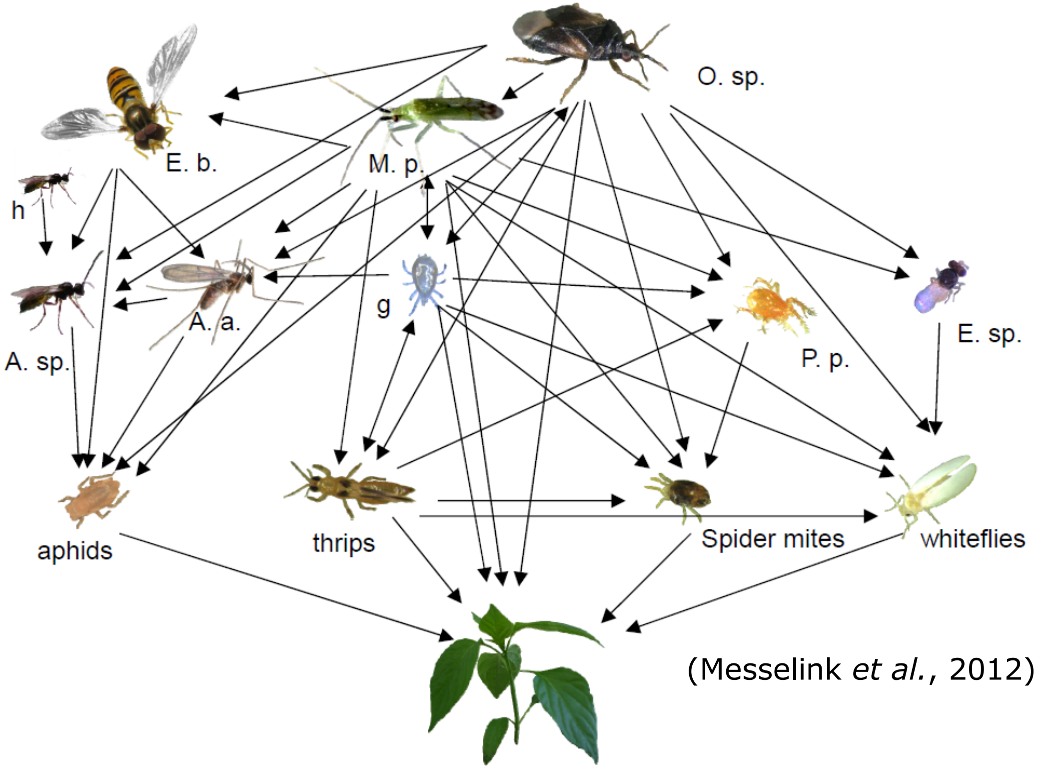
- greater enemy biodiversity might lead to stronger pest suppression when natural enemies occupy different, complementary feeding niches



(Snyder, 2019)

Food webs

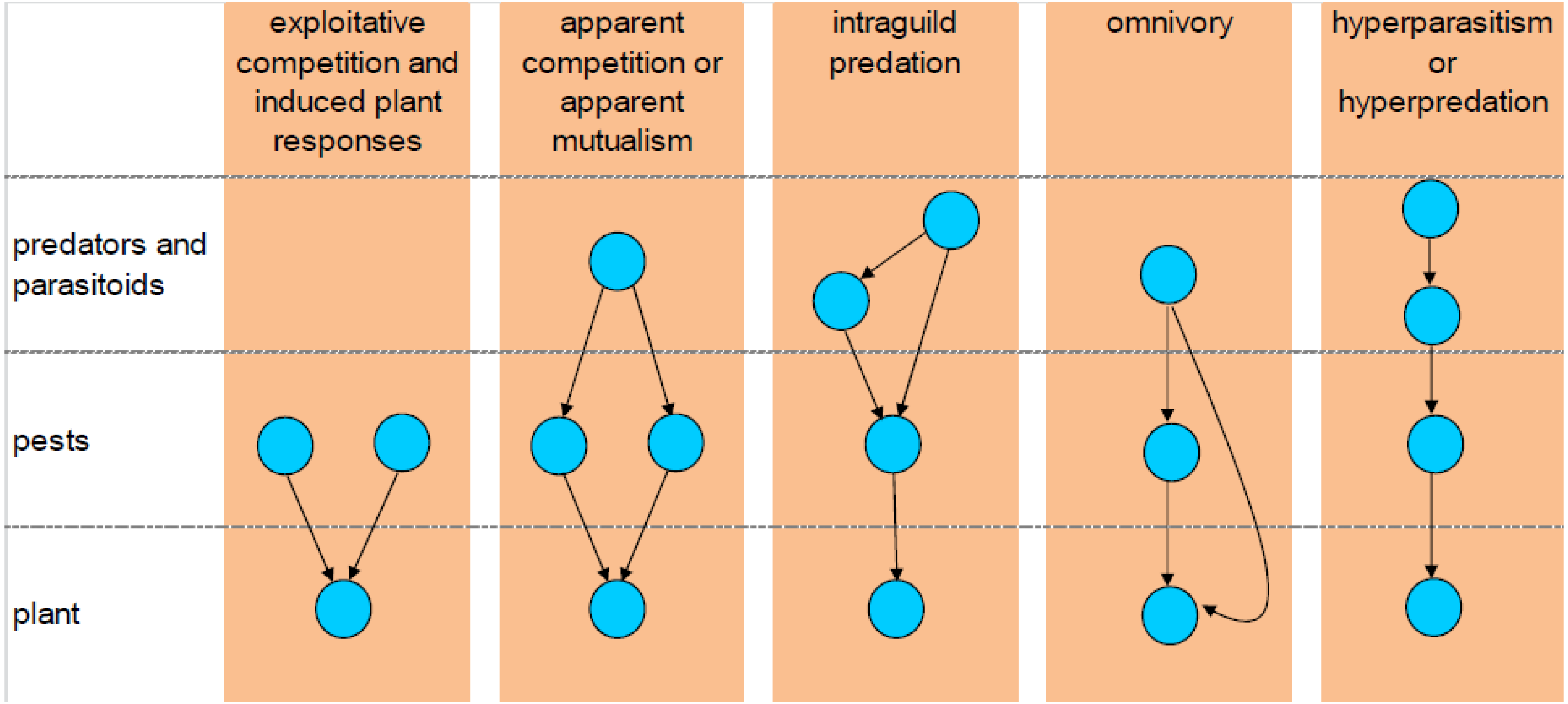
- A **network of food chains** interconnected at various trophic levels so as to form a number of feeding connections amongst different organisms of a biotic community
- Arthropod food webs are often complex and species are rarely arranged in linear food chains (plants, herbivores and predators)
  - **Omnivory and indirect interactions** occur in these food webs



(Messelink *et al.*, 2012)

Food webs

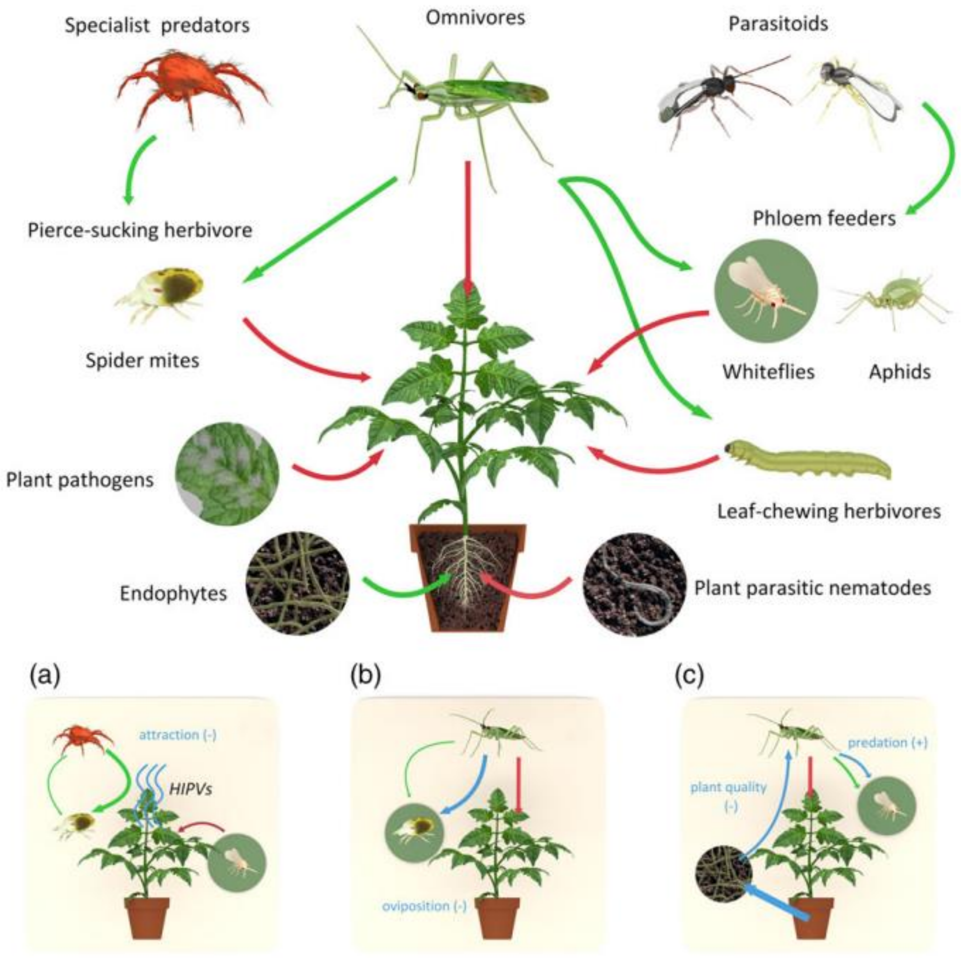
- **Consumption** (i.e. herbivory, predation and parasitism) and **competition** are considered the two most important interactions determining the **structure of communities** (Chase et al., 2002).



(Messelink *et al.*, 2012)

Food web

- **Exploitative competition**
  - two pest species compete for the same plant, but also affect each other's densities through **induced plant defences**
  - Induced plant resistance against insects consists of **direct defences**, such as the production of toxins and feeding deterrents that reduce survival, fecundity or developmental rate, and **indirect defences** such as the production of plant volatiles that attract natural enemies



(Pappas *et al.*, 2017)

Food webs

- **Exploitative competition**
  - Several studies documented indirect interactions between herbivores through induced changes in plant quality

Bulletin of Entomological Research

cambridge.org/ber

Research Paper

CrossMark

Previous herbivory modulates aphid population growth and plant defense responses in a non-model plant, *Carthamus tinctorius* (Asteraceae)

Motahareh Amiri Domari, Seyed Mozaffar Mansouri and Mohsen Mehrparvar

100 YEARS Journal of Ecology British Ecological Society

Journal of Ecology 2013, **101**, 410–417 doi: 10.1111/1365-2745.12041

Herbivore-induced plant volatiles provide associational resistance against an ovipositing herbivore

Ali Zakir[1]*, Medhat M. Sadek[1,2], Marie Bengtsson[1], Bill S. Hansson[1,3], Peter Witzgall[1] and Peter Anderson[1]

SEB SOCIETY FOR EXPERIMENTAL BIOLOGY

Journal of Experimental Botany, Vol. 72, No. 22 pp. 7909–7926, 2021
https://doi.org/10.1093/jxb/erab370 Advance Access Publication 21 September 2021
This paper is available online free of all access charges (see https://academic.oup.com/jxb/pages/openaccess for further details)

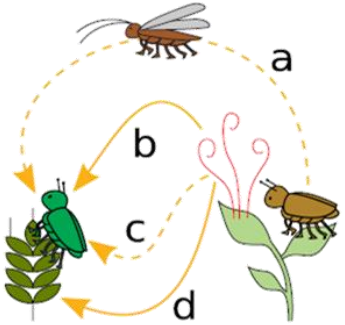
Journal of Experimental Botany

RESEARCH PAPER

Root infection by the nematode *Meloidogyne incognita* modulates leaf antiherbivore defenses and plant resistance to *Spodoptera exigua*

Crispus M. Mbaluto[1,2,*], Fredd Vergara[1], Nicole M. van Dam[1,2] and Ainhoa Martínez-Medina[1,2,3,*]

[1] Molecular Interaction Ecology, German Center for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig; PuschStraße 4, 04103, Leipzig, Germany
[2] Institute of Biodiversity, Friedrich-Schiller-Universität-Jena; DornburgerStraße 159, 07743 Jena, Germany
[3] Plant-Microorganism Interaction, Institute of Natural Resources and Agrobiology of Salamanca (IRNASA-CSIC), Cordel de Merinas, 40, 37008, Salamanca, Spain



Oecologia (2022) 198:443–456
https://doi.org/10.1007/s00442-021-05097-1

COMMUNITY ECOLOGY – ORIGINAL RESEARCH

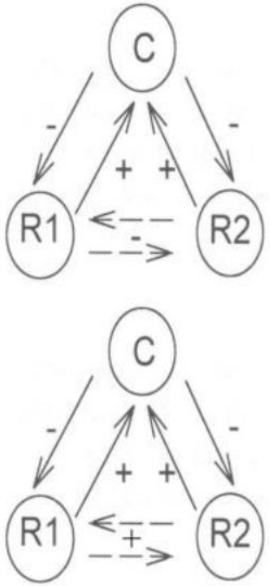
Check for updates

Herbivore-induced plant volatiles, not natural enemies, mediate a positive indirect interaction between insect herbivores

E. Frago[1] · R. Gols[2] · R. Schweiger[3] · C. Müller[3] · M. Dicke[2] · H. C. J. Godfray[4]

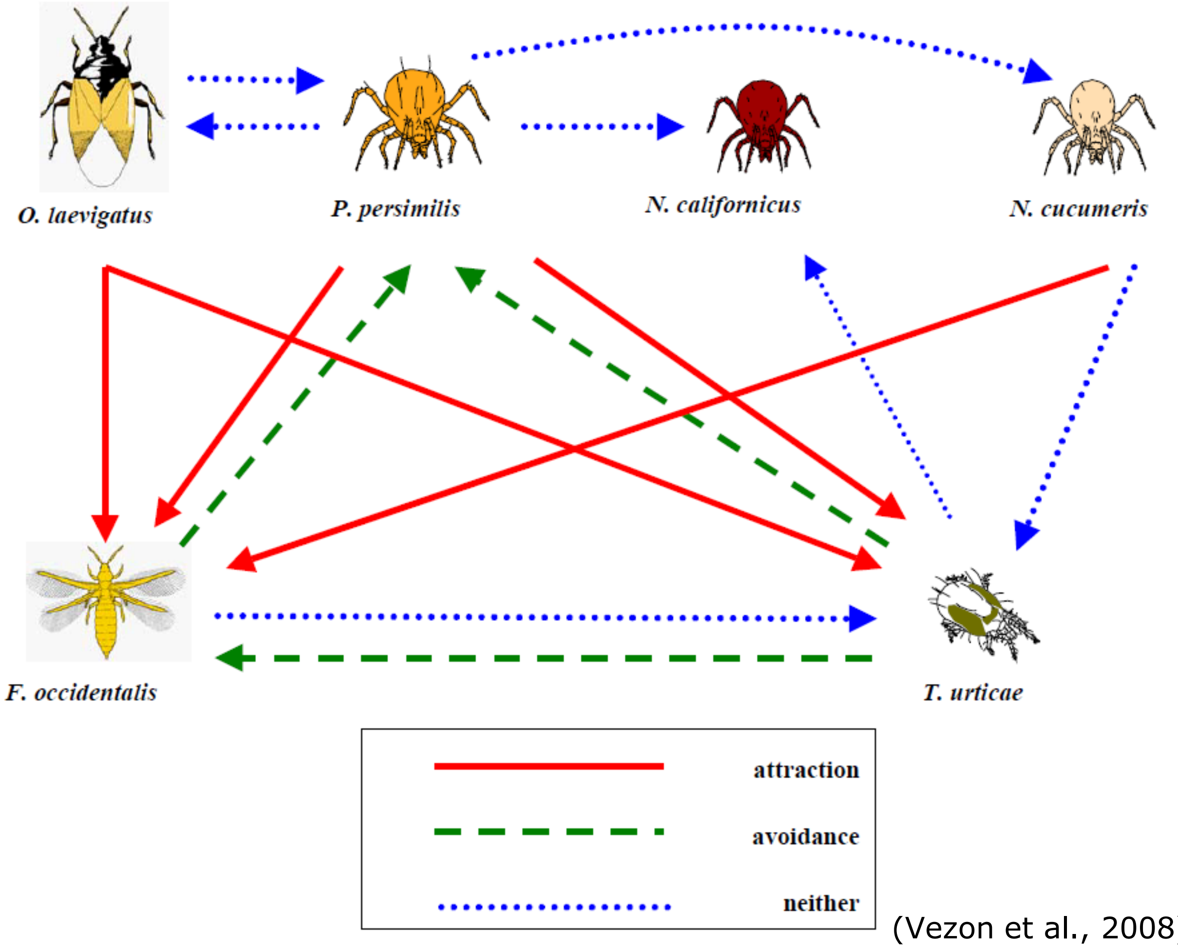
Food webs

➢ apparent competition or apparent mutualism



- Apparent Competition
  - A species negatively affects another via a shared enemy (i.e. predator).
  - Interspecific competition is not required.

- Apparent Mutualism
  - A species positively affects another via a shared enemy
  - mutualism not required.

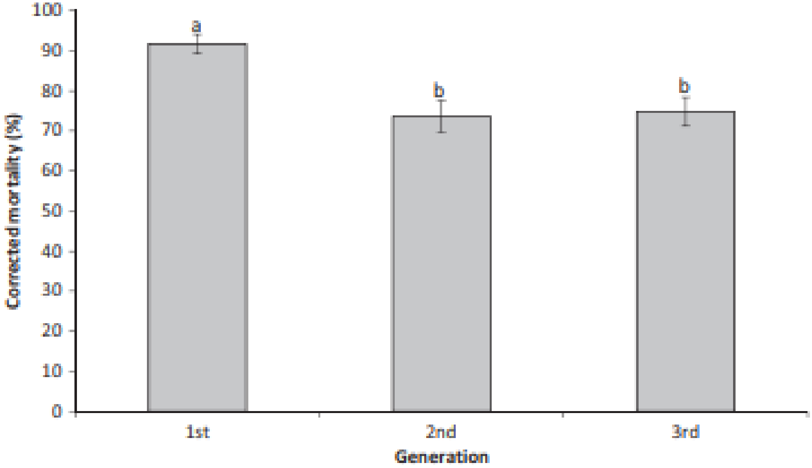


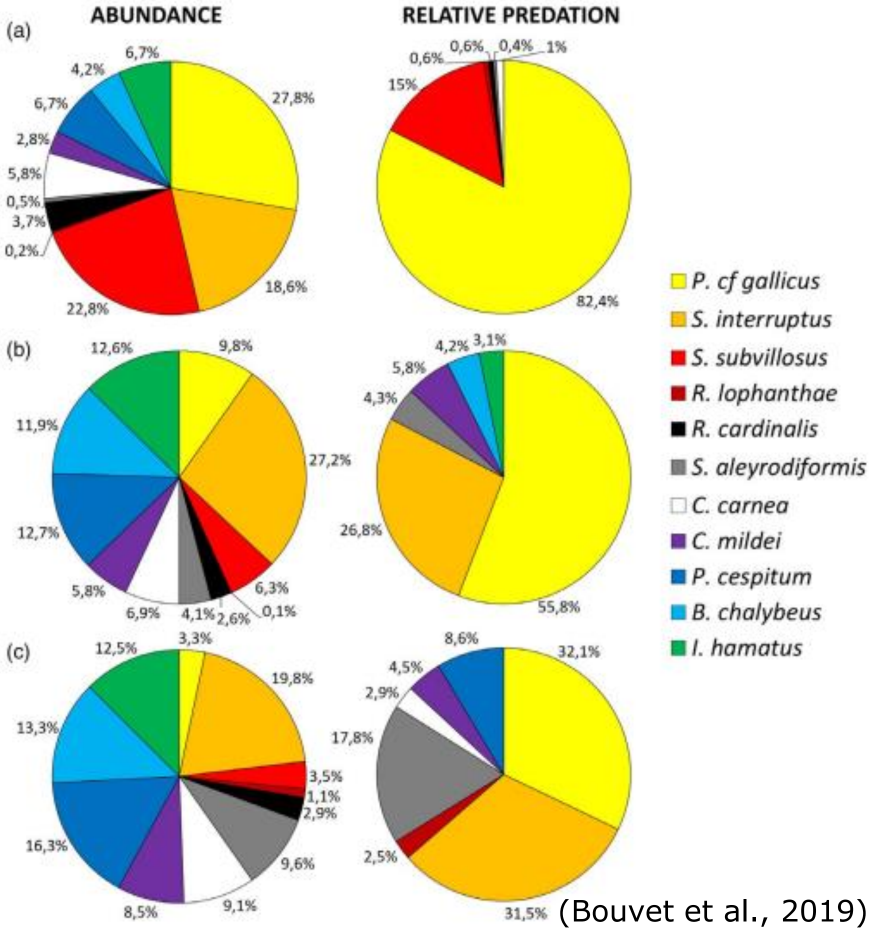
(Vezon et al., 2008)

Food webs

- **apparent competition or apparent mutualism**
  - California Red Scale

Higher abundance of aphid predators

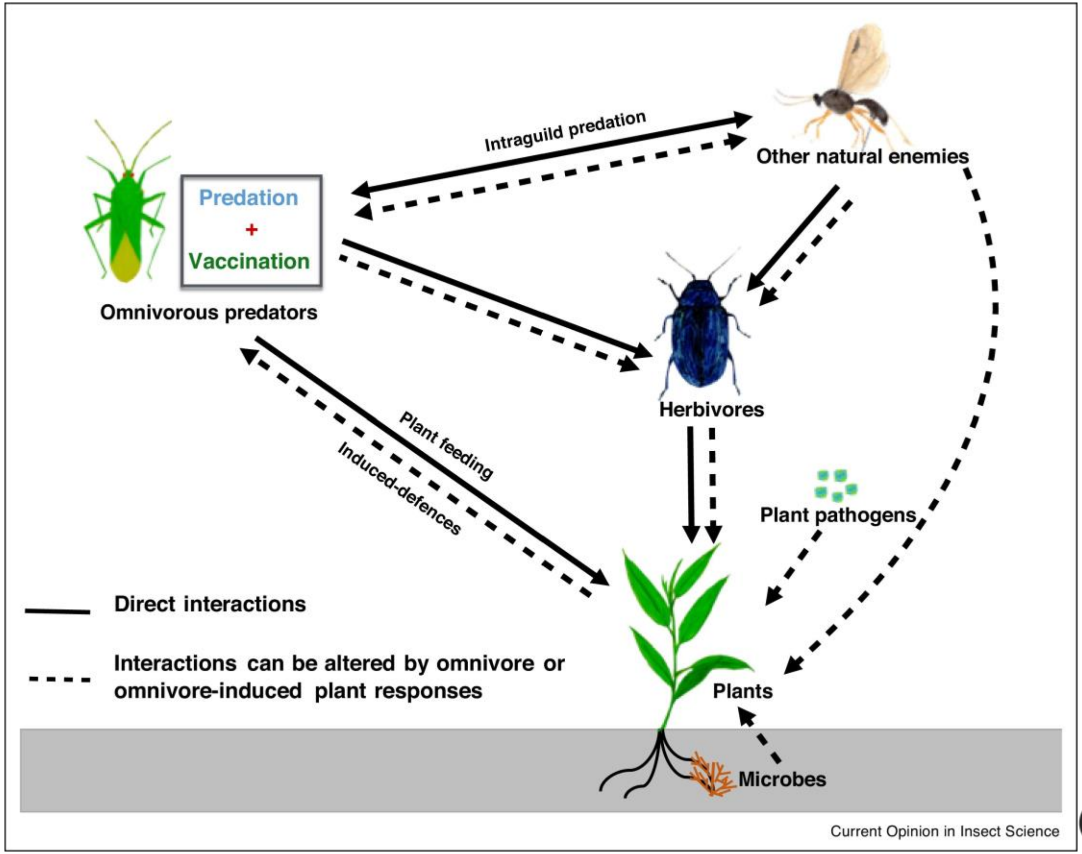




(Bouvet et al., 2019)

Food webs

- **omnivory**
  - consumption of species from more than one trophic level, “true” omnivores are predators that feed on both pests and plants;



(Zhang *et al.*, 2021)

Food webs

- **Omnivory**
  - Plant defence induction

Journal of Pest Science (2022) 95:1343–1355
https://doi.org/10.1007/s10340-021-01463-3

ORIGINAL PAPER

Check for updates

The omnivorous predator *Macrolophus pygmaeus* induces production of plant volatiles that attract a specialist predator

Nina Xiaoning Zhang[1,4] · Joke Andringa[1] · Jitske Brouwer[1] · Juan M. Alba[1] · Ruy W. J. Kortbeek[3] · Gerben J. Messelink[2] · Arne Janssen[1,5]

Research Article

SCI

Received: 8 March 2019 Revised: 13 June 2019 Accepted article published: 8 July 2019 Published online in Wiley Online Library: 14 August 2019

(wileyonlinelibrary.com) DOI 10.1002/ps.5547

Zoophytophagous predator-induced defences restrict accumulation of the tomato spotted wilt virus

Sarra Bouagga,[a] Alberto Urbaneja,[a] Laura Depalo,[b] Luís Rubio[a] and Meritxell Pérez-Hedo[a]*

BioControl (2021) 66:381–394
https://doi.org/10.1007/s10526-021-10077-8

Check for updates

Plant defense responses triggered by phytoseiid predatory mites (Mesostigmata: Phytoseiidae) are species-specific, depend on plant genotype and may not be related to direct plant feeding

Joaquín Cruz-Miralles · Marc Cabedo-López · Michela Guzzo · Meritxell Pérez-Hedo · Víctor Flors · Josep A. Jaques

frontiers in Plant Science

ORIGINAL RESEARCH
published: 02 October 2018
doi: 10.3389/fpls.2018.01419

Check for updates

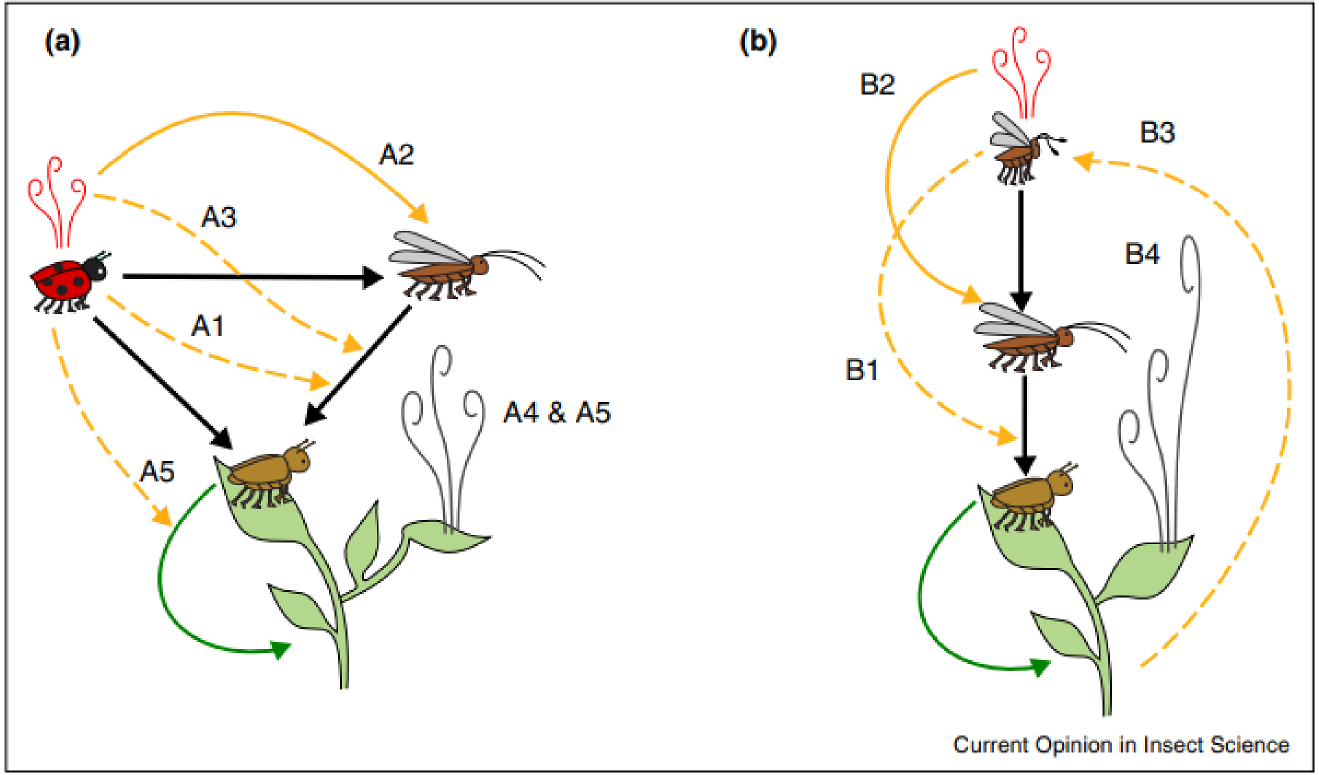
Induced Tomato Plant Resistance Against *Tetranychus urticae* Triggered by the Phytophagy of *Nesidiocoris tenuis*

*Meritxell Pérez-Hedo, Ángela M. Arias-Sanguino and Alberto Urbaneja**

Instituto Valenciano de Investigaciones Agrarias, Centro de Protección Vegetal y Biotecnología, Valencia, Spain

Food webs

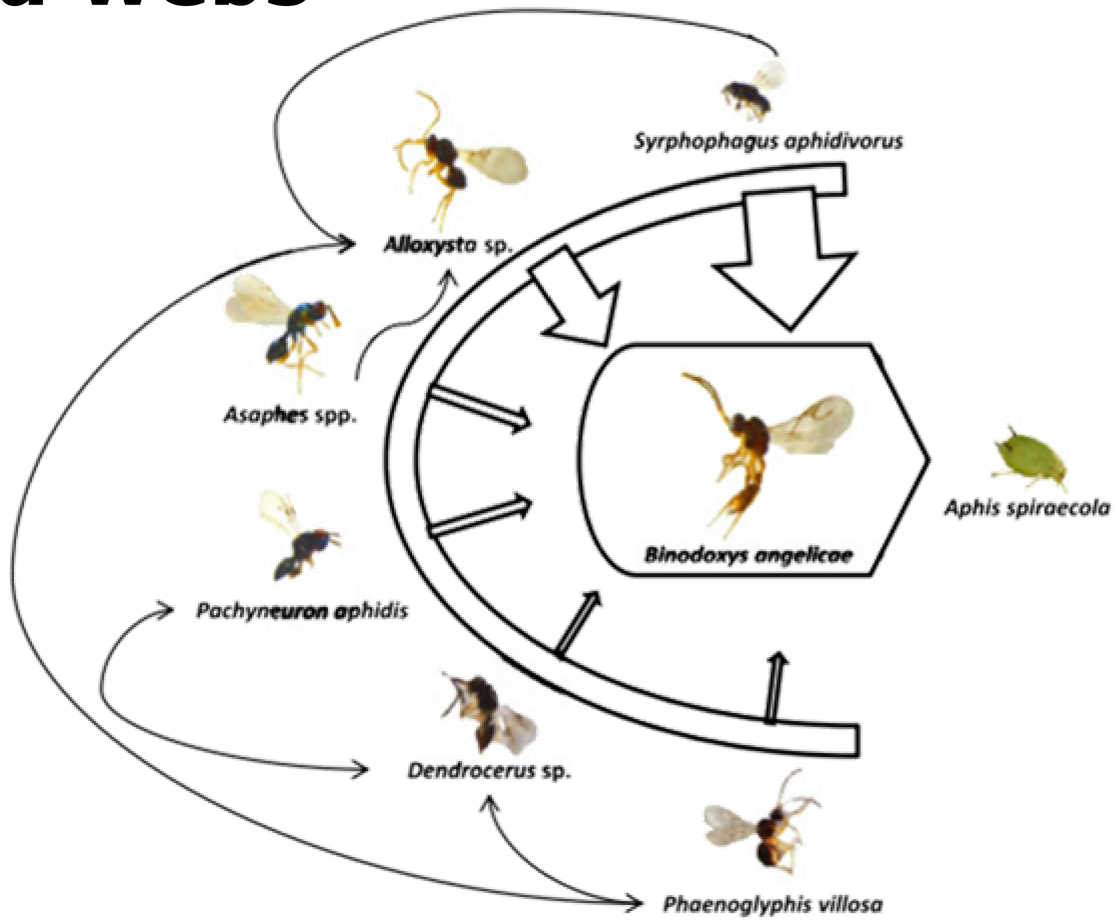
- **intraguild predation**
  - predators consume another natural enemy with whom they also compete for the same pest species;
- **hyperparasitism or hyperpredation**
  - the consumption of natural enemies by other natural enemies with whom they do not compete for shared prey, but they differ by the fact that hyperpredators can develop on alternative prey, whereas true hyperparasitoids are obligate.



(Frago, 2016)

Food webs

- **Molecular techniques** greatly contribute to untangle the trophic links in communities where immature entomophagous species (either in the third or fourth level) develop inside the herbivore



(Gomez-Marco *et al.*, 2015)

Food webs

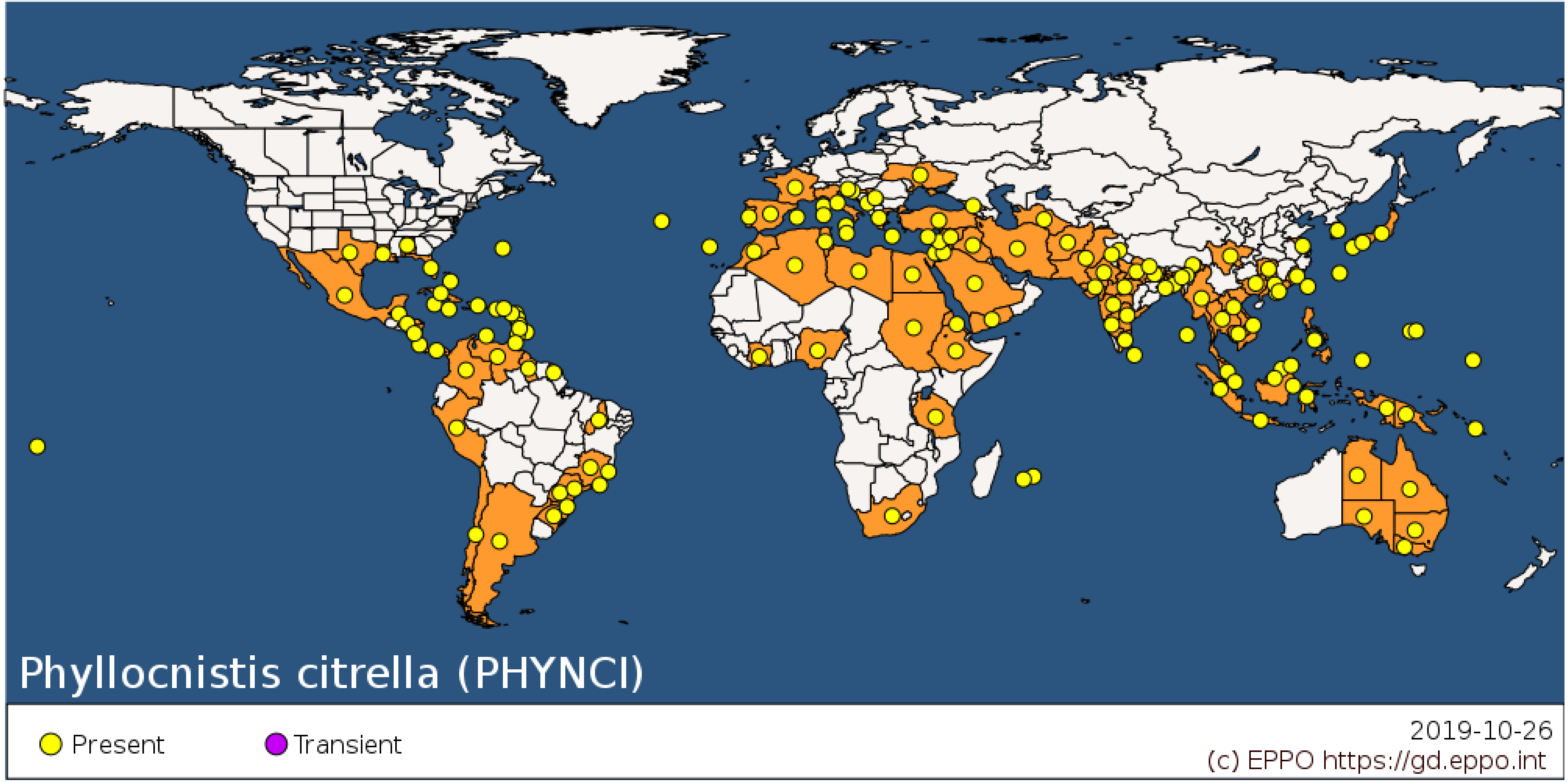
- **Leafminers** are among the most **heavily parasitized** insects (Hawkins, 1994) mainly by polyphagous parasitoids (Askew, 1994)

- When invading a new region they are often quickly adopted by **native parasitoids** that may provide substantial control

From classical-fortuitous biocontrol…

- *Phyllocnistis citrella* Stainton (Citrus leafminer) (Lepidoptera: Gracillariidae)
  - 1st reported in Italy in 1995

Distribution



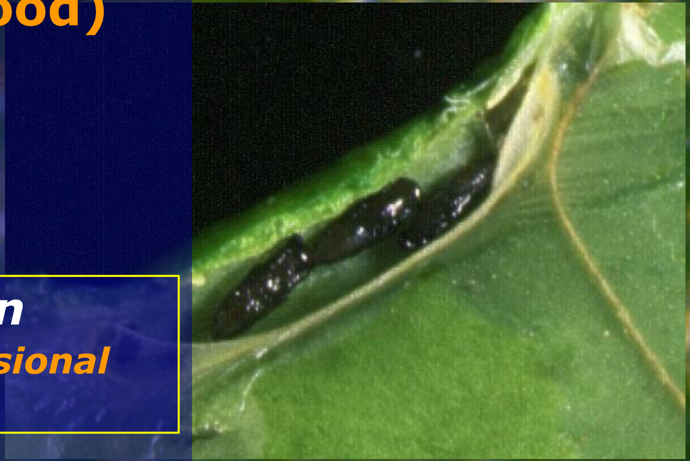
Indigenous parasitoids in the Mediterranean basin

- Fam. Eulophidae
  - Subfam. Entedoninae
    - *Asecodes*
    - *Chrysocharis*
    - *Neochrysocharis*
  - Subfam. Eulophinae
    - *Cirrospilus*
    - *Diglyphus*
    - *Elasmus*
    - *Pnigalio*
    - *Ratzeburgiola*
    - *Sympiesis*
  - Subfam. Tetrastichinae
    - *Apotetrastichus*
    - *Aprostocetus*
    - *Baryscapus*
- Fam. Pteromalidae
  - *Pteromalus*

Indigenous parasitoids in Italy

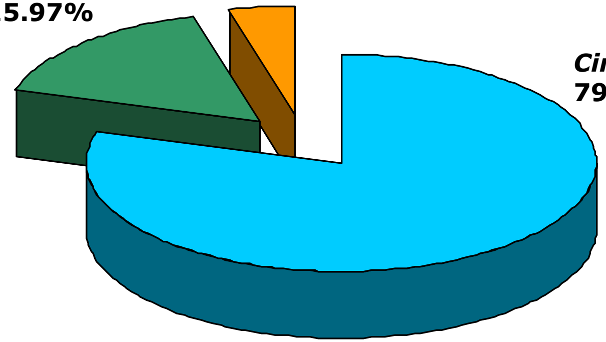
- ***Cirrospilus pictus*** **(Nees)**
- ***Pnigalio agraules*** **(Walker)**
- ***Apotetrastichus postmarginalis*** **(Bouček)**
- ***A. sericothorax*** **(Szelényi)**
- ***Asecodes delucchii*** **(Bouček)**
- ***A. erxias*** **(Walker)**
- ***Neochrysocharis formosa*** **(Westwood)**
- ***Ratzeburgiola incompleta*** **Bouček**
- *Aprostocetus* spp.
- *Baryscapus* sp.
- *Chrysocharis pentheus* (Walker)
- *Cirrospilus diallus* Walker
- *C. vittatus* Walker
- *Diglyphus isaea* (Walker)
- *Pnigalio soemius* (Walker)

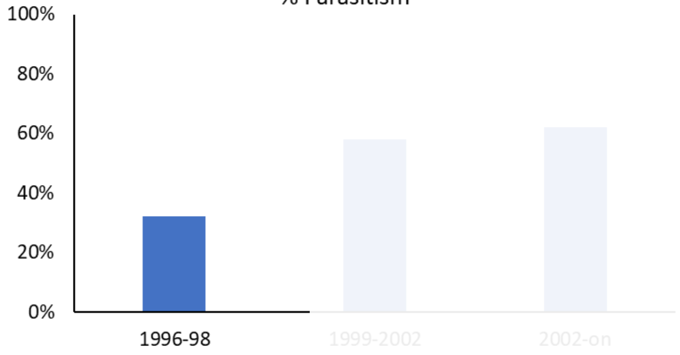
- ***main***
- ***occasional***
- *rare*



CLM parasitic complex in Italy

1996-98 Pre-introduction



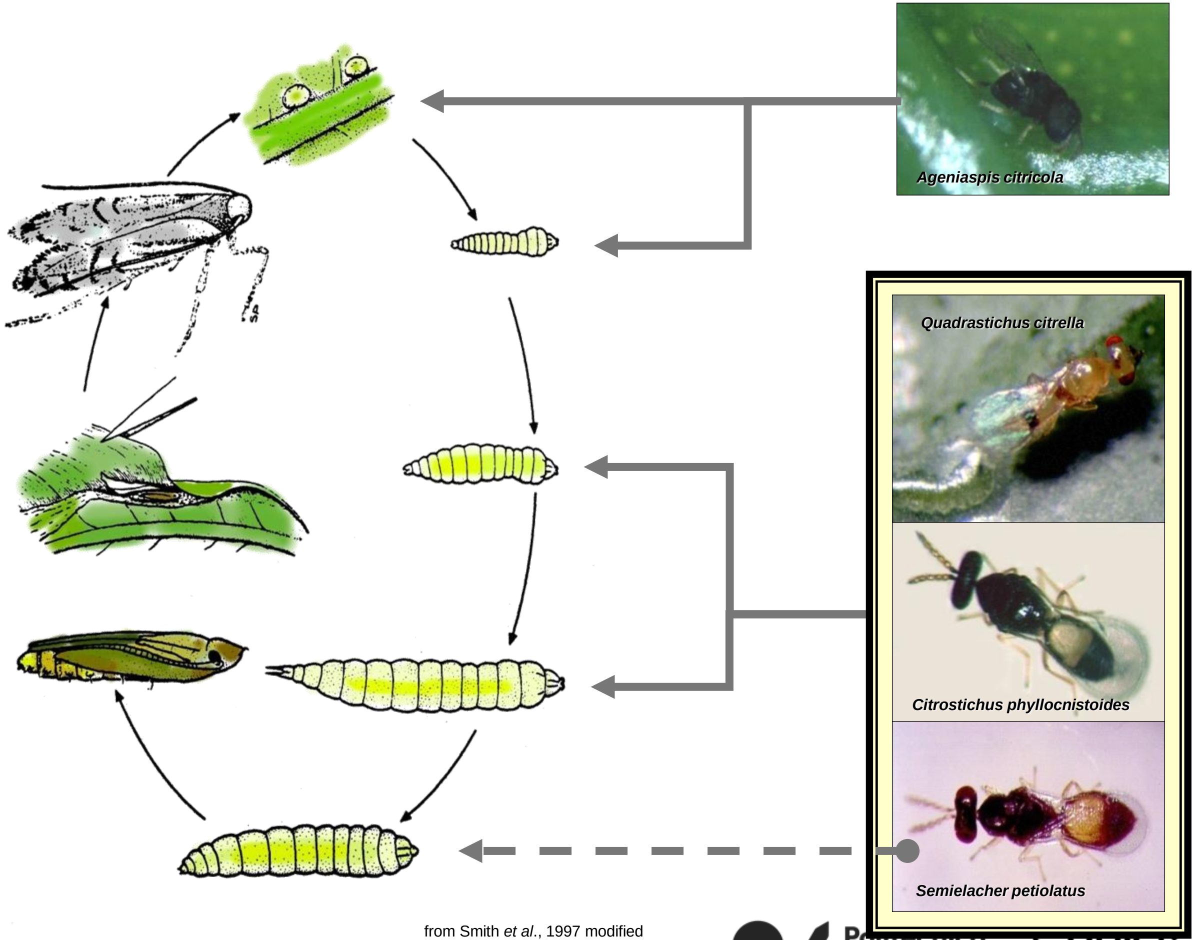


1999-2001 Introduction

2001-2006 Establishment

Exotic parasitoids introduced in Italy

- ***Ageniaspis citricola*** **(Encyrtidae)**
  - koinobiont, egg-L1 endoparasitoid
  - poliembryonic
- ***Quadrastichus*** **sp. (now *Q. citrella*) (Eulophidae)**
  - idiobiont, L2-L3 ectoparasitoid
- ***Citrostichus phyllocnistoides*** **(Eulophidae)**
  - idiobiont, L2-L3 ectoparasitoid
  - alternative hosts
    - Lep. Nepticulidae on Pistacia, Rubus and Salix
- ***Semielacher petiolatus*** **(Eulophidae)**
  - idiobiont, L2-L4 ectoparasitoid
  - alternative hosts
    - Lepidoptera leafminers on *Parietaria, Rubus* and *Echium*
    - Diptera leafminers on *Urtica*, *Sonchus* and *Merculiaris*
  - **<u>accidentally introduced - 1998</u>**



from Smith *et al.*, 1997 modified

Parasitoids released

- *Ageniaspis citricola*
  - Almost 20,000 adults released in 1996-2001
  - **No establishment**
- *Quadrastichus citrella*
  - About 3,000 adults released in 1996
  - **No establishment**
- *Semielacher petiolatus*
  - From 1999 spontaneous diffusion and **permanent establishment** in all citrus areas
- *Citrostichus phyllocnistoides*
  - Almost 4,000 adults released in 1999-2001
  - **Permanent establishment**

Parasitoids released

- *Ageniaspis citricola*
  - Almost 20,000 adults released in 1996-2001
  - No establishment

- *Quadrastichus citrella*
  - About 3,000 adults released in 19
  - No establishment

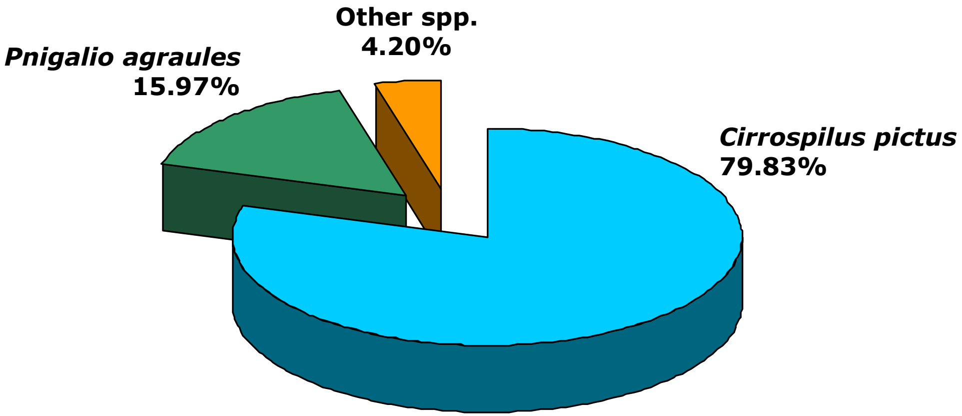
- *Semielacher petiolatus*
  - From 1999 spontaneous diffusion and **permanent establishment** in all citrus areas

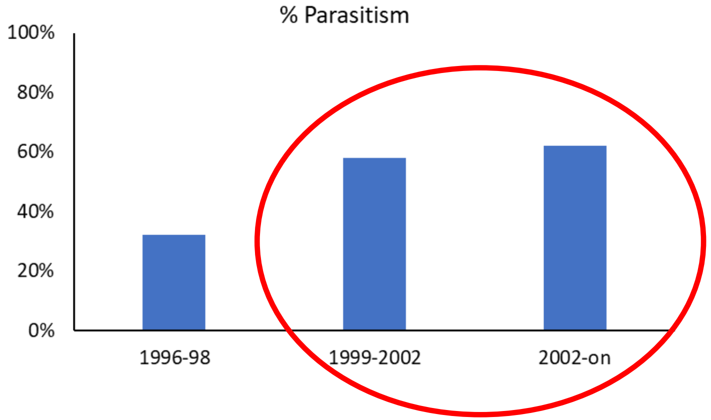
Role of alternative hosts

- *Citrostichus phyllocnistoides*
  - Almost 4,000 adults released in 1999-2001
  - **Permanent establishment**

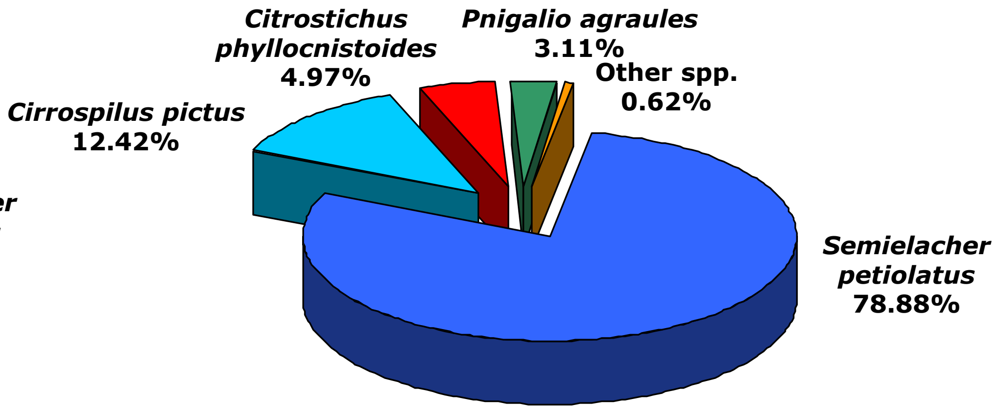
Evolution of CLM parasitic complex in Italy

1996-98 Pre-introduction

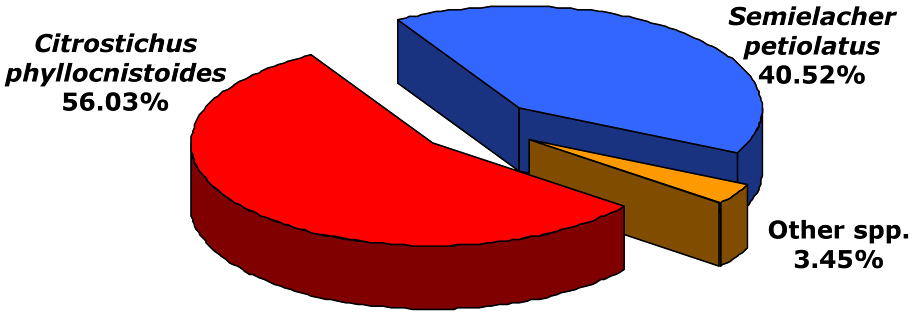




1999-2001 Introduction

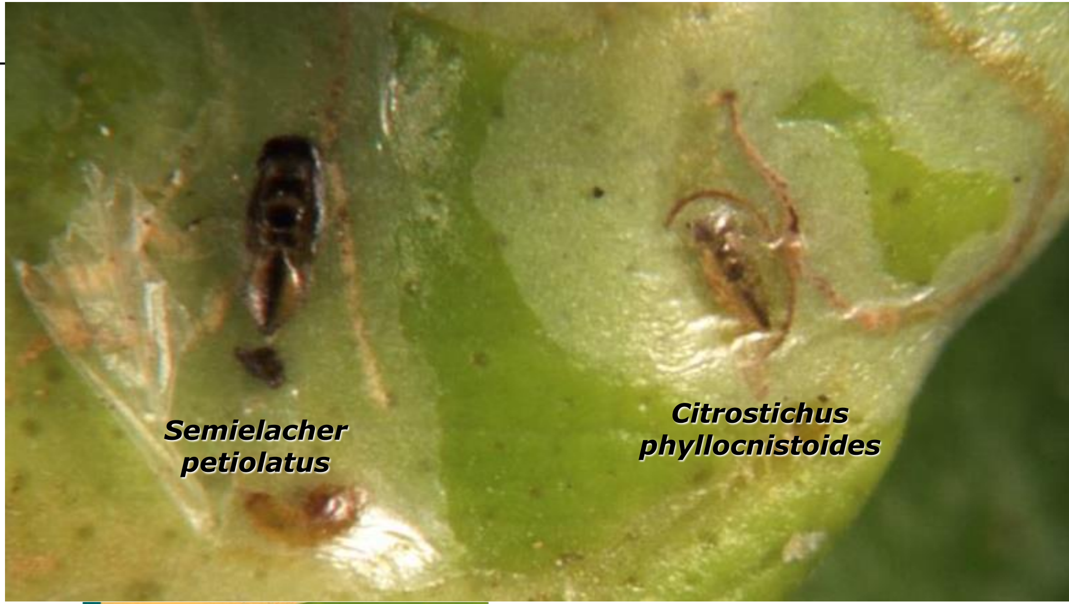


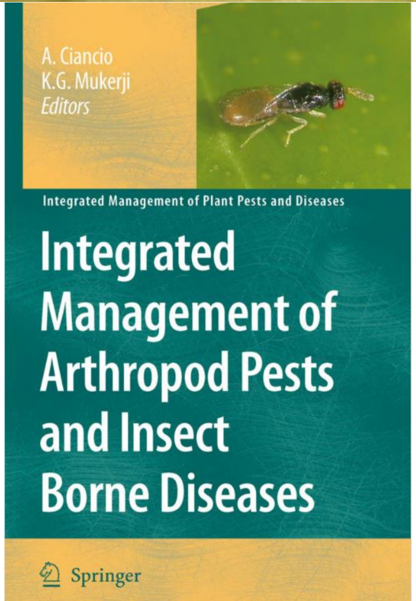
2001-2006 Establishment

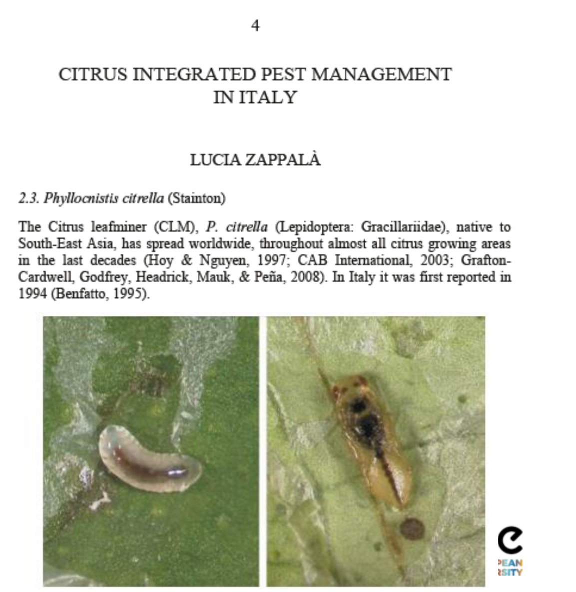


In conclusion

- **Successful biocontrol** in adult citrus orchards
  - High adaptibility of *Semielacher petiolatus* and *Citrostichus phyllocnistoides* to the Italian climate
  - **Seasonal alternation** + "collaboration"
  - Role of the alternative hosts
- Importance of maintaining a **rich biodiversity**
  - Alternative food and shelter
- Different situation in nurseries and re-grafted or young orchards







4

CITRUS INTEGRATED PEST MANAGEMENT IN ITALY

LUCIA ZAPPALÀ

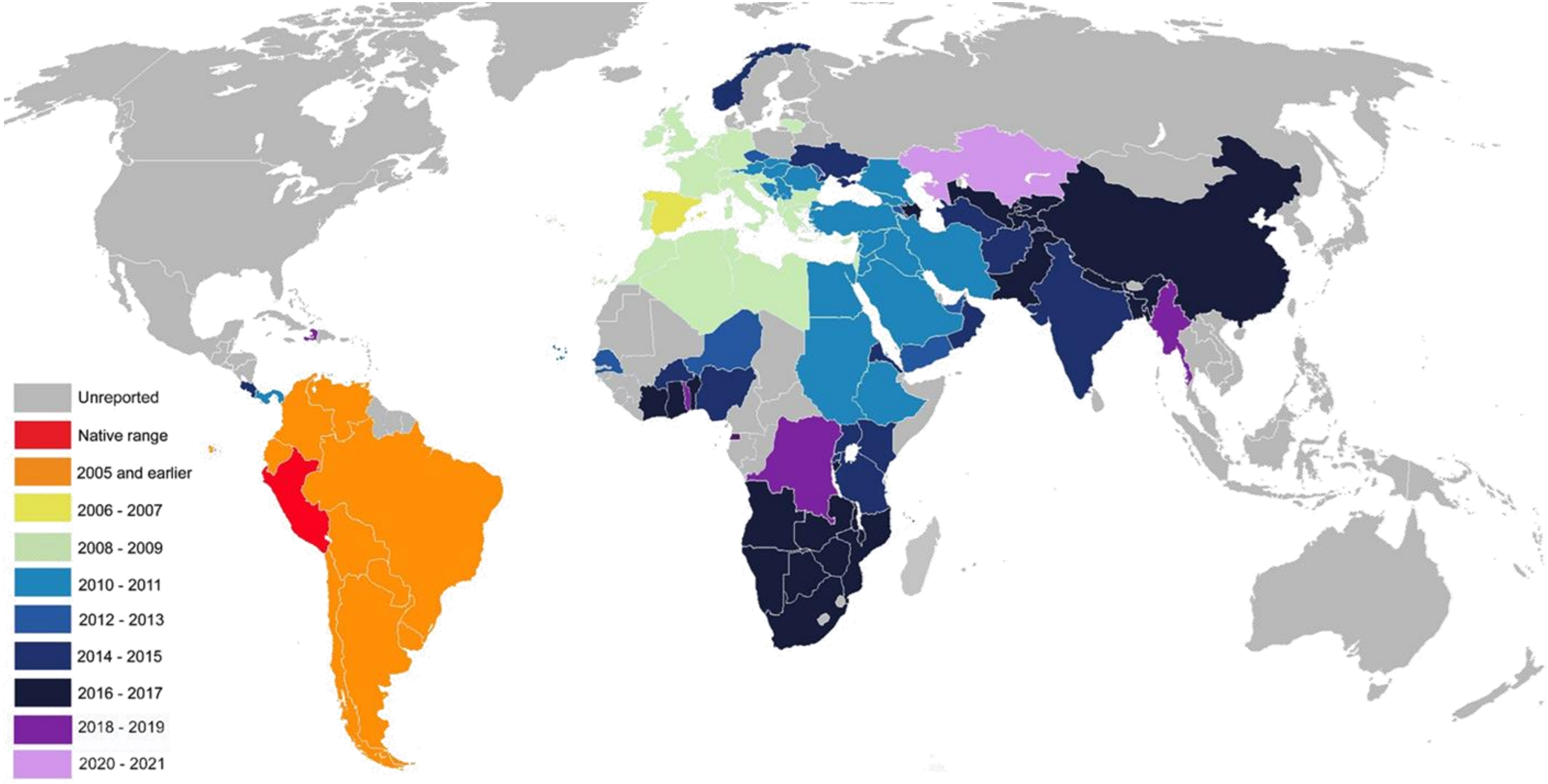
2.3. Phyllocnistis citrella (Stainton)

The Citrus leafminer (CLM), *P. citrella* (Lepidoptera: Gracillariidae), native to South-East Asia, has spread worldwide, throughout almost all citrus growing areas in the last decades (Hoy & Nguyen, 1997; CAB International, 2003; Grafton-Cardwell, Godfrey, Headrick, Mauk, & Peña, 2008). In Italy it was first reported in 1994 (Benfatto, 1995).

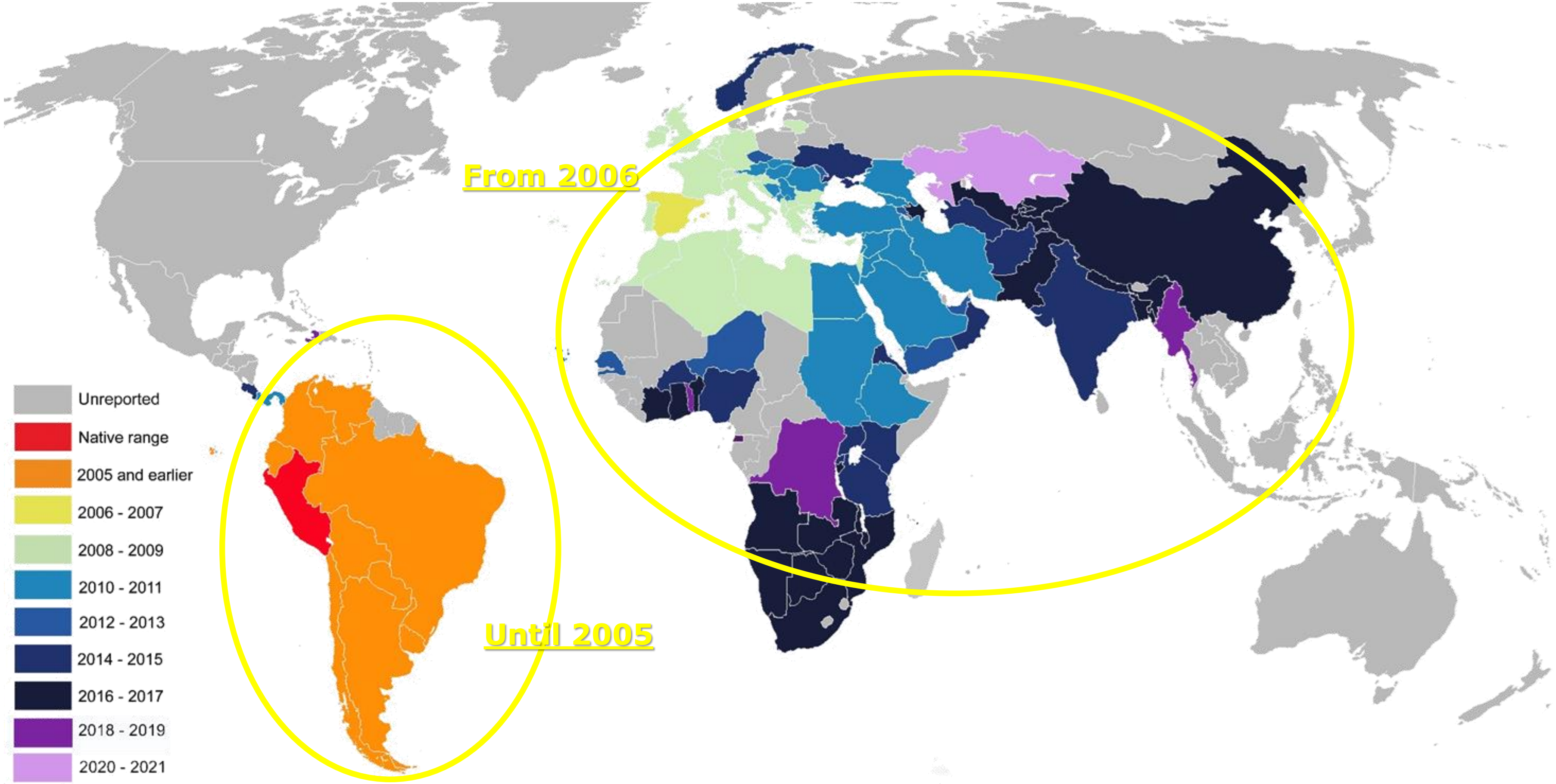
Another example

- *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)
- South American Tomato pinworm, Tomato borer, tomato leafminer

Distribution



Distribution



Biology

- High reproductive potential
  - >150 eggs/female
- No diapause
- Wide host range
  - Crop and non-crop plants
- Pupates also in the soil
- Up to 13 generations/year
- Highly mobile adults


Black nightshade


Eggplant

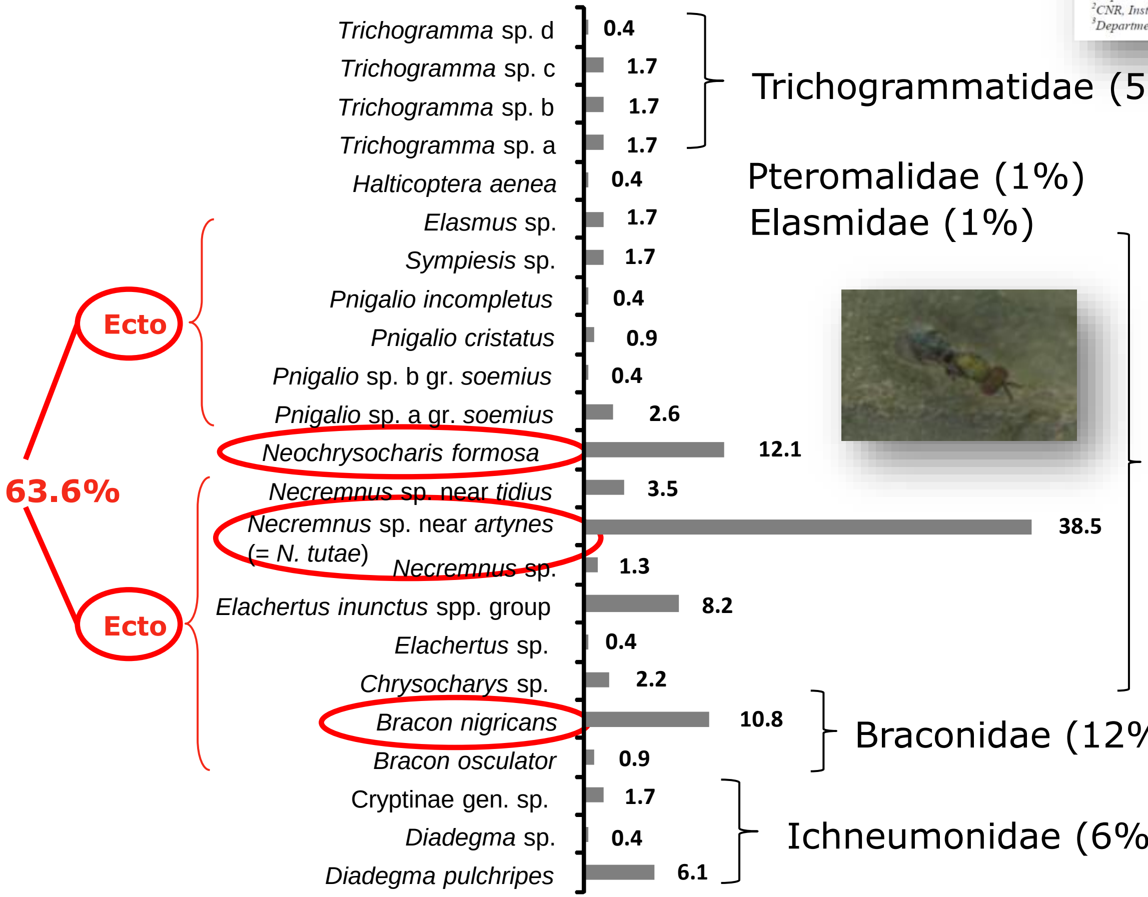
Damage

- Leaves, shoots, fruit

Parasitoid community composition


Bulletin of Insectology 65 (1): 51-61, 2012
ISSN 1721-8861
Recruitment of native parasitoids by the exotic pest *Tuta absoluta* in Southern Italy
Lucia ZAPPALÀ[1], Umberto BERNARDO[2], Antonio BIONDI[1], Arturo COCCO[3], Salvatore DELIPERI[3], Gavino DELRIO[3], Massimo GIORGINI[2], Paolo PEDATA[2], Carmelo RAPISARDA[1], Giovanna TROPEA GARZIA[1], Gaetano SISCARO[1]
[1]Department of Agri-food and Environmental Systems Management, University of Catania, Italy
[2]CNR, Institute for Plant Protection, UOS of Portici, Napoli, Italy
[3]Department of Agriculture, University of Sassari, Italy

- In Italy
  - 23 parasitoid species belonging to 12 genera and 6 families were collected



Trichogrammatidae (5%)

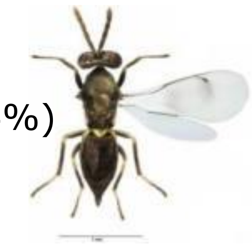
EGG PARASITOIDS

Pteromalidae (1%)

Elasmidae (1%)

LARVAL PARASITOIDS

Eulophidae (74%)



Braconidae (12%)

Ichneumonidae (6%)

PUPAL PARASITOIDS

Parasitoid community composition

- ➢ In Europe and the Med basin
  - ➢ 84 arthropod species
    - – 80% parasitoids (>50 species)
    - – 20% predators (18 species)

J Pest Sci (2013) 86:635–647
DOI 10.1007/s10340-013-0531-9

RAPID COMMUNICATION

Natural enemies of the South American moth, *Tuta absoluta*, in Europe, North Africa and Middle East, and their potential use in pest control strategies

Lucia Zappalà · Antonio Biondi · Alberto Alma · Ibrahim J. Al-Jboory · Judit Arnò · Ahmet Bayram · Anaïs Chailleux · Ashraf El-Arnaouty · Dan Gerling · Yamina Guenaoui · Liora Shaltiel-Harpaz · Gaetano Siscaro · Menelaos Stavrinides · Luciana Tavella · Rosa Vercher Aznar · Alberto Urbaneja · Nicolas Desneux

BIOCONTROL SCIENCE AND TECHNOLOGY
https://doi.org/10.1080/09583157.2019.1572711
Taylor & Francis
Taylor & Francis Group

Natural enemies of *Tuta absoluta* in the Mediterranean basin, Europe and South America

Chiara Ferracini[a], Vanda H. P. Bueno[b], Maria Luisa Dindo[c], Barbara L. Ingegno[a], María G. Luna[d,e], Nadia G. Salas Gervassio[d,e], Norma E. Sánchez[d], Gaetano Siscaro[f], Joop C. van Lenteren[b,g], Lucia Zappalà[f] and Luciana Tavella[a]

Generalist predators

- Prominent role in agricultural pest management
- Some species can feed also on various non-pest substrates (**omnivorous**)
- **Alternative host plants** can play a relevant ecological role


Nesidiocoris tenuis


Dicyphus errans


Macrolophus pygmaeus

Augmentative and conservation biocontrol

- Enhancing the role of indigenous natural enemies
- Inoculative releases

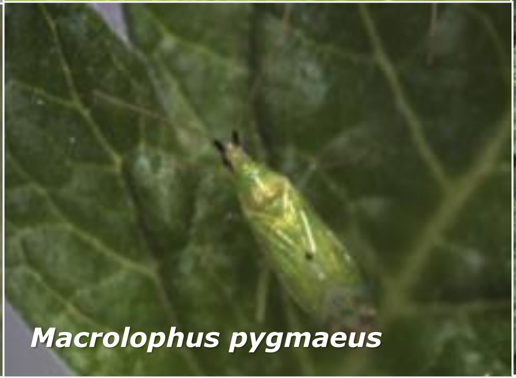
Bracon nigricans

Diadegma pulchripes

Nesidiocoris tenuis

Necremnus tutae

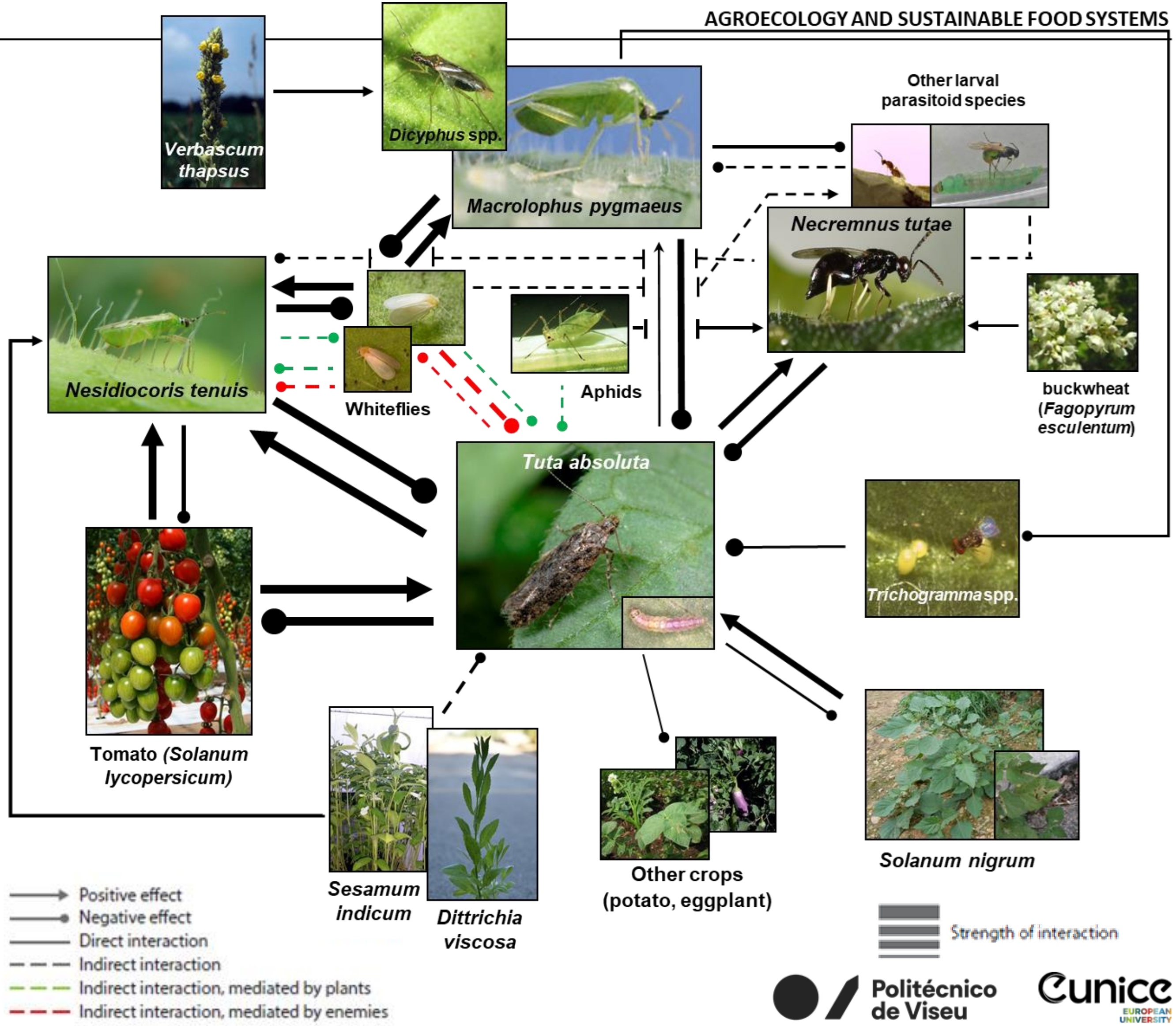
Neochrysocharis formosa



Macrolophus pygmaeus

Food web

- Biological interactions among components inside and outside the agroecosystem

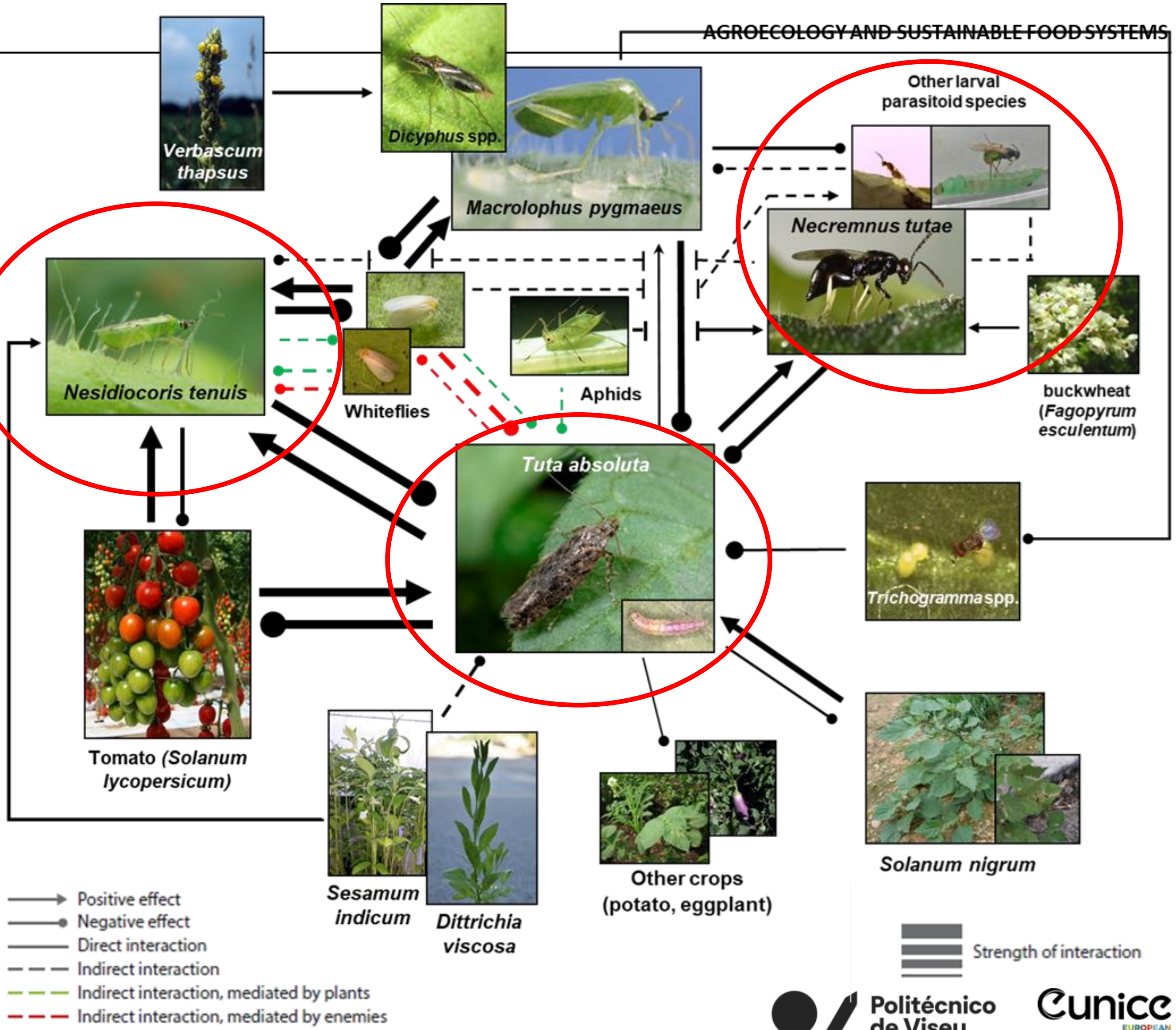


(modified from Biondi *et al.*, 2018)

Politécnico de Viseu
Eunice European University

Food web

- Biological interactions among components inside and outside the agroecosystem



Intraguild interactions

- *N. tenuis* feeds
  - on *T. absoluta* larvae parasitized by *N. tutae* and *B. nigricans* (kleptoparasitism) - scavenging
  - on *B. nigricans* (less) and on *N. tutae* (more) larvae (Intraguild predation)

Research Article

SCI

Received: 10 October 2016 Revised: 23 February 2017 Accepted article published: 16 March 2017 Published online in Wiley Online Library: 30 March 2017

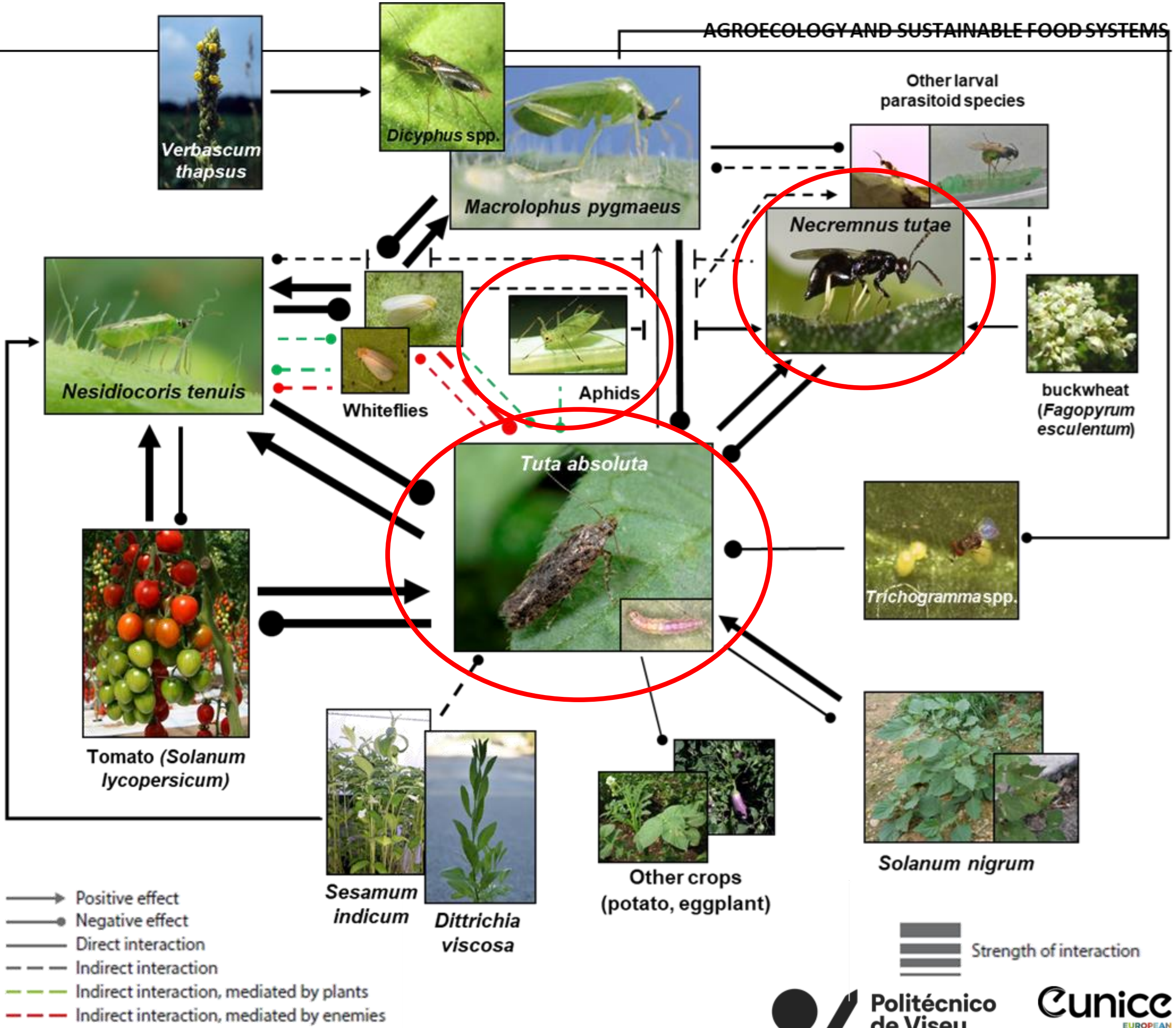
(wileyonlinelibrary.com) DOI 10.1002/ps.4562

Insights into food webs associated with the South American tomato pinworm

Mario Naselli,[a] Antonio Biondi,[a] Giovanna Tropea Garzia,[a] Nicolas Desneux,[b] Agatino Russo,[a] Gaetano Siscaro[a] and Lucia Zappalà[a*]

Food web

- Biological interactions among components inside and outside the agroecosystem

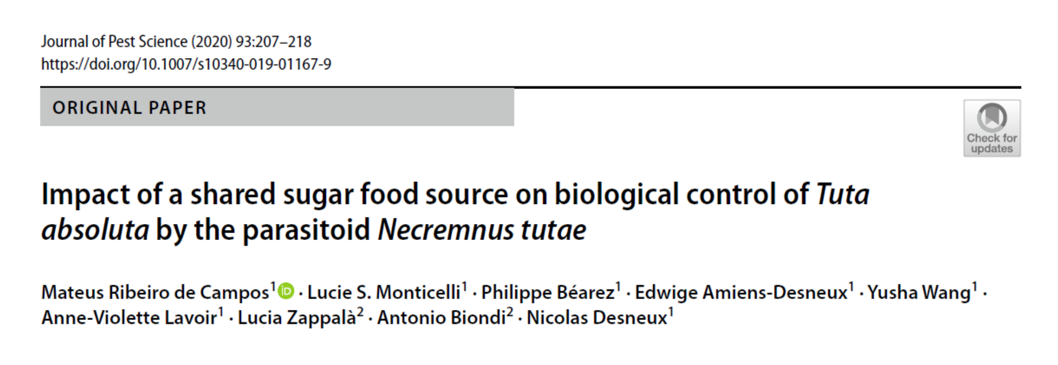


AGROECOLOGY AND SUSTAI

Shared food source

- Aphid honeydew increases *N. tutae* longevity

- Negative effects on *T. absoluta* by aphid populations
  - resource competition
  - induction of plant defenses



Journal of Pest Science (2020) 93:207–218
https://doi.org/10.1007/s10340-019-01167-9

ORIGINAL PAPER

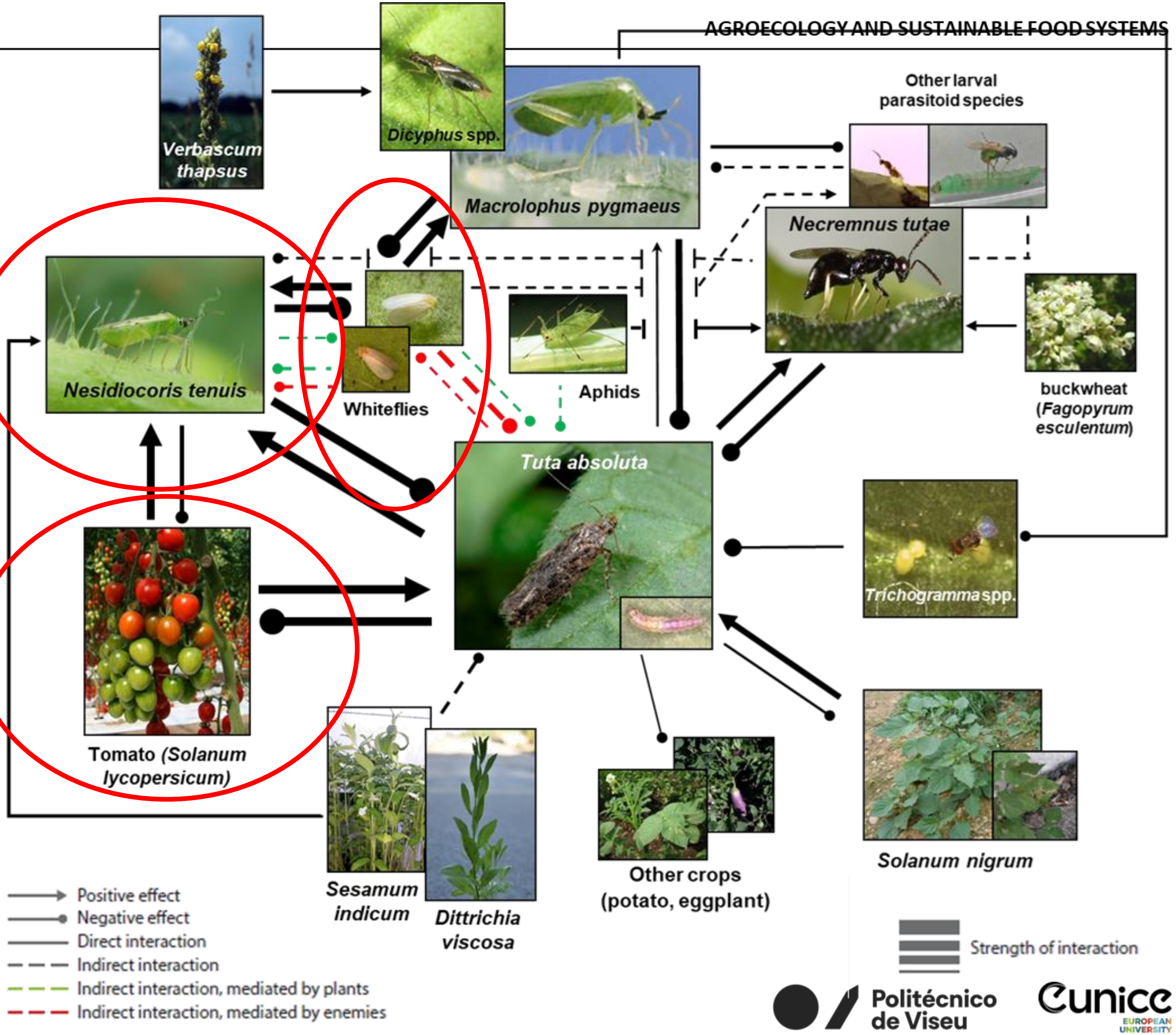
Check for updates

Impact of a shared sugar food source on biological control of *Tuta absoluta* by the parasitoid *Necremnus tutae*

Mateus Ribeiro de Campos[1] · Lucie S. Monticelli[1] · Philippe Béarez[1] · Edwige Amiens-Desneux[1] · Yusha Wang[1] · Anne-Violette Lavoir[1] · Lucia Zappalà[2] · Antonio Biondi[2] · Nicolas Desneux[1]

Food web

- Biological interactions among components inside and outside the agroecosystem



Induced plant defenses

- *N. tenuis* induces direct and indirect plant defenses in tomato

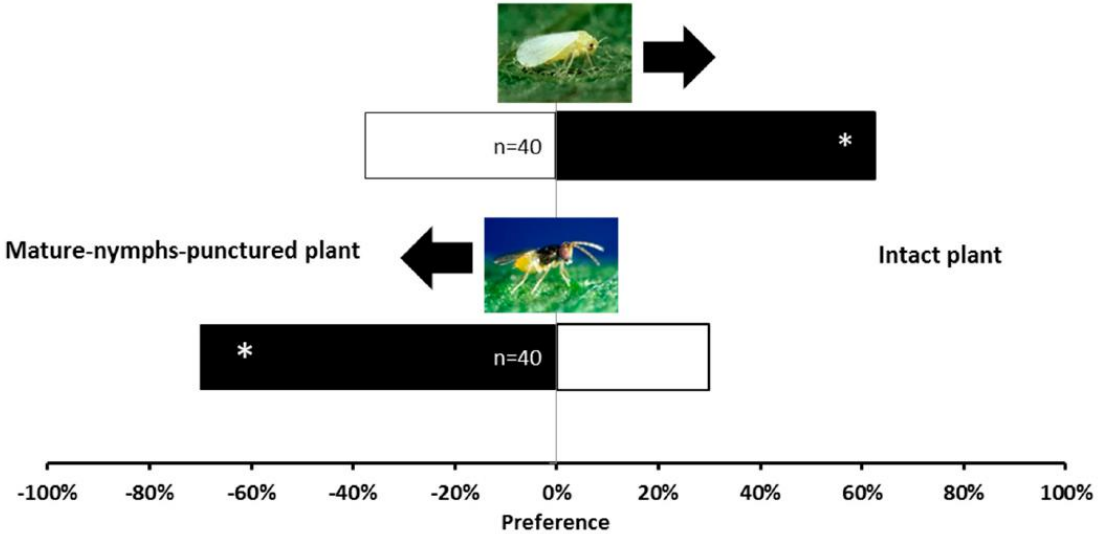

International Journal of *Molecular Sciences*

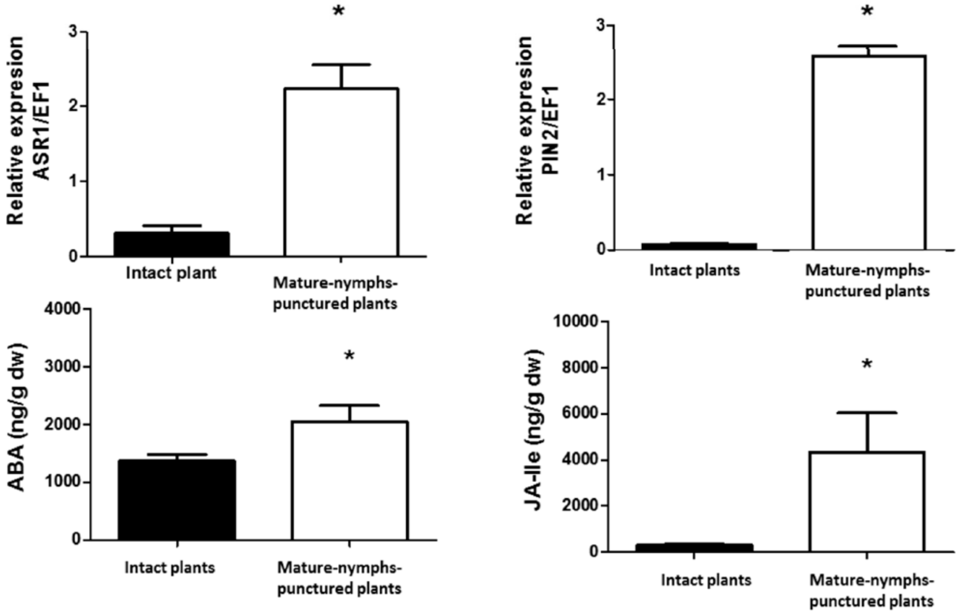
MDPI

Article

Stage-Related Defense Response Induction in Tomato Plants by *Nesidiocoris tenuis*

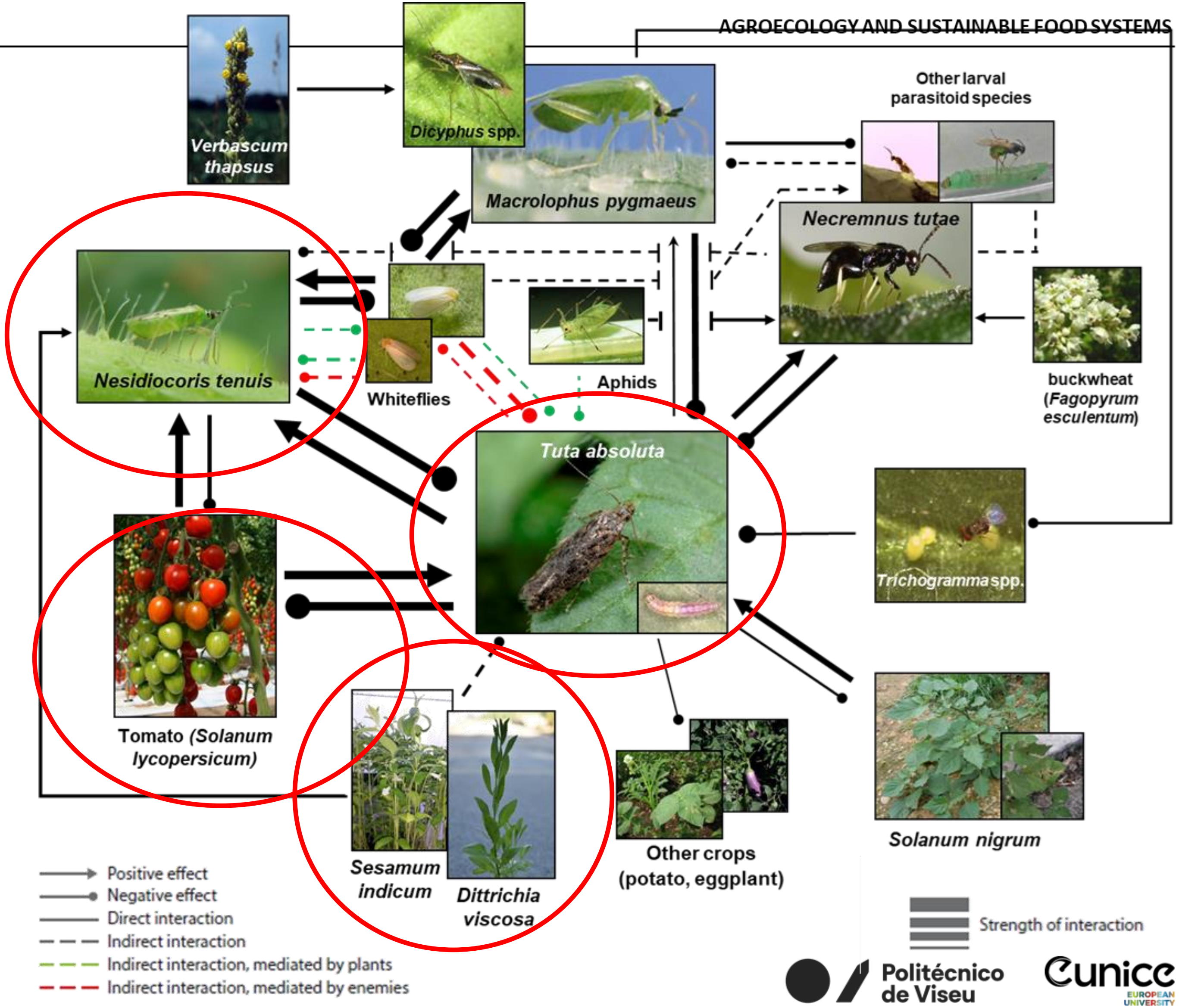
Mario Naselli [1], Alberto Urbaneja [2], Gaetano Siscaro [1], Josep A. Jaques [3], Lucia Zappalà [1], Víctor Flors [3] and Meritxell Pérez-Hedo [2,3,*]





Food web

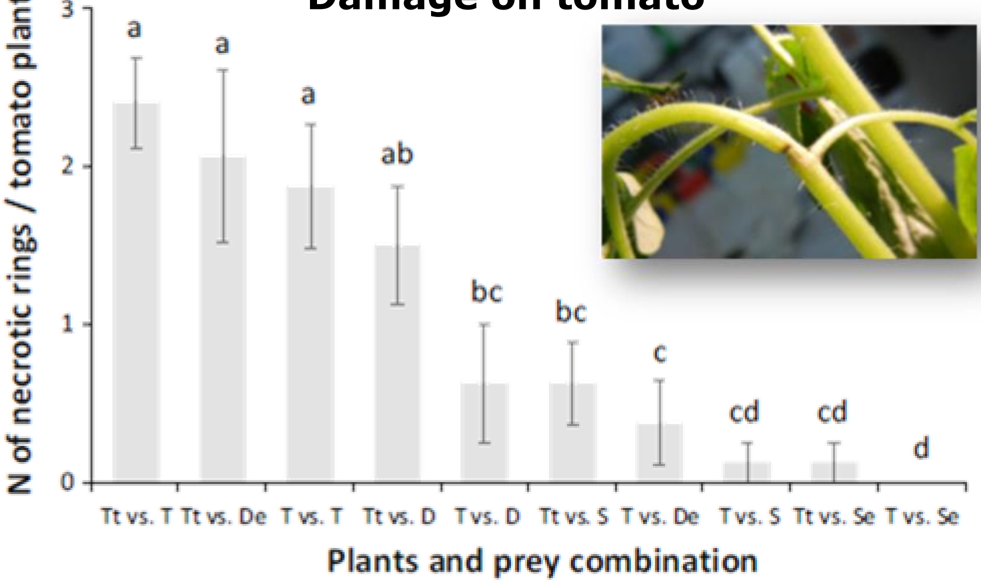
- Biological interactions among components inside and outside the agroecosystem



Companion plants

- *Sesamum indicum*
  - more attractive
  - it reduced *N. tenuis* damage, but not its predatory activity
  - it is a suitable host plant for its development and oviposition without any additional prey

Damage on tomato



BioControl (2016) 61:79–90
DOI 10.1007/s10526-015-9700-5

CrossMark

Can alternative host plant and prey affect phytophagy and biological control by the zoophytophagous mirid *Nesidiocoris tenuis*?

Antonio Biondi · Lucia Zappalà · Angelo Di Mauro · Giovanna Tropea Garzia · Agatino Russo · Nicolas Desneux · Gaetano Siscaro

		Tomato	*Dittrichia viscosa*	*Sesamum indicum*
Nymph survival		0.00% ± 0.00 a	0.00% ± 0.00 a	99.6% ± 1.15 b
Nymph development time (days)	females	-	-	14.2 ± 0.65 a
	males	-	-	11.4 ± 0.67 b
Lifetime fertility (n. nymphs/female)		2.03± 0.62 a	2.45±0.74 a	61.05±5.76 b
Daily fertility (n. nymphs/female/day)		0.22 ± 0.06 a	0.21 ± 0.06 a	1.43 ± 0.21 b
Longevity (days)	females	8.92 ± 0.62 a	11.15 ± 0.77 a	48.20 ± 3.39 b
	males	9.81 ± 0.68 a	7.00 ± 0.43 a	60.25 ± 4.24 b

Companion plants

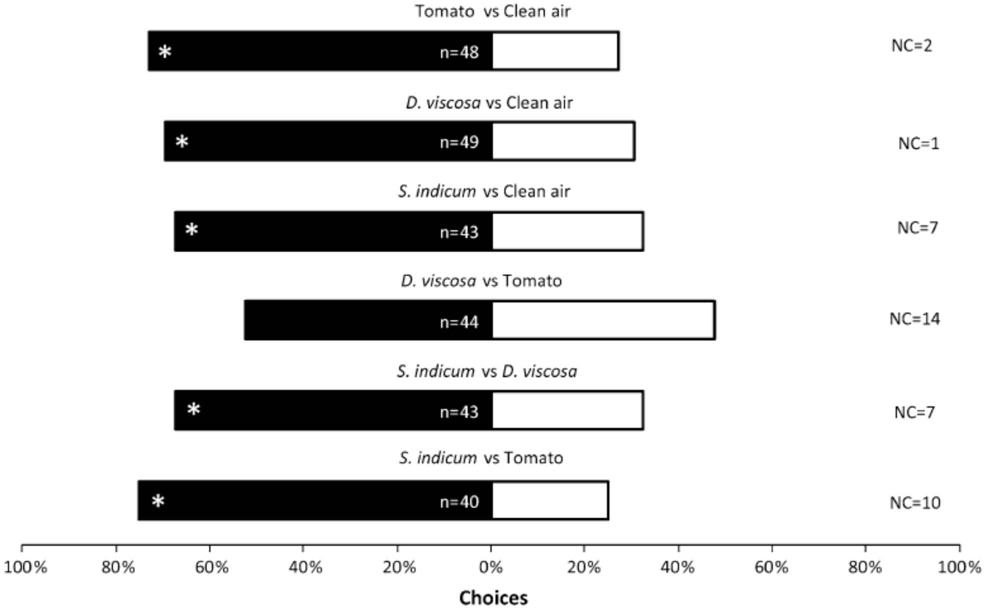
- Olfactory trials
  - significantly higher attractivity of *S. indicum* both compared to *D. viscosa* and to tomato
  - both tested pest instars did not significantly increase the attractivity of tomato plants
  - prevalent phytophagous behavior?

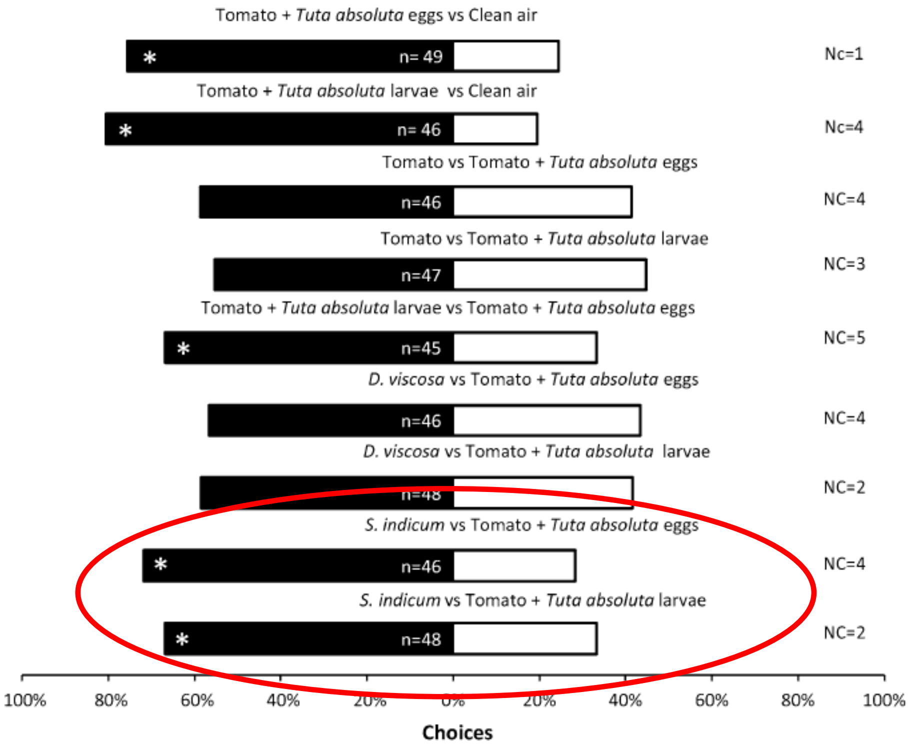
Arthropod-Plant Interactions (2017) 11:121–131
DOI 10.1007/s11829-016-9481-5

ORIGINAL PAPER

Olfactory response of the zoophytophagous mirid *Nesidiocoris tenuis* to tomato and alternative host plants

Mario Naselli[1] · Lucia Zappalà[1] · Antonio Gugliuzzo[1] · Giovanna Tropea Garzia[1] · Antonio Biondi[1] · Carmelo Rapisarda[1] · Fabrizio Cincotta[2] · Concetta Condurso[3] · Antonella Verzera[2] · Gaetano Siscaro[1]





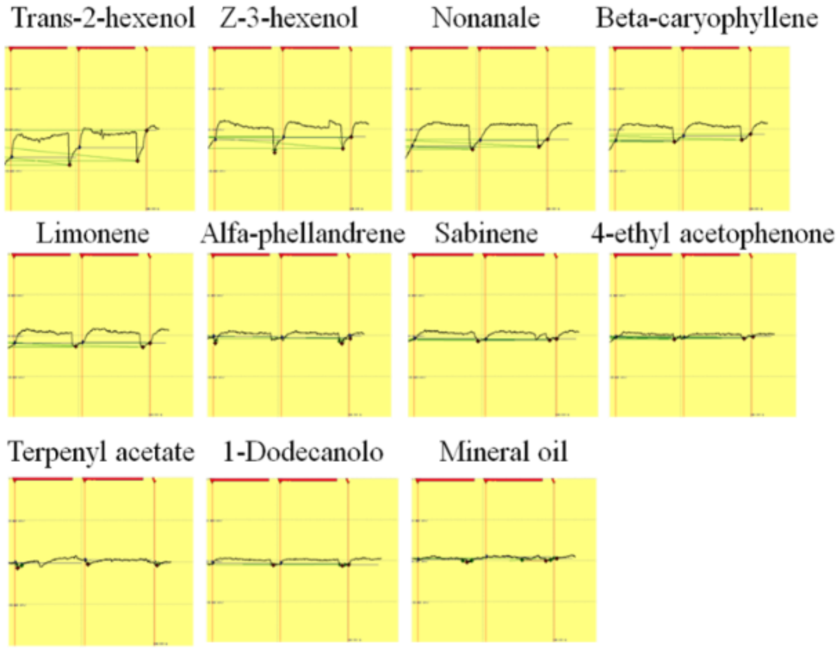
Companion plants

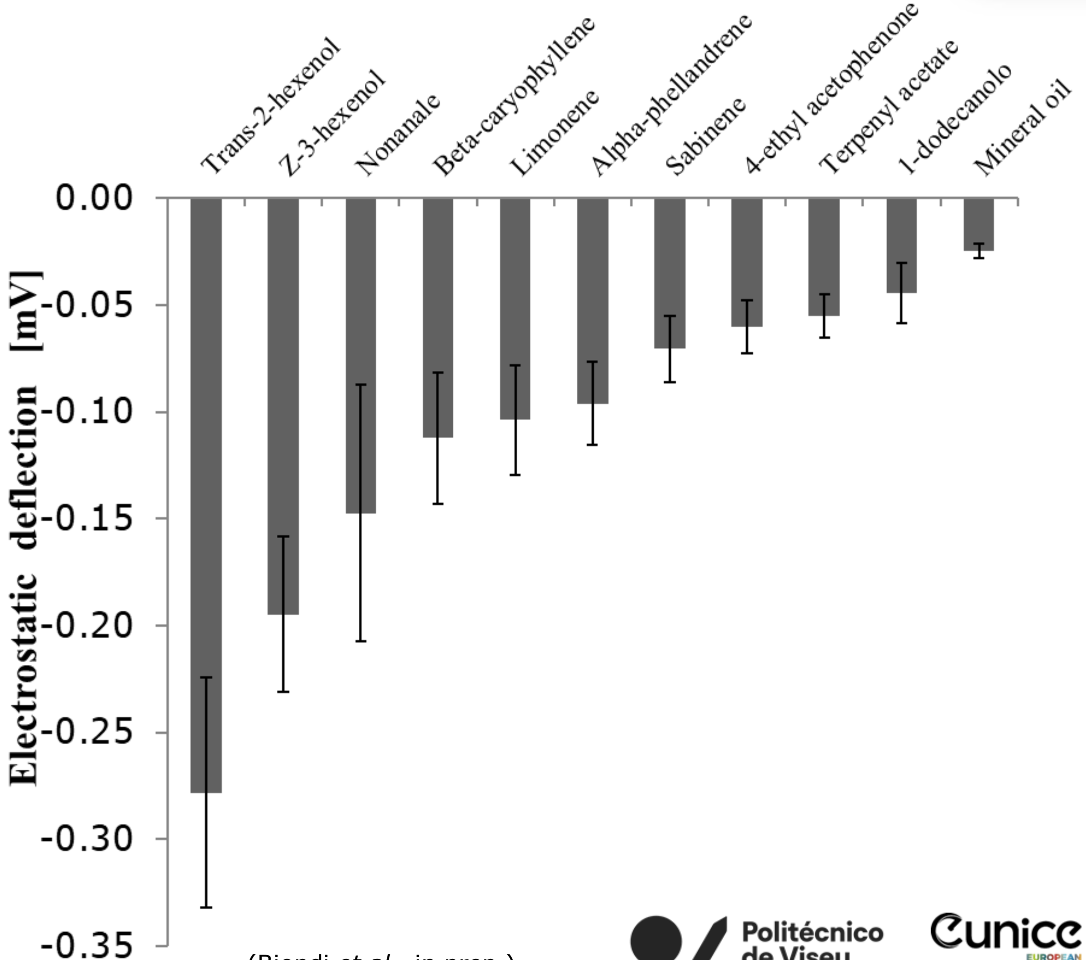
Code	Compounds	Tomato Healthy	Tomato Egg	Tomato Larvae	D. viscosa	S. indicum
	Terpenes					
2)	α-Pinene	0.07b±0.025	0.09b±0.025	0.20a±0.016	0,08b±0.011	-
3)	α-Tujene	-	-	-	0.01±0.002	-
5)	Camphene	0.02a±0.005	tr b	0.02a±0.001	0.01a±0.002	tr b
6)	β-Pinene	tr b	-	0.01b±0.002	0.04a±0.014	-
7)	Sabinene	0.81b±0.241	0.99b±0.243	1.77a±0.451	trc	0.01c±0.003
9)	δ-3-Carene	tr b	tr b	0.01b±0.002	0.02a±0.004	-
10)	Myrcene	-	-	-	0.02±0.002	-
11)	α-Phellandrene	0.26a±0.029	0.34a±0.052	0.58a±0.147	tr b	tr b
12)	α-Terpinene	0.07a±0.014	0.06a±0.014	0.09a±0.019	0.01b±0.002	-
14)	Limonene	0.57a±0.0195	0.59a±0.53	0.95a±0.141	0.15b±0.037	0.02c±0.005
15)	β-Phellandrene	1.24b±0.318	1.67b±0.376	2.40a±0.568	tr c	0.02c±0.004
17)	γ-Terpinene	0.01a±0.002	0.01a±0.002	0.02a±0.003	0.01a±0.002	-
18)	Terpinolene	0.02a±0.005	0.01a±0.003	0.02a±0.007	0.01b±0.001	tr c
	All	*3.07*	*3.76*	*6.07*	*0.36*	*0.05*
	Oxygenated terpenes					
16)	Eucalyptol	-	-	-	0.02±0.001	-
21)	(Z)-Rose oxide	tr	tr	0.01±0.002	-	-
43)	Terpenyl acetate	1.07a±0.310	0.16b±0.006	0.90a±0.184	0.28b±0.016	0.41b±0.106
47)	p-Menth-ene-3-one (Piperitone)	-	0.01±0.002	0.01±0.003	0.01±0.002	-
50)	Cuminaldehyde	0.01b±0.002	0.02a±0.004	0.02a±0.002	-	-
53)	4-Ethyl acetophenone	0.68b±0.147	0.45b±0.038	0.48b±0.010	1.49a±0.206	0.91a±0.242
	All	*1.76*	*0.64*	*1.41*	*1.80*	*1.32*
	Sesquiterpenes hydrocarbons					
27)	α-Cubebene	0.01	0.02	0.01	0.01	-
28)	Ylangene	-	-	-	0.02	-
30)	Cycloisolongifolene	-	-	-	0.01	-
31)	(E)-α-Bergamotene	-	-	-	0.01	-
33)	β-Caryophyllene	0.03b	0.09a	0.05b	0.03b	0.05b
34)	β-elemene	-	trb	-	0.08a	-
35)	Sesquiterpene n.i.	0.01	0.02	0.02	0.02	-
37)	Sesquiterpene n.i.	0.01	0.01	0.01	-	-
38)	Alloaromadendrene	-	-	-	tr	-
39)	γ-Elemene	0.01	-	-	-	-
40)	(E)-β-Cubebene	-	-	-	0.01	-
41)	α-Humulene	0.24	0.27	0.15	-	-
42)	D germacrene	-	-	-	0.09±0.025	-
44)	β-Cadinene	-	-	-	tr	-
45)	α-Selinene	-	-	-	0.01±0.002	-
46)	β-Selinene	-	-	-	0.01±0.001	-
48)	δ-Cadinene	-	-	-	0.01±0.001	-
49)	α-Curcumene	-	-	-	0.03±0.008	-
51)	(Z)-Calamenene	-	-	-	0.01±0.002	-
	All	*0.31*	*0.41*	*0.24*	*0.30*	*0.05*
	Oxygenated sesquiterpenes					
57)	α-Cadinol	-	-	-	0.07±0.027	-
	All	-	-	-	*0.07*	-
	C_{13}-norisoprenoids					
8)	4-Methyl-5-penten-2-one	0.10a±0.026	-	0.04a±0.006	tr b	-
22)	6- Methyl-5-hepten-2-one	0.11a±0.003	0.14a±0.035	0.13a±0.018	0.03b±0.002	0.10a±0.023
52)	Geranyl acetone	0.20a±0.031	0.23a±0.031	0.25a±0.062	-	0.14b±0.005
56)	β-Methyl-ionone	-	-	-	-	0.12±0.035
	All	*0.41*	*0.37*	*0.42*	*0.03*	*0.36*
	Aliphatic compounds					
	Aldehydes					
19)	Octanal	-	-	-	-	0.08±0.007
25)	Nonanal	0.19b±0.016	0.15b±0.035	0.15b±0.027	-	0.31a±0.038
	All	*0.19*	*0.15*	*0.15*	-	*0.39*
	Esters					
36)	Methylbenzoate	-	-	-	0.03±0.002	-
	All	-	-	-	*0.03*	-
	Alcohols					
20)	(E)-2-penten-1-ol	-	-	-	-	0.02±0.009
23)	Diacetonealcohol	-	-	-	-	0.03±0.004
24)	(Z)-3-hexen-1-ol	0.05±0.019	0.05±0.013	0.04±0.003	-	-
26)	Heptanol	-	-	-	-	0.03±0.001
55)	Dodecanol	-	-	-	-	0.07±0.023
	All	*0.05*	*0.05*	*0.04*	-	*0.15*
	Hydrocarbons					
1)	Decane	-	-	-	-	tr
4)	Toluene	-	-	-	-	tr
13)	Dodecane	-	-	-	-	tr
29)	Pentadecane	-	-	-	-	0.07±0.009
32)	Hexadecane	-	-	-	0.02±0.003	-
54)	Nonadecane	-	-	-	-	0.01±0.002
	All	-	-	-	*0.02*	*0.08*
	Total volatiles	*5.79*	*5.38*	*8.33*	*2.61*	*2.40*

unice EUROPEAN UNIVERSITY

Companion plants

- EAG trials

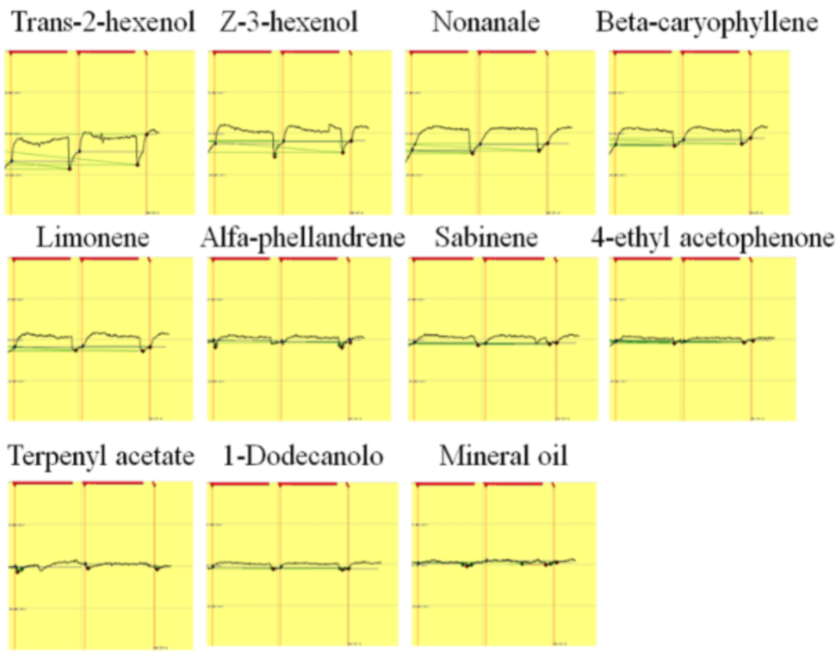


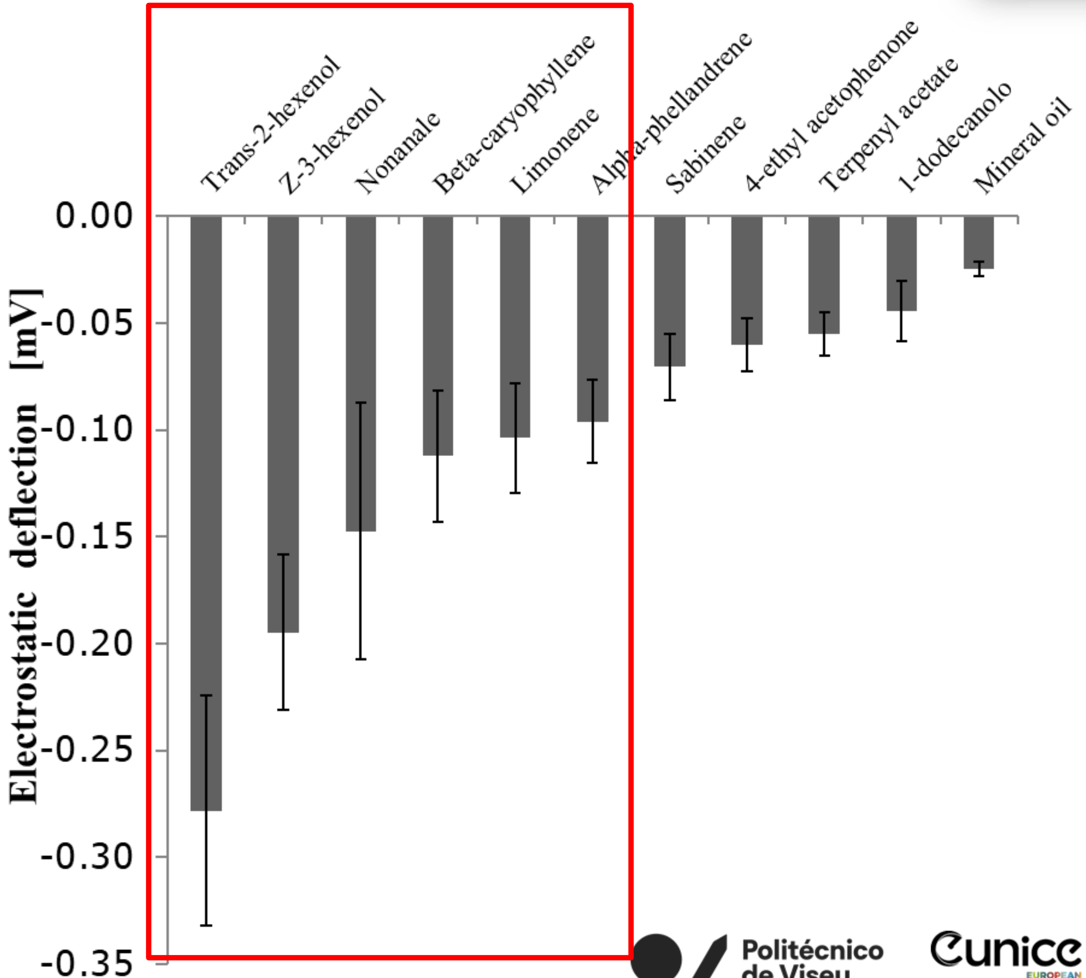


(Biondi *et al.*, in prep.)

Companion plants

- ➢ EAG trials





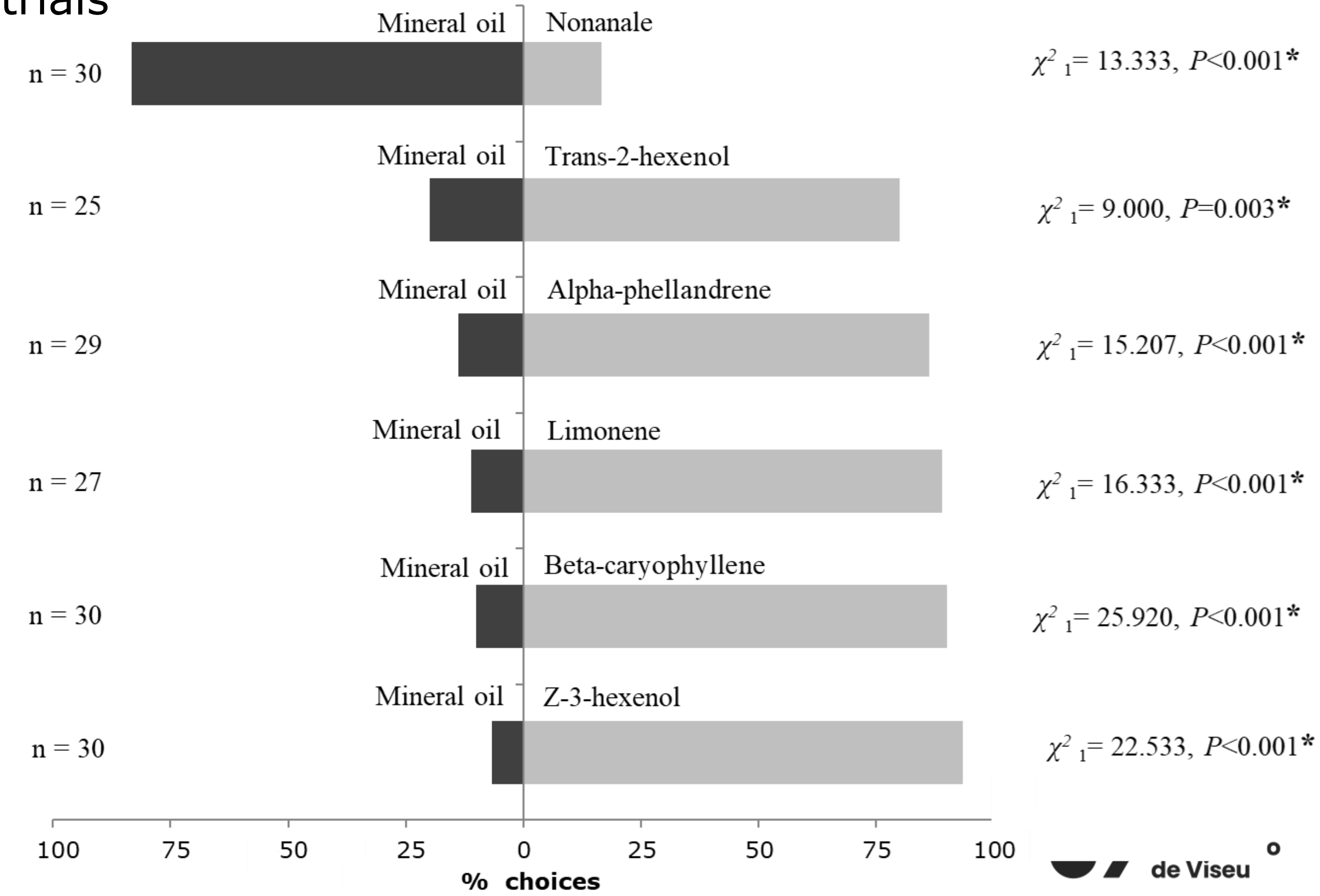
(Biondi *et al.*, in prep.)

Politécnico de Viseu

Eunice EUROPEAN UNIVERSITY

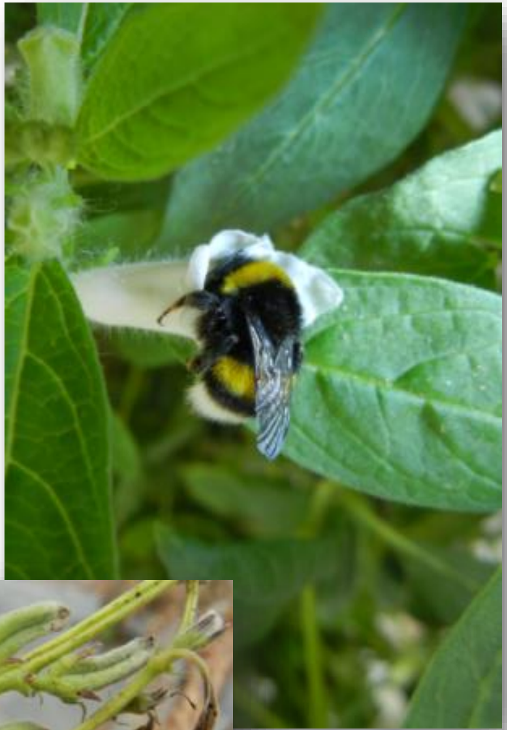
Companion plants

- Olfactometer trials

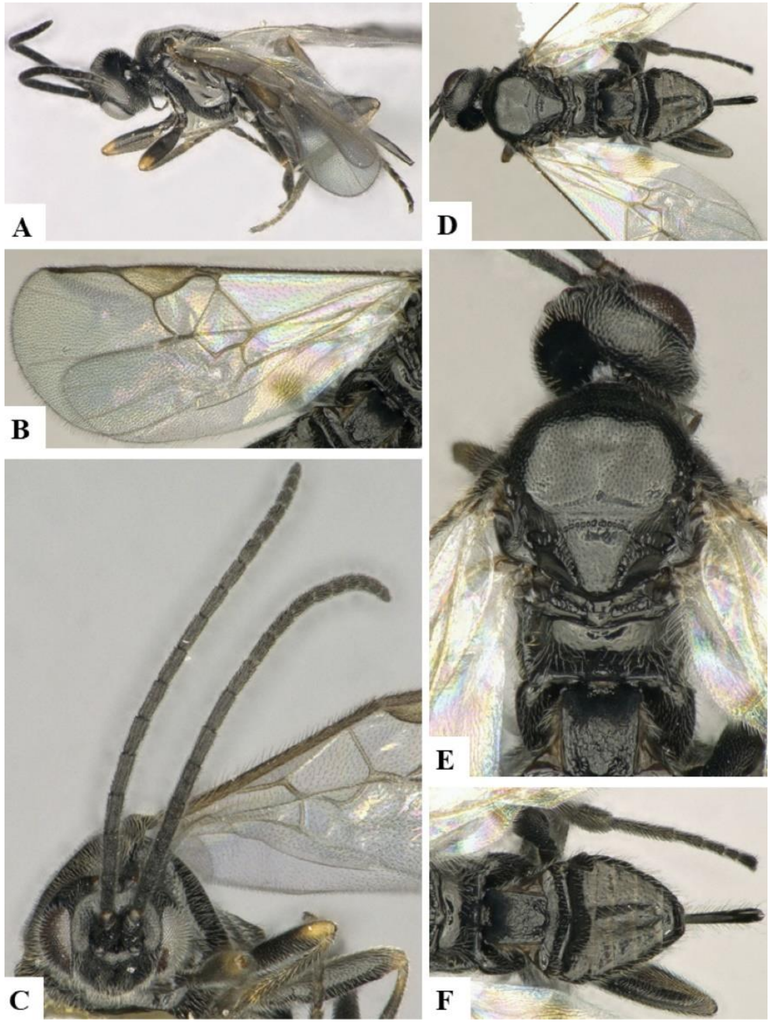


(Biondi *et al.*, in prep.)

Companion plants



Further food web element



- ➢ ***Dolichogenidea gelechiidivoris***
  - – Hymenoptera: Braconidae
  - – Native to the Neotropics
  - – koinobiont solitary endoparasitoid of *T. absoluta* and a few other closely related species
    - • e.g. *Phthorimaea operculella*, *Keiferia lycopersicella*
  - – Imported in Kenya from Peru
  - – Fortuitously recovered in Spain and Algeria

(Denis *et al.*, 2021)

Acknowledgements

- Project ASTER, PRIMA SECTION 2 2021 - MULTI-TOPIC
- ENI Cross-Border Cooperation Programme Italy-Tunisia 2014-20, INTEMAR project -IS_2.1_073
- Agritech National Research Center European Union Next-Generation EU

ASTER
Agroecology-inspired Strategies and Tools to Enhance Resilience and ecosystem services in tomato crop

INTEMAR

Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | agritech

Politécnico de Viseu | Eunice EUROPEAN UNIVERSITY


Thank you for your attention!

ERASMUS + BLENDED
INTENSIVE PROGRAMME

AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS

VISEU, PORTUGAL, 16 - 22 JUNE 2024

Politécnico de Viseu

Eunice EUROPEAN UNIVERSITY

Funded by
the European Union