Effective phytochemicals against the tomato leafminer *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). A review

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Our generation`s struggle portrays the sustainable development in a globalized world on the background of dramatic climate disorders, critical biodiversity losses and ecosystems risks. Today`s agriculture must provide safe and high-quality food to the world's population, which has grown from less than two billion to nearly seven billion in just 100 years (Roser et al.,2018). As example, in their struggle to save the tomato production from the tomato leafminer, *Tuta absoluta*, growers applied insecticides as often as 23 treatments per season (Zlof and Suffert, 2012), even more than 2 times a week (Moreno et al., 2011), more than 40 applications per crop cycle (Brito et al., 2015), and even 60 to 80 insecticide applications per season (Bacci et al., 2018). The intensive use of insecticides favored the insecticides resistance to many different insecticides groups. For organic farmers, the pressure to identify appropriate control measures is even higher. As insecticide-resistance phenomenon has unguessable implications for our future and today`s population is more than ever involved in a healthy lifestyle, preferring organic food, there is **an urgency to develop safe alternatives of pest control and plant protection** (Moreno et al., 2011).

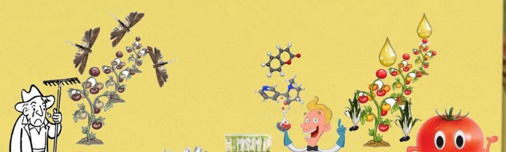
One of the "bio" ways to control pests is represented by plant-derived products. *Phytochemicals* are non-nutritive compounds, produced by plants to protect themselves from biotic stressors. Formulated as botanical pesticides, these secondary metabolites are safer for the environment due to their biodegradability, easily available for small farmers, ecologically sound and sustainable (Joshi et al., 2018) and as they leave no toxic residues and usually posses also medicinal properties for humans, are considered of low toxicity for mammals. In India, botanical insecticides were used more than 4000 years ago while China and Egypt protect their stored grains with phytochemicals more than 3200 years ago.

One of the most frightening invasive pests is the tomato leafminer, a devastating pest of cultivated tomato, although could be hosted on different Solanaceous crops, like potatoes, sweet pepper, eggplants (Desneux et al., 2010) Currently this pest is in transition to polyphagy, as more than 40 plant species, 9 families, including Monocotiledonatae, are now reported to be its host. The present review synthetizes the research concerning **the use of phytochemicals in tomato leafminer control.**

Materials and methods

Available articles on *T. absoluta*:
Google Scholar > 20.000
ResearchGate < 10.000
Academia - 3404
Scopus - 614
WoS - 557
PubAg - 270

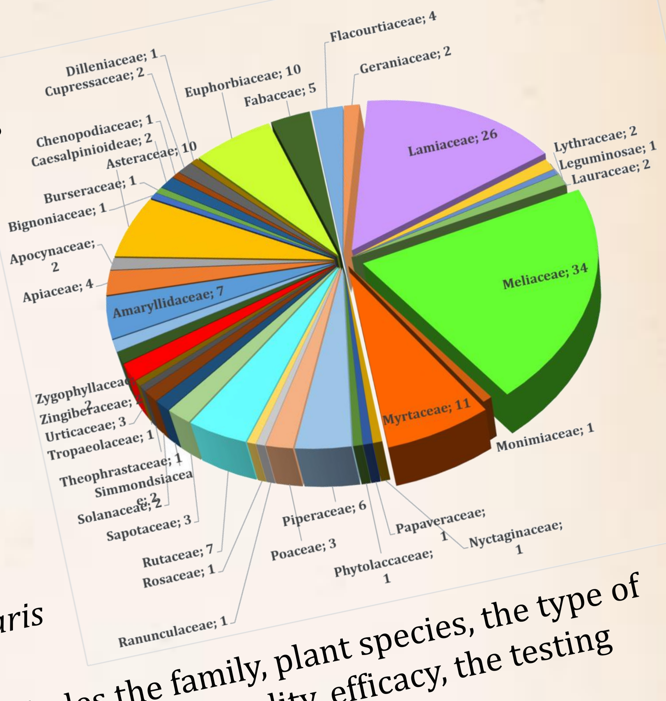
Graphical abstract



Results

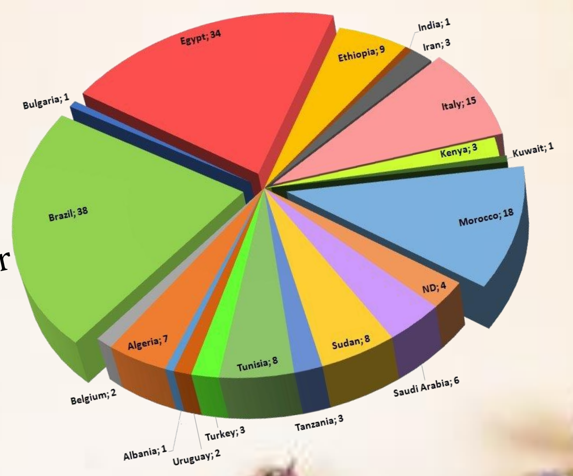
In total 166 trials, using plants belonging to 37 botanic families, 94 species were used in tests to control *T. absoluta*.

The plant species most often used was the neem, *Azadirachta indica*, also used as a control for different tests. Several commercially available products are mentioned. The second most commonly used plant was basil, *Ocimum basilicum*, the 3[rd] *Allium sativum*, the 4[th] *Jatropha curcas*, *Thymus vulgaris* and *Syzygium aromaticum*.



For each mention, the synthesis table includes the family, plant species, the type of preparation, information regarding LD_{50}, LD_{90}, dose, mortality, efficacy, the testing method, the country and the reference.

Family	Plant species	BI type	LD50 (µl ml−1) /Dose/Mortality	Test on T.a.	Country	Reference
Asteraceae	Acmella oleracea L.	AE (HE and EE)	88.3% (EE), 100% (HE); LD 50 HE 1.	L., topical	Brazil	Moreno et al., 2011
Asteraceae	Ageratum conyzoides (L.) L.	HE extract	0.44 (at 24h)	impregnation and to	Brazil	Moreira et al, 2004
Asteraceae	Ageratum conyzoides L.	AE (HE and EE)	35.0% (EE), 51.7% (HE)	L., topical	Brazil	Moreno et al., 2011
Apocynaceae	Allamanda cathartica L.	AE (HE and EE)	25.0% (EE), 23.3% (HE)	L., topical	Brazil	Moreno et al., 2011
Amaryllidaceae	Allium cepa L.	WE	for 2% & 6% conc. - 67.3 & 69.2 %	L. & F.	Saudi Arabia	Ghanim et al., 2017
Amaryllidaceae	Allium sativum L.	WE	for 2% & 6% conc. - 52.5 & 75.2 %	L. & F.	Saudi Arabia	Ghanim et al., 2018
Amaryllidaceae	Allium sativum L.	WE	L.: eff. 95%; G.: 59.92%	L. & G.	Ethiopia	Shiberu and Getu, 2017a
Amaryllidaceae	Allium sativum L.	WE	eff. (10d) 72.49%	F.; natural infestatic	Ethiopia	Shiberu and Getu, 2017b
Sapotaceae	Argania spinosa	ME	5 819 778 ppm	L., leaf-dip bioassay	Morocco	Ait Taadaouit et al., 2012
Sapotaceae	Argania spinosa	ME	LD90 364.97x103	L., leaf-dip bioassay	Morocco	Nilahyane et al., 2014
Papaveraceae	Argemone mexicana L.	AE (HE and EE)	28.3% (EE), 48.7% (HE)	L., topical	Brazil	Moreno et al., 2011
Asteraceae	Artemisia cina Berg ex Poljakov	E-Ac E	74.19 % efficacy	naturally infested gı	Egypt	Derbalah et al., 2012
Asteraceae	Artemisia vulgaris L.	AE (HE and EE)	15.0% (EE), 8.3% (HE)	L., topical	Brazil	Moreno et al., 2011
Meliaceae	Azadirachta indica A. Juss	HE	LD50 = 41.73	L., topical	Brazil	Moreno et al., 2012
Meliaceae	Azadirachta indica A.Juss	Nimbecidine (EC)	LC50 0.064%	L. & F.; IRAC-022	Egypt	Sammour et al., 2018
Meliaceae	Azadirachta indica A.Juss	WE	nd/nd/ c. 5% - 100% (soil), 98.3% (	L., G.; soil, leaves, t	Brazil	Gonçalves-Gervásio and Vendram
Meliaceae	Azadirachta indica A.Juss	EE	24.5% egg ,86.7%, 100% larval mo	4d	nd	Chhetri, 2018
Meliaceae	Azadirachta indica A.Juss	WE	L.: eff. 98.33%; G.: 66.54%	L. & G.	Ethiopia.	Shiberu and Getu, 2017a
Meliaceae	Azadirachta indica A.Juss	WE	eff. (10d) 74.26%	F.; natural infestatic	Ethiopia.	Shiberu and Getu, 2017b
Meliaceae	Azadirachta indica A.Juss	ME	nd/nd/ 100% at 6 days	L., leaf-dip bioassay	Brazil	Trindade et al., 2000
Flacourtiaceae	Banara guianensis Aubl.	AE (HE and EE)	36.7% (EE), 41.7% (HE)	L., topical	Brazil	Moreno et al., 2011
Flacourtiaceae	Banara nitida Spruce ex Benth.	AE (HE and EE)	23.3% (EE), 18.3% (HE)	L., topical	Brazil	Moreno et al., 2011
Caesalpinioideae	Bauhinia variegate L.	AE (HE and EE)	11.7% (EE), 15.0% (HE)	L., topical	Brazil	Moreno et al., 2011
Nyctaginaceae	Bougainvillea glabra Choisy	AE (HE and EE)	33.3% (EE), 51.7% (HE)	L., topical	Brazil	Moreno et al., 2011
Asteraceae	Calendula officinalis L.	AE (HE and EE)	13.3% (EE), 15.0% (HE)	L., topical	Brazil	Moreno et al., 2011
Chenopodiaceae	Chenopodium ambrosioides L.	AE (HE and EE)	16.7% (EE), 21.7% (HE)	L., topical	Brazil	Moreno et al., 2011
Rutaceae	Citrus limon (L.) Osbeck	EO & EO-NP	7.58(EO) & 11.06(NP); ingest.2.5-4	Lab.; ingestion anf t	Italy	Campolo et al., 2017
Rutaceae	Citrus reticulata Blanco, 1837	EO & EO-NP	6.45(EO) & 23.09(NP); ingest.2.5-4	Lab.; ingestion anf t	Italy	Campolo et al., 2018
Rutaceae	Citrus × sinensis (L.) Osbeck	EO & EO-NP	5.77(EO) & 7.98(NP); ingest. 2.5-4	Lab.; ingestion anf t	Italy	Campolo et al., 2019
Theophrastaceae	Clavija weberbaueri Mez.	AE (HE and EE)	25% (EE), 36.7% (HE)	L., topical	Brazil	Moreno et al., 2011
Caesalpinioideae	Copaifera duckei Dwyer	AE (HE and EE)	36.7% (EE), 63.3% (HE)	L., topical	Brazil	Moreno et al., 2011
Apiaceae	Coriandrum sativum L.	AE (HE and EE)	21.7% (EE), 66.7% (HE)	L., topical	Brazil	Moreno et al., 2011
Lamiaceae	Coridothymus capitatus L. Reich	EO	nd/ nd /0%; 100% at 3µl/ml	L., Potter tower,	Italy	Vella, 2016
Cupressaceae	Cupressus sempervires L.	EO	nd/ nd /16,6%	L., Potter tower,	Italy	Vella, 2016
Dilleniaceae	Curatela americana L.	AE (HE and EE)	41.7% (EE), 48.3% (HE)	L., topical	Brazil	Moreno et al., 2011
Zingiberaceae	Curcurma longa L.	EO (EW, W/O/W &	LC50 0.192%	L. & F.; IRAC-022	Egypt	Sammour et al., 2018
Poaceae	Cymbopogon citratus	WE	eff. (10d) 69.19%	F.; natural infestatic	Ethiopia.	Shiberu and Getu, 2017b
Poaceae	Cymbopogon citratus (DC.) Sta	WE	eff. 97,67%; G.: 57.94%	L. & G.	Ethiopia.	Shiberu and Getu, 2017a
Myrtaceae	Eucalyptus camaldulensis Dehn	EO	63% at 2000 ppm, 6 days	1st instars larvae	nd	Chhetri, 2023
Myrtaceae	Eugenia egensis DC.	AE (HE and EE)	30.0% (EE), 37.7% (HE)	L., topical	Brazil	Moreno et al., 2011
Euphorbiaceae	Jatropha curcas L.	HE	25% egg and 87%, 100% larval mo	4d	nd	Chhetri, 2018
Lauraceae	Laurus nobilis L	EO	nd/ nd /16,6%; 100% at 175 µl/ml	L., Potter tower,	Italy	Vella, 2016
Lythraceae	Lawsonia inermis	ME		L., leaf-dip bioassay	Morocco	Ait Taadaouit et al., 2012
Lythraceae	Lawsonia inermis	ME	LD90 1258.84 x103	L., leaf-dip bioassay	Morocco	Nilahyane et al., 2017
Flacourtiaceae	Mayna parvifolia Sleumer	AE (HE and EE)	26.7% (EE), 30.0% (HE)	L., topical	Brazil	Moreno et al., 2011
Meliaceae	Melia azedarach L.	WE	for 2% & 6% conc. - 84.5 & 88.1 %(	L. & F.	Saudi Arabia	Ghanim et al., 2016
Meliaceae	Melia azedarach L.	WE	laraval and pupal stage lenght	L., leaf-dip bioassay	Brazil	Brunherotto and Vendram
Lamiaceae	Mentha piperita L.	EO	nd/ nd /0%	L., Potter tower,	Italy	Vella, 2016
Solanaceae	Nicotiana sp	WE	eff. (10d) 49.35%	F.; natural infestatic	Ethiopia.	Shiberu and Getu, 2017b
Solanaceae	Nicotiana sp.	WE	L.: eff. 80%; G.:62.1%	L. & G.	Ethiopia.	Shiberu and Getu, 2017a
Lamiaceae	Ocimum basilicum L.	EO (EW, W/O/W &	LC50 0.126%	L. & F.; IRAC-022	Egypt	Sammour et al., 2018
Lamiaceae	Ocimum basilicum L.	6% basil WE	for 2% & 6% conc. - 54.1 & 56.3 %(	L. & F.	Saudi Arabia	Ghanim et al., 2014
Lamiaceae	Ocimum basilicum L.	Pl. & EO in paraffir	nd. Preference and oviposition w	L.; dual-choice beha	Belgium	Yarou et al., 2017
Lamiaceae	Ocimum basilicum L.	EO	nd/ nd /41,6%	L., Potter tower,	Italy	Vella, 2016
Lamiaceae	Ocimum gratissimum L.	Pl. & EO in paraffir	nd. Preference and oviposition w	L.; dual-choice beha	Belgium	Yarou et al., 2017



* Of the 166 analysed trials, almost a half (43,37%) have been done in Brazil and Egypt, followed by Morocco and Italy. Althgough it is obvious that much more studies have been done, their availability is limited. A troughout bibliographical review in colaboration with researchers from each of the main countries invaded by *T. absoluta* is recomended, in order to have a complete view of the plant-derived phytochemicals tested on this pest.

* The most used extraction method was extraction with methanol, ethanol, hexane and water extracts.

* The essential oils were used in 21% of tests and obtained either by hydro distillation using Clevenger apparatus or commercially purchased.

* The main phytochemical compounds were seldom determined, just in 12.7% of the tests. The majority, as limonene, camphene, caryophyllene, alpha humelene, p-cymene, γ-terpinene, diethyl ester, decanedioic acid, hexadecanoic acid, octadecenoic acid, octadecanoic acid, thiosulphuric acid, eugenol, thymol, estragol, linalol, carvacrol, coumarin etc. were already known as having insecticide action.

* Spilanthol was determined as a very promising candidate for futures insecticide. It is a fatty acid amide isolated from *Acmella oleracea* L., having also local anesthetic properties on humans.

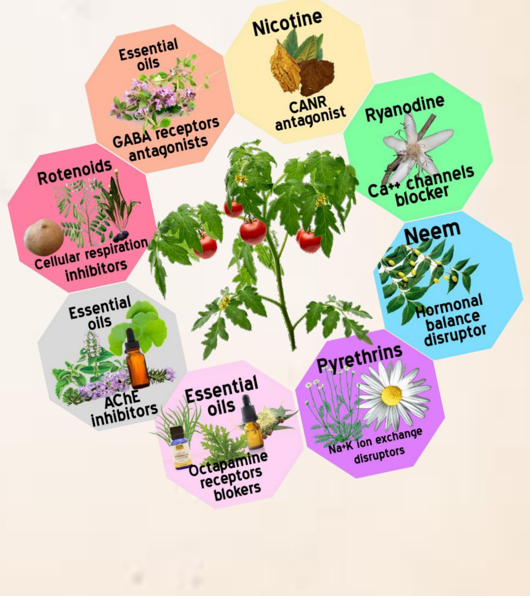
* Simmondsin, extracted from jojoba seeds, *Simmondsia chinensis* (Link) C. K. Schneid. was also a promising trial. This compound was initially believed toxic, but currently it started to be used in humans, as an appetite suppressant, with possible implications in obesity treatment.

* The way of expressing the insecticide effect varied greatly among studies and almost no value could be confirmed, LD_{50}, LD_{90}, dose, mortality, efficacy… were the most often used.

Future trends and challenges

- Enhancing microbial inoculants activity
- "Personalized" phytochemical extractions
- Tomato plant breeding following VOCs analysis
- Development of phytochemical pheromones, based on *T. absoluta* ovipostion behavior or other newly discovered host plant<->tomato leafminer interrelations.
- Nanoformulations and microencapsulation of the plant derived compounds
- Exploiting the compounds synergies, by rather using extracts and mixes of essential oils than developing new formulations based on a single active compound.

Conclusions



- Proper study design and consistency in the way of expressing results in the future studies, to allow conclusion drawing from meta-analysis, is needed.
- Standardization of extraction methods
- Side effects evaluation, for the useful entomofauna, soil, cultivated plants, environment and humans is a must
- Optimize IPM programs for *T. absoluta* and use mixes of different botanical insecticides for a safer and sustainable tomato production and environment.

Acknowledgement

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