# The invasive South American tomato pinworm, Tuta absoluta, continues to spread in Afro-Eurasia and beyond: the new threat to tomato world production

Nicolas Desneux, Maria G. Luna, Thomas Guillemaud, Alberto Urbaneja

# The invasive South American tomato pinworm, *Tuta absoluta*, continues to spread in Afro-Eurasia and beyond: the new threat to tomato world production

**Nicolas Desneux · María G. Luna · Thomas Guillemaud · Alberto Urbaneja**

The economic and ecological effects of invasive species, notably pests (Mack et al. 2000; Suckling and Brockerhoff 2010; Ragsdale et al. 2011), are now widely recognized (Thomas 1999; Pysek and Richardson 2010). The South American tomato pinworm *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) is an invasive pest, native to South America which was detected in eastern Spain at the end of 2006. Since then, *T. absoluta* has spread to the European and the North African Mediterranean Basin countries where it has become a serious agricultural threat to tomato production in both greenhouse and outdoor tomato crops (see Desneux et al. 2010 for a thorough review). This pest spreads rapidly and its status in the world has completely changed within only a few years from a South American tomato pest to a major threat to tomato world production. In this letter, we update the available information on the current distribution of *T. absoluta* in the world. Moreover, we describe and discuss the threat represented by the rapid spread of *T. absoluta* and how this pest is going to change world tomato production.

N. Desneux (✉) · T. Guillemaud
French National Institute for Agricultural Research (INRA), 400 Route des Chappes, 06903 Sophia Antipolis, France
e mail: nicolas.desneux@sophia.inra.fr

M. G. Luna
CEPAVE (CCT La Plata CONICET UNLP), Calle 2 Nro. 584 (1900), La Plata, Argentina

A. Urbaneja
Unidad de Entomología, Centro de Protección Vegetal y Biotecnología, Instituto Valenciano de Investigaciones Agrarias (IVIA), Carretera Moncada Náquera km 4,5, 46113 Moncada, Valencia, Spain

## Exceptional speed of spread in invaded areas

*Tuta absoluta* is thought to be native to Central America although records until recently are unsure and the pest has not been reported in this area for almost 50 years. Dissemination throughout South America was attributed to fruit commercialization (Cáceres 1992), but this has not been supported by any further datasets. Nevertheless, introductions into new regions appear to be somehow linked to importation of tomato fruits, with confirmed cases in Eurasia (UK, Netherlands, Russia, and Lithuania). Conversely, although data from sampling with pheromone traps seem to indicate that *T. absoluta* is characterized by an active dispersal capacity, more reliable information is not available to shed light on how *T. absoluta* adult dispersion contributes to its rapid spread in Mediterranean countries. Data on its flight ability and how wind currents may contribute to long range dispersal are still lacking, though the history of invasion in Afro-Eurasia and Middle East countries suggests that *T. absoluta* is able to spread and rapidly colonize new areas without any human-related help.

In 2007, *T. absoluta* was found in multiple locations in Spain, and in the following years in main Mediterranean coastal tomato-producing areas with populations quickly reaching damaging levels (Desneux et al. 2010). This occurred despite plant protection agencies' efforts, demonstrating how fast *T. absoluta* populations can build up when resources are available. In Afro-Eurasia, the pest was reported by the end of 2011 (by academic scientists, extension scientists and/or government official reports) in

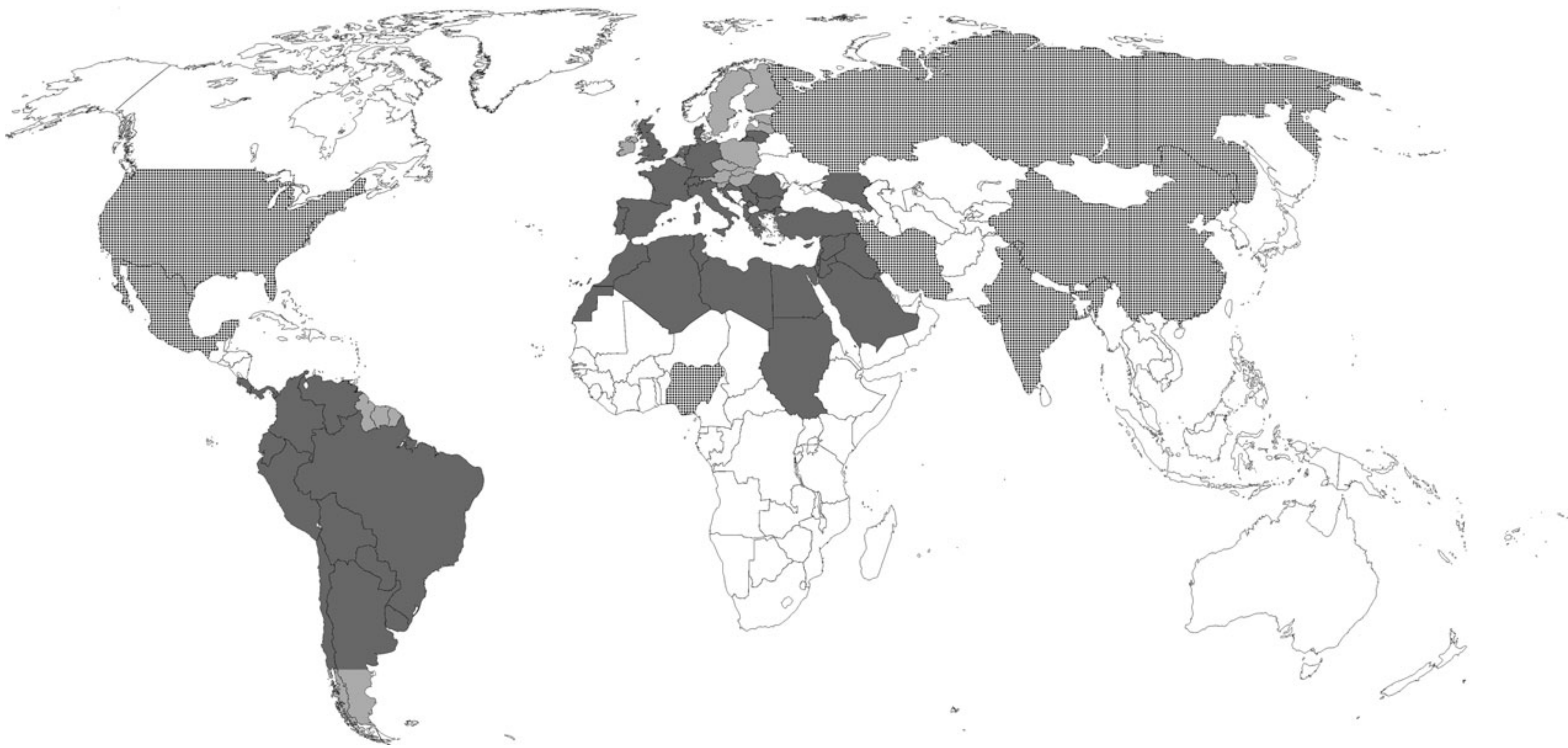

**Fig. 1** Current distribution (late 2011) of *Tuta absoluta* in the world and important countries for tomato world production. Countries (or specific areas) are indicated as (i) *T. absoluta* presence has been confirmed (*dark grey*), (ii) *T. absoluta* is considered present because of geographic proximity (*light grey*), and (iii) important countries for tomato production (i.e. >2% of tomato-planted world surface or >2% of world tomato production) that are at risk of invasion because of recent moves of *T. absoluta* in the world (*dotted drawing*). The information provided is based on a compilation of reports from plant protection services and extension specialists and on published scientific articles

Albania, Algeria, Bahrain, Bosnia and Herzegovina Bulgaria, Cyprus, Croatia, Denmark, Egypt, France, Germany, Greece, Hungary, Israel, Iraq, Italy, Jordan, Kosovo, Kuwait, Libya, Lithuania, Malta, Morocco, Netherlands, Portugal, Romania, Russia (Krasnodar area), Saudi Arabia, Serbia, Spain, Switzerland, Syria, Tunisia, Turkey, and United Kingdom (Buhl et al. 2010; Cîuljak et al. 2010; Desneux et al. 2010; Duric and Hrnic 2010; Erler et al. 2010; Keresi et al. 2010; Kiliç 2010; Ostrauskas and Ivinskis 2010; Seplyarsky et al. 2010; Izhevsky et al. 2011) (Fig. 1). Moreover, because of geographic proximity, *T. absoluta* is also considered by Plant Protection agencies such as USDA-APHIS (U.S. Department of Agriculture Animal and Plant Health Inspection Service) to be present in the following countries: Austria, Belgium, Czech Republic, Estonia, Finland, Ireland, Latvia, Luxembourg, Poland, Russia (European border), Slovakia, Slovenia, and Sweden (Bech 2011) (Fig. 1). Based on the current speed of spread observed in the mainland of the Afro-Eurasian super continent and on tomato crops not infested in Asia yet (1.9 M ha of tomato, with 20.9, 13.6, and 3.7% of the world tomato-planted surface in China, India, and Iran, respectively), *T. absoluta* may invade Iran in 2011 2012, India in 2013 2014, China in 2015 2016 and the pest would ultimately reach the Pacific Coast around 2016 2017. This would mainly depend on measures that the Indian and Chinese governments would take to slow down the spread in these countries.

## Insights on scenarios of invasion by *T. absoluta*

Introductions of individuals in remote geographical areas can, in certain circumstances, lead to invasions, i.e., to their establishment, increase in number and geographical spread. Reasons for success or failure of such introductions remain unclear and constitute a significant research area in invasion biology (Kolar and Lodge 2001). Both the success and failure of invasions can be observed in various locations in the case of multiple introductions, some of them invading and some of them failing to establish, as in the case of the western corn rootworm *Diabrotica virgifera* (Ciosi et al. 2008). They can also be observed over a period of time when a recent burst of invasions suddenly occurs after a long period of unsuccessful introductions, as in the case of the Asian ladybird *Harmonia axyridis* (Lombaert et al. 2010). The recent history of *T. absoluta* most likely fits the latter case: it remained in South America, at high density in some locations, for more than 40 years and then suddenly became successfully invasive in various parts of the world, including remote areas such as Africa and Europe, and the northern part of its native range (Central America). Possible explanations include (i) changes in the intercontinental migration regime, with introductions occurring only recently or being more frequent than before, (ii) changes in the environment allowing a new fit between the introduced individuals and their environment, or (iii) evolutionary changes in the pest biological characteristics also leading to a better match between the exotic environment and the introduced species (Facon et al. 2006). In addition, after the establishment of the introduced individuals, the colonization of the Mediterranean countries has been exceptionally rapid, with a geographical spread of ca. 4,000 km in about 5 years. Such speed may be explained by intra-continental dispersal facilitation due to human transportation, but it can also be caused by ecological or evolutionary phenomena. First, the Mediterranean environment may be particularly suitable for the pest because of various factors including climatic conditions or tomato varieties. The absence of co-evolved natural enemies may also explain why the dynamics in the invaded area looks so explosive in comparison to the native area where natural enemies are frequent (Luna et al. 2007 and references therein). The tomato-production system is more intensive in Europe and North Africa and thus constitutes a richer and more homogeneous environment than in South America which may have a positive effect on growth and dispersion of *T. absoluta*. Second, a rapid post introduction evolution of the newly introduced pest population may explain its impressive dynamics: the literature on invasions shows that dispersal capabilities can increase during colonization (Phillips et al. 2006) because of a simple evolutionary process (best dispersers mate together on the colonization front (Shine et al. 2011)). A similar process may explain the increase in growth ability (evolution toward r strategy) of the invader during colonization (Burton et al. 2010).

In order to understand what processes actually happened and to propose a likely explanation for the recent invasions of *T. absoluta* and their dynamics, we need to describe its 'routes of invasion', i.e., the history of their populations of origin and the historical, demographic and genetic features of the introduced, established and invasive populations (Estoup and Guillemaud 2010). It is worth noting that the description of invasion routes including the finding of the precise population(s) of origin can also facilitate how to design strategies to prevent new introductions and to control invasive populations (Estoup and Guillemaud 2010). The main questions related to the invasion routes of *T. absoluta* are the following: (i) Did a single or multiple transatlantic introduction from South America account for both European and African invasions? (ii) If only one transatlantic introduction occurred, what was the sequence of the events an introduction from the native area to Africa and then from Africa to Europe or the opposite? (iii) Where is (are) precisely located the source population(s) in

South America? Historical records suggest that southern Europe was the first and may be the sole introduction point from South America because the tomato borer had never been observed in Europe or Africa until its detection in eastern Spain in 2006. However, recent literature shows that great discrepancies may exist between inferences made from direct recordings and invasion routes inferred from population genetics studies (e.g., Miller et al. 2005).

Various teams in the world are currently working at inferring the routes of invasion of *T. absoluta* using molecular genetic markers to describe the population genetics variability of the tomato borer in its whole geographical range. The study of Cifuentes et al. (2011) is the first attempt to do so, but unfortunately they could not provide any information because the molecular markers that were used (ITS1, ITS2, and COI) displayed no variation throughout the whole geographical range of the tomato borer. Today, the exact origin of invasive *T. absoluta* and its invasion pathways remain unresolved. However, there is no doubt that both ongoing and future studies using more appropriate variable molecular markers such as microsatellites, SNPs, or RADs (Restriction site Associated DNA, Hohenlohe et al. 2010) will soon provide a window into the history of *T. absoluta* invasiveness.

## *Tuta absoluta* emerging as a major threat to sustainability of tomato world production

Tomato world production in 2009 was about 152 M tons fresh tomatoes produced on 4.4 M ha. The top ten leading tomato-producing countries are China, USA, India, Turkey, Egypt, Italy, Iran, Spain, Brazil, and Mexico. Production has increased by 40% in only 10 years with Asia accounting for 84% of increased production (China alone accounts for 63% of this increase). Tomato is the second most important vegetable crop next to potato in the world and *T. absoluta*-related threat to world tomato production has drastically changed since 2006. The pest was limited to South America for almost 40 years prior the invasion of Spain. During this 'South American' period, only 3.1% of surface cultivated and 5% of tomato production was infested in the world. However, because of invasion in 2006 and rapid spread during the following years (up to 2011), 21.5% of surface cultivated (0.95 M ha), and 27.2% of tomato production (41 M tons) are now infested by *T. absoluta* (Food and Agriculture Organization Data, FAOSTAT). Based on the current known distribution (Fig. 1), the pest is now threatening huge tomato-production areas in Asia (e.g., Iran, India, and China), in North America (since it recently moved to Central America), and Africa (e.g., Nigeria represents 5.1% of the surface planted with tomato in the world). Overall, areas not infested yet but presently at risk for *T. absoluta* invasion represent 63.4% (2.78 M ha) of world tomato-cropped surface and 60.2% (92.1 M tons) of tomato production. A total of 84.9% (3.7 M ha) and 87.4% (133.7 M tons) of world tomato-cropped surface and world tomato production, respectively, are now directly threatened by *T. absoluta* and could be infested in the near future.

The presumed worldwide invasion would ultimately result in large environmental and economic issues. For example, the first years after the detection of *T. absoluta* in the Mediterranean Basin, it caused great damage to production and led to substantial increase of insecticide applications. At that time, up to 15 insecticide applications specifically targeting *T. absoluta* were added to Integrated Pest Management (IPM) schemes. For example, in Spain it led to an increase of 450 € per ha in cost related to pest management (per cropping season). Currently, because of optimization and better knowledge on *T. absoluta* biology and potential natural enemies, this cost has decreased to around 100 150 € per ha (A. Montserrat, Consejeria Agricultura, Región de Murcia, personal com.). In Argentina, management of *T. absoluta* is mainly based on preventive weekly or bi-weekly applications using about 16 different neurotoxic insecticides (Sánchez et al. 2009). IPM programs relying on monitoring methods and usage of selective insecticides (notably pyrethroids-, avermectin-, and spinosad-based products) are also recommended but still applied to a lesser extent (Polack and Mitidieri 2005). In central Argentina, management of *T. absoluta* accounts for 46 and 70% of pest management cost for early (Sept Dec) and late (Jan May) tomato crops, respectively, ranging between US $80 and $460 per ha (Strassera 2009). In the Northern Argentinean areas, costs usually remain stable throughout the cropping season (Apr Dec) and account for 38% (US $175 per ha) of total IPM costs (Molina et al. 2011).

In the worst case scenario, future invasions by *T. absoluta* in the world would result in an increase of around 240 420 M € (based on the Spanish case, i.e., 100 150 € per ha) and US $487 M (based on the Argentinean case, i.e., US $175 per ha) per year for pest management in tomato crops. In addition, extensive insecticide use by tomato growers may cause multiple negative side-effects (Desneux et al. 2006, 2007). In particular it would negatively affect natural enemies used in IPM programs in tomato crops (Arnó and Gabarra 2011; Zappalà et al. 2011), thus, compromising sustainability and efficacy of such programs in newly invaded countries.

Finally, *T. absoluta* appears as a major threat to countries, whose tomato exports are important for the economy, especially exporters such as Mexico, USA, Canada, India, and China (they are not infested yet but are now at high risk since the recent invasions both in the Afro-Eurasian continent and Central America, i.e., Panama). In several of these countries, including also many already infested, multiscale (local, regional, national, and international) programs are taking place or are being developed to reduce current and potential future impacts of *T. absoluta* on tomato production. However, it is unclear how they would be efficient in slowing down or preventing further spread of *T. absoluta*. The current distribution in the whole Afro-Eurasian continent appears almost irreversible and effective management would require the coordinated efforts of research scientists, extension specialists and growers not only in already invaded countries but also in those currently at risk of invasion.

**Acknowledgments** The authors thank Antonio Montserrat (Consejería de Agricultura, Región de Murcia) for providing information on costs related to *T. absoluta* management in Spain, the Plant Health & Environment Department of INRA for funding to ND and TG, and the Instituto Nacional de Investigación y Tecnología Agraria (INIA CC09 048) for funding to AU.

## References

Arnó J, Gabarra R (2011) Side effects of selected insecticides on the *Tuta absoluta* (Lepidoptera: 1 Gelechiidae) predators *Macrolophus pygmaeus* and *Nesidiocoris tenuis* (Hemiptera: Miridae). J Pest Sci. doi:10.1007/s10340 011 0384 z

Bech RA (2011) Federal import quarantine order for host materials of tomato leafminer, *Tuta absoluta* (Meyrick). Plant Protection and Quarantine, USDA APHIS

Buhl O, Falck P, Karsholt O, Larsen K, Vilhelmsen F (2010) Records of microlepidoptera from Denmark in 2009 (Lepidoptera). Entomol Medd 78:101 116

Burton OJ, Phillips BL, Travis JMJ (2010) Trade offs and the evolution of life histories during range expansion. Ecol Lett 13:1210 1220

Cáceres S (1992) La polilla del tomate en Corrientes. Biología y control. Estación Experimental Agropecuaria Bella Vista, INTA

Cifuentes D, Chynoweth R, Bielza P (2011) Genetic study of Mediterranean and South American populations of tomato leafminer *Tuta absoluta* (Povolny, 1994) (Lepidoptera: Gelechiidae) using ribosomal and mitochondrial markers. Pest Manag Sci 67:1155 1162

Ciosi M, Miller NJ, Kim KS, Giordano R, Estoup A, Guillemaud T (2008) Invasion of Europe by the western corn rootworm, *Diabrotica virgifera virgifera*: multiple transatlantic introductions with various reductions of genetic diversity. Mol Ecol 17:3614 3627

Cîuljak TG, Razov J, Gomboc S, Grubisic D, Juran I, Zianic K (2010) The first record of tomato leaf miner *Tuta absoluta* Povolny, 1994 (Lepidoptera: Gelechiidae) in Croatia. Glas Biljn Zastite 10:273 281

Desneux N, Ramirez Romero R, Kaiser L (2006) Multistep bioassay to predict recolonization potential of emerging parasitoids after a pesticide treatment. Environ Toxicol Chem 25:2675 2682

Desneux N, Decourtye A, Delpuech JM (2007) The sublethal effects of pesticides on beneficial arthropods. Annu Rev Entomol 52:81 106

Desneux N, Wajnberg E, Wyckhuys KAG, Burgio G, Arpaia S, Narváez Vasquez CA, González Cabrera J, Catalán Ruescas D, Tabone E, Frandon J, Pizzol J, Poncet C, Cabello T, Urbaneja A (2010) Biological invasion of European tomato crops by *Tuta absoluta*: ecology, history of invasion and prospects for biological control. J Pest Sci 83:197 215

Duric Z, Hrnic S (2010) Tomato leaf miner *Tuta absoluta* Meyrick in the Republic of Srpska. Agroznanje Agro knowl J 11:17 23

Erler F, Can M, Erdogan M, Ates AO, Pradier T (2010) New record of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) on greenhouse grown tomato in southwestern Turkey (Antalya). J Entomol Sci 45:392 393

Estoup A, Guillemaud T (2010) Reconstructing the routes of invasion: what for, how and so what? Mol Ecol 19:4113 4130

Facon B, Genton BJ, Shykoff J, Jarne P, Estoup A, David P (2006) A general eco evolutionary framework for understanding bioinvasions. Trends Ecol Evol 21:130 135

Hohenlohe PA, Bassham S, Etter PD, Stiffler N, Johnson EA, Cresko WA (2010) Population genomics of parallel adaptation in threespine stickleback using sequenced RAD tags. PLoS Genetics 6:e1000862

Izhevsky SS, Akhatov AK, Sinyov SY (2011) *Tuta absoluta* has been detected in Russia. Zashchita Karantin Rast 3:40 44

Keresi T, Ivanovic M, Tolic D (2010) Tomato moth (*Tuta absoluta* Povolny) new potential threat to tomato production in Serbia. Biljn Lek 38:474 484

Kiliç T (2010) First record of *Tuta absoluta* in Turkey. Phytoparasitica 38:243 244

Kolar CS, Lodge DM (2001) Progress in invasion biology: predicting invaders. Trends Ecol Evol 16:199 204

Lombaert E, Guillemaud T, Cornuet J M, Malausa T, Facon B, Estoup A (2010) Bridgehead effect in the worldwide invasion of the biocontrol harlequin ladybird. PLoS ONE 5:e9743

Luna M, Sánchez NE, Pereyra PC (2007) Parasitism of *Tuta absoluta* (Lepidoptera, Gelechiidae) by *Pseudapanteles dignus* (Hymenoptera, Braconidae) under laboratory conditions. Environ Entomol 36:887 893

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecol Appl 10:689 710

Miller N, Estoup A, Toepfer S, Bourguet D, Lapchin L, Derridj S, Kim KS, Reynaud P, Furlan L, Guillemaud T (2005) Multiple transatlantic introductions of the western corn rootworm. Science 310:992 992

Molina N, Verón R, Altamirano J (2011) Producción Hortícola Correntina. Análisis técnico y económico del tomate en la campana 2010. Boletín Electrónico de Tomate no. 27

Ostrauskas H, Ivinskis P (2010) Records of the tomato pinworm (*Tuta absoluta,* Meyrick 1917) Lepidoptera: Gelechiidae in Lithuania. Acta Zool Litu 20:151 155

Phillips BL, Brown GP, Webb JK, Shine R (2006) Invasion and the evolution of speed in toads. Nature 439:803

Polack AL, Mitidieri M (2005) Producción de tomate diferenciado. Protocolo preliminar de manejo integrado de plagas y enfermedades. INTA EEA, San Pedro

Pysek P, Richardson DM (2010) Invasive species, environmental change and management, and health. Annu Rev Environ Resour 35:25 55

Ragsdale DW, Landis DA, Brodeur J, Heimpel GE, Desneux N (2011) Ecology and management of the soybean aphid in North America. Annu Rev Entomol 56:375 399

Sánchez NE, Pereyra PC, Luna MG (2009) Spatial patterns of parasitism of the solitary parasitoid *Pseudapanteles dignus* (Muesebeck) (Hymenoptera: Braconidae) on the tomato leafminer *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Environ Entomol 38:365 374

Seplyarsky V, Weiss M, Haberman A (2010) *Tuta absoluta* Povolny (Lepidoptera: Gelechiidae), a new invasive species in Israel. Phytoparasitica 38:445 446

Shine R, Brown GP, Phillips BL (2011) An evolutionary process that assembles phenotypes through space rather than through time. Proc Natl Acad Sci USA 108:5708 5711

Strassera ME (2009) Análisis de la sustentabilidad de tres alternativas de manejo de plagas en tomate bajo cubierta en el Cinturón Hortícola Platense (Analysis of sustainability among three pest management alternatives in greenhouse tomato at La Plata Horticultural Belt, Buenos Aires, Argentina). Master Thesis, Fac Cs Agrarias y Forestales, UNLP

Suckling DM, Brockerhoff EG (2010) Invasion biology, ecology, and management of the light brown apple moth (Tortricidae). Annu Rev Entomol 55:285 306

Thomas MB (1999) Ecological approaches and the development of 'truly integrated' pest management. Proc Natl Acad Sci USA 96:5944 5951

Zappalà L, Siscaro G, Biondi A, Mollá O, González Cabrera J, Urbaneja A (2011) Efficacy of sulphur on *Tuta absoluta* and its side effects on the predator *Nesidiocoris tenuis*. J Appl Entomol. doi:10.1111/j.1439 0418.2011.01662.x