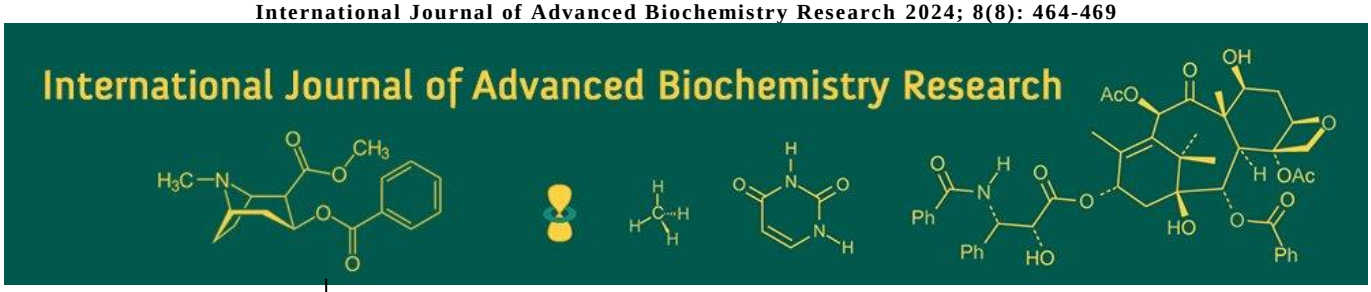

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Emerging threat: Reviewing the impact and management of South American tomato pinworm (*Phthorimaea absoluta)*

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Abstract
The South American tomato pinworm (*Phthorimaea absoluta*) poses a significant threat to global tomato (*Solanum lycopersicum*) production due to its rapid spread, devastating feeding habits, and ability to develop resistance to insecticides. This review provides a comprehensive examination of the biology, ecology, economic impact, and current management strategies of *P. absoluta*. The pest's lifecycle, from egg to adult, its preferred environmental conditions, and factors contributing to its successful establishment in new regions are discussed. Economic losses associated with *P. absoluta* infestations, including yield reductions and control costs, are highlighted. Current management practices, including chemical, biological, and cultural control methods, are evaluated, with an emphasis on integrated pest management (IPM) approaches. Furthermore, emerging technologies such as RNA interference (RNAi) for targeted pest control and the development of resistant tomato varieties are explored as sustainable alternatives to traditional insecticide use. This review underscores the urgent need for coordinated efforts among researchers, growers, and policymakers to mitigate the impact of *P. absoluta* and safeguard global tomato production.

Keywords: Biological control, epidermis, mirid bugs, *Phthorimaea absoluta*, resistance

Introduction
Tomato (*Solanum lycopersicum*) is one of the most economically significant vegetable crops globally, with production valued at billions of dollars annually. However, its cultivation faces numerous challenges, including pest infestations that can lead to substantial yield losses and increased production costs. Among these pests, the South American tomato pinworm (*Phthorimaea absoluta*) stands out as a formidable threat.

Phthorimaea absoluta, native to South America, has gained notoriety as a destructive pest of tomato crops worldwide. Since its introduction into Europe in the 1980s, likely through international trade, the pinworm has rapidly spread to various tomato-growing regions, including North and South America, Africa, Asia, and Oceania. Its ability to adapt to diverse climates and agricultural systems, coupled with its prolific reproductive capacity and voracious feeding habits, has contributed to its status as a key pest of concern.

The lifecycle of *P. absoluta* is characterized by four stages: egg, larva, pupa, and adult. Eggs are typically laid on the undersides of tomato leaves, from which larvae emerge and tunnel into plant tissues, causing characteristic mining damage. Larval feeding not only reduces photosynthetic capacity but also compromises the structural integrity of leaves and fruits, leading to premature defoliation and fruit drop. In severe infestations, yield losses can reach up to 100%, posing significant economic repercussions for growers and stakeholders along the tomato supply chain.

The success of *P. absoluta* as an invasive pest can be attributed to several factors, including its high reproductive potential, rapid development of insecticide resistance, and ability to complete multiple generations within a single growing season. Moreover, global trade and transportation networks facilitate the unintentional movement of *P. absoluta* across continents, contributing to its widespread distribution and establishment in new regions.

Efforts to manage *P. absoluta* have traditionally relied heavily on chemical insecticides.

However, the rapid evolution of resistance in *P. absoluta* populations to multiple classes of insecticides has necessitated the development and implementation of integrated pest management (IPM) strategies. IPM approaches encompass a range of tactics, including cultural practices, biological control agents, and the judicious use of chemical treatments, aimed at reducing pest populations while minimizing environmental impact and preserving natural enemies.

Recent advancements in biotechnological and genetic approaches offer promising avenues for enhancing *P. absoluta* management. Techniques such as RNA interference (RNAi) have shown potential for targeted suppression of key genes in *P. absoluta*, thereby disrupting its lifecycle and reducing pest populations without the need for broad-spectrum insecticides. Furthermore, ongoing research into the development of tomato varieties resistant to *P. absoluta* promises sustainable, long-term solutions to mitigate the impact of this invasive pest on global tomato production. In this review, we comprehensively examine the impact of *Phthorimaea absoluta* on tomato cultivation, elucidate its biological and ecological characteristics, assess current management strategies, and discuss emerging technologies for sustainable pest control. By synthesizing current knowledge and identifying gaps in research, we aim to provide insights into effective strategies for mitigating the economic and environmental impacts of *P. absoluta* infestations, ensuring the resilience and sustainability of tomato production worldwide.

Pest control measures

The eggs are laid singly on leaves of the upper part of the canopy, on the young stems and on sepals. The underside of the leaf is preferred in plants before flowering. However, adult females prefer both sides for oviposition in plants after flowering. The most preferred part is young, expanded leaves (73%), stems (21%), sepals (5%), and finally green fruits (1%) (Estay 2000). The 3rd and 4th leaves were often preferred by females for egg laying (Dervisoglou *et al*. 2022). Time required for egg hatching is 3.90±0.13days at 27 °C. According to Silva *et al*. (2015) [26] the larval developmental period is 8.91±0.09 days (d) at 25±1 °C, and 9.87±0.29 d at 30±1 °C. Pupal period lasted for 7.08±0.23d at 25±2 °C (Gharekhani*et al*. 2014) and 9.84±0.16d at 26±0.5 °C. A single female lays 260 eggs during lifetime at 27 °C. The life cycle completion from egg to adult of *P. absoluta* required 23.8±0.65 d at 25 °C, 19.06±0.56 d at 25 °C (Silva *et al*. 2015) [26], and 26±0.50 d at 33 °C. The optimum temperature for egg, larval and pupal development were 26, 28, and 30 °C, respectively. Temperature thresholds for development of egg, larva and pupa were estimated to be 6.9±0.5, 7.6±0.1 and 9.2±1 °C, respectively (Urbaneja *et al*. 2013). The thermal constant from egg to adult has been estimated to be 453.6-degree days (DD). Accordingly, thermal constants for egg, larva and pupa were 103.8±1.4, 238.5±0.5 and 117.3±5.3 DD, respectively. *P. absoluta* may complete up to 10 generations annually in South America (Desneux *et al*. 2010) [6] in tomatoes. In Italy, 9 generations per year and in Spain 13 generations per year have been reported in tomato crop systems.

P. absoluta larvae mine into the leaf feeding on the mesophyll tissue, creating galleries leaving the epidermis intact. According to Garzia *et al*. (2012), photosynthetic capacity is highly reduced by the larval phytophagy, reducing the production levels in open field and protected tomato crops. The larvae cause damage on tomato fruits creating small holes beneath the sepals. The damaged fruits loose their market value, leading to reduced farmers'profit. Apart from this, the infested fruits are difficult to be located and removed from the produce, making post-harvest procedures cost-ineffective for the farmer. Larvae also feed on the flower buds. Although the most devastating damage is done through the leaf mesophyll feedingand fruit boring, the larva stem mining deters the growth and development of the tomato plant. Such infestations lead to commercial downgrading of the produce and also affect the market chain of tomato.

Biology and Life Cycle

Phthorimaea absoluta, commonly known as the South American tomato pinworm, undergoes a complete metamorphosis consisting of four distinct life stages: egg, larva, pupa, and adult. Eggs are typically laid in clusters on the undersides of tomato leaves by female moths. Depending on environmental conditions and host availability, a female moth can lay several hundred eggs throughout her lifespan. Egg development is influenced by temperature and humidity, with hatching occurring within a few days under optimal conditions.

Upon hatching, larvae emerge and immediately begin to feed on tomato foliage. They bore into leaves and stems, creating characteristic mines and tunnels as they feed. Larval feeding can severely impact plant health by reducing photosynthetic capacity, causing leaf necrosis, and ultimately leading to premature defoliation. Larval development spans several weeks, during which larvae molt through multiple instars depending on food availability and environmental factors.

Mature larvae pupate within leaf mines or in soil near host plants. The pupal stage is a non-feeding, quiescent period during which larvae undergo metamorphosis into adult moths. Pupal development duration varies based on temperature and humidity, typically lasting several days to weeks before adult emergence. Adult *P. absoluta* moths are small, measuring 6-8 mm in wingspan, and are characterized by mottled brown wings with distinct markings. They are nocturnal and exhibit active flight behavior, dispersing to locate suitable host plants for oviposition. The adult lifespan is relatively short, ranging from 1 to 2 weeks, during which females continue to lay eggs and perpetuate the lifecycle.

Phthorimaea absoluta primarily targets solanaceous crops, with tomatoes (*Solanum lycopersicum*) being its preferred host. However, the pest is known to infest other related host plants such as potatoes (*Solanum tuberosum*), eggplants (*Solanum melongena*), and peppers (*Capsicum* spp.). The ability of *P. absoluta* to utilize multiple host plants contributes to its adaptability and persistence in agricultural ecosystems. Larvae of *P. absoluta* exhibit voracious feeding behavior, consuming plant tissues and causing extensive damage. Early instar larvae feed on leaf mesophyll, creating shallow mines that increase in size and depth as larvae mature. Severe infestations can result in significant yield losses, affecting both quantity and quality of harvested fruits.

Understanding the biology and feeding habits of *Phthorimaea absoluta* is crucial for developing integrated pest management strategies that effectively mitigate pest

damage while ensuring sustainable tomato production practices.

Ecology and Spread

Phthorimaea absoluta, originating from South America, has rapidly spread across various continents and become a global concern in tomato (*Solanum lycopersicum*) production. The pest's ability to adapt to diverse climates and agricultural systems has facilitated its establishment in new regions, posing significant challenges to growers worldwide.

In its native habitat, *P. absoluta* thrives in warm and humid conditions, which are conducive to its lifecycle and reproductive success. The pest's rapid population growth is supported by multiple generations per year, with females laying eggs prolifically on tomato and other solanaceous host plants. This reproductive strategy allows *P. absoluta* populations to build quickly, leading to widespread infestations under favorable environmental conditions.

Globalization and international trade have played crucial roles in the unintentional spread of *P. absoluta* to new geographical regions. Infestations often accompany the movement of plant materials, including seedlings, fruits, and vegetables, which serve as unwitting carriers of eggs or larvae. Once introduced into new areas, *P. absoluta* can establish local populations rapidly, particularly in regions where environmental conditions mimic those of its native range.

The ecological impact of *P. absoluta* extends beyond its direct damage to tomato crops. The pest's ability to infest multiple host plants within the Solanaceae family, including potatoes and peppers, broadens its ecological niche and enhances its survival in agroecosystems. This adaptability complicates pest management efforts, as control strategies must address multiple host plants and potential reservoirs of *P. absoluta* populations.

Effective monitoring and early detection are essential for preventing the establishment and spread of *P. absoluta* in new regions. Integrated pest management (IPM) approaches, incorporating cultural practices, biological control agents, and judicious use of insecticides, offer sustainable strategies for mitigating *P. absoluta* infestations while minimizing environmental impact. Continued research into the pest's ecological interactions, genetic variability, and adaptation mechanisms is crucial for developing proactive management strategies and safeguarding global tomato production against the threat posed by *Phthorimaea absoluta*.

Table 1: Summary of Studies on *Tuta absoluta* Management and Control

Study Title	Authors	Year	Journal/Source	Key Findings
Control failure likelihood and resistance mechanisms	Silva *et al.*	2011	Pest Management Science	Identified resistance mechanisms in *T. absoluta* to insecticides.
Biological control with *Nesidiocoris tenuis*	Urbaneja *et al.*	2012	BioControl	*N. tenuis* effectively predates *T. absoluta* eggs, aiding in pest control.
Efficacy of plant extracts against *T. absoluta*	Hernández-Suárez *et al.*	2014	Journal of Pest Science	Plant extracts showed promising insecticidal properties against *T. absoluta*.
Impact of *Nesidiocoris tenuis* on *T. absoluta* in tomatoes	Urbaneja-Bernat *et al.*	2020	Journal of Pest Science	Study on predatory impact of *N. tenuis* on *T. absoluta* larvae in greenhouse tomatoes.
Spread and management strategies of *T. absoluta*	Biondi *et al.*	2018	Annual Review of Entomology	Comprehensive review on global spread and management strategies for *T. absoluta*.
Effects of diatomaceous earth on *T. absoluta*	Kavallieratos *et al.*	2014	Journal of Pest Science	Evaluation of diatomaceous earth formulations as a control method for *T. absoluta*.
Natural enemies of *T. absoluta* in the Mediterranean	Zappalà *et al.*	2013	BioControl	Identification and role of natural enemies in controlling *T. absoluta*.
Economic impact of *T. absoluta* in Brazil	Campos and Silva	2017	Crop Protection	Quantified economic losses attributed to *T. absoluta* in Brazilian tomato production.
Overwintering and population dynamics of *T. absoluta*	Diamantidis *et al.*	2011	Environmental Entomology	Study on population dynamics and overwintering behavior of *T. absoluta* in Mediterranean climate.
Entomopathogenic nematodes against *T. absoluta*	Cocco *et al.*	2016	Journal of Pest Science	Effectiveness of nematodes in controlling *T. absoluta* larvae in laboratory and greenhouse trials.

This table format allows for a clear and concise summary of key studies, their authors, publication year, source, and main findings related to *Phthorimaea absoluta*. Adjust the columns and rows as needed to fit additional studies or specific details relevant to your review article.

Host Range and Feeding Behavior

Phthorimaea absoluta, commonly known as the South American tomato pinworm, exhibits a selective yet adaptable host range predominantly within the Solanaceae family. While tomatoes (*Solanum lycopersicum*) are its primary host and preferred target, *P. absoluta* can also infest other solanaceous crops such as potatoes (*Solanum tuberosum*), eggplants (*Solanum melongena*), and various species of peppers (*Capsicum* spp.). This broad host range within a single plant family enhances the pest's resilience and ability to persist across diverse agricultural landscapes.

The feeding behavior of *P. absoluta* larvae is characterized by their voracious consumption of plant tissues, particularly leaves and stems. Upon hatching, larvae immediately begin to feed by burrowing into leaf tissue, creating characteristic mines and tunnels as they consume mesophyll cells. This feeding activity disrupts plant physiology, reducing photosynthetic efficiency and compromising the structural integrity of leaves. As larvae mature, their feeding intensifies, leading to increased mine size and depth, which can eventually result in extensive defoliation if left unchecked.

Early instar larvae initially create shallow mines near leaf surfaces, gradually progressing deeper into the leaf as they develop. This feeding behavior not only affects the current season's growth but also impacts the plant's overall health and future productivity. Severe infestations can lead to significant yield losses, affecting the quantity and quality of harvested fruits by reducing plant vigor, increasing

susceptibility to secondary infections, and causing premature fruit drop.

Understanding the host range and feeding behavior of *Phthorimaea absoluta* is crucial for implementing effective pest management strategies. Integrated approaches that combine cultural practices, biological control agents, and targeted chemical applications can help mitigate *P. absoluta* infestations while promoting sustainable agricultural practices. Furthermore, ongoing research into the pest's interactions with different host plants and its adaptability to changing environmental conditions is essential for developing resilient and proactive management strategies to protect solanaceous crops from the devastating impact of this invasive pest.

Conclusion

Phthorimaea absoluta poses a significant threat to global tomato (*Solanum lycopersicum*) production due to its rapid spread, destructive feeding habits, and ability to develop resistance to insecticides. Originating from South America, this invasive pest has established populations across various continents, impacting both field-grown and greenhouse tomato crops.

The economic impact of *P. absoluta* is substantial, with infestations causing yield losses ranging from 40% to 100% in severe cases. Direct losses result from reduced marketable yields and increased production costs associated with intensive insecticide applications. Indirect costs include market instability and quality concerns, affecting profitability and sustainability within the tomato industry. Efforts to manage *P. absoluta* have traditionally relied on chemical insecticides, but the pest's rapid development of resistance to multiple classes of insecticides has necessitated integrated pest management (IPM) strategies. IPM approaches emphasize a combination of cultural practices, biological control agents, and targeted chemical treatments to reduce pest populations while minimizing environmental impact and preserving natural enemy populations.

Biological control agents, such as predatory insects and parasitoids, offer sustainable alternatives to synthetic pesticides, contributing to integrated pest management programs. Additionally, advancements in biotechnological approaches, including RNA interference (RNAi), hold promise for developing targeted control strategies that disrupt *P. absoluta*'s lifecycle without adversely affecting non-target organisms or the environment. Future research directions should focus on enhancing our understanding of *P. absoluta*'s genetic variability, ecological interactions, and adaptation mechanisms. This knowledge will support the development of proactive management strategies tailored to local conditions and production systems, ensuring sustainable tomato production while minimizing the impact of *P. absoluta* on global food security. In summary, addressing the challenges posed by *Phthorimaea absoluta* requires a collaborative and multidisciplinary approach involving researchers, growers, policymakers, and industry stakeholders. By implementing integrated and sustainable pest management practices, we can mitigate the economic and environmental impacts of *P. absoluta* while safeguarding tomato production for future generations.

Competing Interests

Authors have declared that no competing interests exist.

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