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THE MAIN PESTS ON SOLANACEA CROPS IN ZONA 1 OF ECUADOR

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Abstract
The family *Solanaceae* is considered as the third important agronomical botanical family in the word. In the Zone 1 of Ecuador, potato is grown in the provinces of Imbabura and Carchi (8000 ha), tomato (3000 ha under cover, 4000 ha in open field). The poor phytosanitary status of the plants badly affects its final quality, which can not allow taking an advantage of all production for agro industrial processing in search of the export market. In this review article are described the main pests affected *Solanaceae* crops – their biology and ecology, damage and symptoms, key management strategies and integration of control measures.

INTRODUCTION

Invasive arthropods cause significant damage in agricultural crops and natural environments across the globe. Potentially threatened regions need to be prepared to prevent new pests from becoming established. Therefore, information on pest identity, host range, geographical distribution, biology, tools for detection and identification are all essential to researchers and regulatory personnel. The family *Solanaceae* is considered as the third important agronomical botanical family in the word. In the Zone 1 potato is grown in the provinces of Imbabura and Carchi (8000 ha), tomato (3000 ha under cover, 4000 ha in open field). The poor phytosanitary status of the plants badly affects its final quality, which can not allow taking an advantage of all production for agro industrial processing in search of the export market. In this article are described the main pests affected *Solanaceae* crops – their biology and ecology, damage and symptoms key management strategies and integration of control measures.

THE MAIN PESTS ON SOLANACEA CROPS

The most important pests on *Solanacea* crops are *Tuta absoluta* (Meyrick), *Phtorimaea operculella* (Zeller) and *Tecia solanivora* (Povolny); Lepidoptera: *Gelechiidae*.

1. The tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera:*Gelechiidae*)

It is a pest of great economic importance in several countries in Latin America and the Mediterranean basin**.** Tomato is the main host plant, but *T. absoluta* also attacks other crop plants of the nightshade family, including potato, eggplant, pepino and tobacco. It is known from many solanaceous weeds, including *Datura stramonium*, *Lycium chilense*, and *Solanum nigrum. Tuta absoluta,* synonym *Gnoromoschema absoluta* (Clarke, 1962), *Scrobipalpula absoluta* (Povolny, 1964)

1.1. Insect description and life cycle

Tuta absoluta is a micro-lepidopteran insect. The adults are silvery brown, 5-7 mm long. The total life cycle is completed in an average 24-38 days. The minimum temperature for biological activity is 4^{o}C. After copulation females lay up to 300 individuals small (0.35 mm long), cylindrical creamy yellow eggs, which are often found alongside the rachis. Freshly hatched larvae are light yellow or green and only 0.5 mm in length. As they mature larvae develop a darker green color and a characteristic dark band posterior to the head capsule. Four larval instars develop. Larvae do not enter diapause when food is available. Pupation may take place in the soil, on the leaf surface, within mines or in packing material. A

cocoon is a built if pupation does not take place in the soil. 10-12 generation can be produced each year. *Tuta absoluta* can overwinter as egg, pupae or adult depending on envinromental conditions. Under open – field condition *Tuta absoluta* is usually found up till 1000 m above sea level. In Ecuador we found the tomato leaf miner in Imbabura, 2225 m above sea level and Carchi provinces, where the altitude is around 3100 m above sea level.

1.2. Presence and distribution of the pest

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 (Desneux *et al.*, 2010) . 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.

1.3. Damage and symptoms

Infestation of tomato plants occurs throughout the entire crop cycle. Feeding damage is caused by all larval instars and throughout the whole plant. On leaves, the larvae feed on the mesophyll tissue, forming irregular leaf mines which may later become necrotic. Larvae can form extensive galleries in the stems which affect the development of the plants. Fruit are also attacked by the larvae, and the entry ways are used by secondary pathogens, leading to fruit rot. The extent of infestation is partly dependent on the variety. Potential yield loss in tomatoes (quantity and quality) is significant and can reach up to 100% if the pest is not managed. The damage caused by this pest is severe, especially in young plants. When potato plants have completed the cycle, larvae of *Tuta absoluta* mine tubers underneath the epidermis. Larval feeding can cause the tubers to rot.

1.4. Risk for insecticide resistance development

Pests like *Tuta absoluta*, with high reproduction capacity and short cycle, are the higher risk of developing resistance to insecticides. This risk increases significantly when management of the pests relies exclusively on chemical control with limited number of effective insecticides available. This situation usually leads to an increase in the frequency of use and, thus, increased selection pressure for resistance. *Tuta absoluta* has been a key pest in tomato in Latin America for decades and resistant to a range of mode of action groups.

1.5. Resistance status in Latin America

In Latin America, high level and widespread resistance is known to exist in field populations of *Tuta absoluta*, mainly to organophosphates, pyrethroids, chloride channel activators and benzoyluras. The resistance levels appears to be correlated with grater use of these compounds by growers and the resistance profiles seem to shift quickly with the pattern of insecticide use. The more relevant resistance mechanisms appear to be metabolic in nature increased activity of specific detoxification enzymes. In Latin America, resistance has also developed to never classes of insecticides introduced after year 2000 (Silva *et al.*, 2011).

1.6. Impact

The impact of the pest includes severe yield loss reaching 100%, increasing tomato prices, bans on the trade of tomato including seedlings, an increase in synthetic insecticide applications, disruption of integrated management programmes of other tomato pests, and an increase in the cost of crop protection. In addition, the outbreak of this pest led to a significant augmentation of risks for growers, consumers and the environment associated with the blind use of chemicals (USDA-APHIS, 2012; Zappalà *et al.*, 2012; Zlof and Suffert, 2012). Considering its high biotic potential, its ability to adapt to various climatic conditions and the speed with which it has colonized Europe and North Africa, the potential invasion of African and especially Asian tomato crops by *T. absoluta* will probably impact heavily on the livelihood of local tomato growers and tomato agribusinesses in these regions.

1.7. Key management strategy and integration of control measures

There are a number of cultural control measures that aid the eradication of this pest. Crop rotation, crop residue removal and the selective removal and destruction of infested plant are important practices that help eradicate this pest in greenhouses. Wild host plants in infested areas should be removed and destroyed to prevent the buildup of potential population reservoir. All infested plant materials should be removed and disposed of in a phytosanitary secure manner. Allow a minimum of 6 weeks from crop destrution to planting the next crop to prevent carry over of the pest from previous crop. Between planting cycles cultivate the soil and cover with plastic mulch or perform soil solarisation. Prior to transplanting install sticky traps. Use pest free transplants. Seal greenhouse with high quality nets suitable for *Tuta absoluta.*

The recommendations for sustaining the effectiveness of available insecticides are centered on integration of as many pests management tool as possible, use of insecticides only when needed based on established threshold, and rotation of effective insecticides with different modes of action.

***2. Phthorimaea operculella* (Zeller) (Lepidoptera: *Gelechiidae*)**

Phthorimaea operculella (Zeller) (Lepidoptera: *Gelechiidae*), the potato tuberworm or tobacco splitworm, is a key pest causing severe damage to potato, which, in turn, is a food crop of essential importance worldwide. The pest is indigenous to South America but at present is spreading in all the potato production areas in temperate and subtropical climatic regions. Potato tuberworms are mainly associated with potatoes; however, they have been observed feeding on other plants such as tomatoes, eggplants (*Solanum melongena* L.), peppers (*Capsicum* spp.), tobacco, and wild solanaceous plants like Jimson weed or datura (*Datura stramonium* L.) (Alvarez *et al.*, 2005).

2.1. Insect description and life cycle

P. operculella adults are small elongate gelechiid moth, measuring about 1 cm in length when at rest, coloured pale brown with darker marbling. Wingspan 15-17 mm. Head and thorax pale are brown, palpi curved, ascending, terminal segment about as long as second. Antennae are brown, 0.7 x wing length. Front wings pale are brown with small blotches of mid brown, and hind wings pale grey. The tip of the male abdomen is spinose, and distinctive when viewed through a microscope**.** Eggs are broadly oval, smooth and yellowish, iridescent. When fully grown, *P. operculella* larvae are about 15 mm in length. Head is dark brown; prothoracic plate sometimes pinkish; body is greyish-white or pale greenish-grey. Pinacula is small, dark brown or black. Anal plate is brown. Pupa is yellowish or reddish brown, eighth abdominal segment with spiracles on slightly raised, backward pointing spiracles; cremaster with a median, dorsal, thorn-like spine and eight slender hooks.

2.2. Biology and ecology

The eggs are laid singly or in batches on the leaves of the host plant, or on exposed tubers near the eye buds. A total of 40-290 eggs are laid which take 3-15 days to hatch. In winter this stage can last up to 58 days, but eggs cannot tolerate low temperatures; eggs kept at 1-4°C for 4 months failed to hatch (Langford and Cory, 1932).The larva at first bores into the petiole, or a young shoot or main leaf vein, and mines the leaf making a blotch. Later it bores into a tuber, making a long irregular gallery. On stored tubers feeding on the tubers begins immediately. The larval stage lasts 13-33 days.Pupation normally takes place in the soil; the pupal period is 6-29 days. Adults fly chiefly by night and are attracted to light. They live for up to 10 days. The moth breeds continuously where conditions permit; up to 13 generations a year have been recorded in India (Mukherjee, 1948). The complete life cycle ranges from 17 to 125 days. Development of all stages is greatly influenced by temperature: the maximum fecundity has been recorded at 28°C and temperatures tolerated are in the range 15-40°C.

2.3. Presence and distribution

Phthorimaea operculella (Zeller) is believed to have originated in the tropical mountains of South America. Potato tuberworm is a cosmopolitan pest. In the United States it has been reported in at least 25 states from the Atlantic to the Pacific coast. This pest occurs in most areas where potatoes or other solanaceous plants are grown. It is currently found in over 90 countries across the globe. Adults are weak fliers, and cosmopolitan distribution and range expansion of potato tuber moth is probably due largely to movement or larvae- infested seed.

2.4. Damage and symptoms

Larvae feed on potato leaves, stems, petioles, and more importantly potato tubers in the field and in storage. The newly hatched larvae create mines on leaves by feeding on leaf tissue while leaving the upper and lower epidermis of the leaf intact. They prefer feeding on young foliage (Trivedi and Rajagopal, 1992). Typical damage results from larvae boring tunnels in tubers. Larvae depositing their excreta make tubers unfit for consumption. Potato tuber eyes become pink due to deposition of silk and excrement by potato tuberworm infestation. Severe infestations result in yield and quality losses during storage where previously infested tubers are stored with healthy potato tubers (Malakar and Tingey, 2006, Rondon, 2010). This generally destroys the entire crop of stored potatoes. Most economic damage occurs to potato tubers in storage conditions in developing countries and is caused by larval feeding. Presence of even one larva is sufficient to spoil and destroy a tuber. Rapidly moving caterpillars penetrate the tubers, form galleries coated with silken threads and eject frass outside the tuber. On leaves, caterpillars form galleries and then penetrate other plant parts. After two to three weeks, caterpillars leave the plant (caterpillars can move through cracks in soil) and pupate on walls of potato bags lying in potato fields. Fungi, bacteria, and mites can develop inside the tunnels made by the larvae, which causes the tubers to rot and emit an unpleasant smell. Stored crop losses in potatoes ranging from 50% in Yemen and Peru, 86% in Tunisia, Algeria, and Turkey, 90% in Kenya, and 100% in India and the Philippines have been reported (Alvarez *et al.*, 2005). In Egypt, potato tuber moth has caused up to 100% losses to potato plants in fields as well as in storage (Ahmed *et al.*, 2013). Potato tuber moth is also a pest of tomatoes where larvae damage the leaves, stem and the unripe fruits.

2.5. Impact

Potato tuber moth is a serious major pest in areas where the climate favours its development, and where its host plants are grown on a large scale.

2.6. Field management

2.6.1. Reject seed lots from fields or storage that had been infested with PTM or PTW, or tubers that are infested.

2.6.2. Avoid letting tubers be exposed outside of hill or be shallow, less than two inches covered by soil. Keep potato plants well hilled with tubers adequately covered, deeper planting depth and broader hills.

2.6.3. Avoid late-season washed out areas as this will expose tubers above ground and PTMs can lay their eggs on the exposed tubers.

2.6.4. Avoid deep soil cracks (2 inches and greater) using cultural practices such as irrigation. This will inhibit female PTM from laying eggs on the tubers and wandering PTW from getting through soil to the tubers.

2.6.5. Irrigate slightly after vine desiccation to avoid soil cracking and harvest tubers as soon as skin sets.

2.6.6. Do not leave potato tubers in containers in the field overnight; likewise do not dig and leave tubers atop of ground to be picked up the next day and stored. At night the female PTM is most active laying eggs.

2.6.7. Do not use vines as a cover for tubers as the PTW will move from them to tubers as the vines wilt.

2.6.8. Bury or feed to cattle cull piles or in some way destroy them.

2.6.9. Eliminate volunteer potato plants.

2.7. Storage Management

PTM/PTW damage is year long as the PTM will continue to breed in storage and lay eggs which will hatch into PTW. The length of the life cycle will depend on the storage temperature.

2.7.1. Sanitize storage facility (walls, floors, ceiling).

2.7.2. Treat facility with malathione, if PTM or PTW was detected the previous year. Keep storage temperatures below 52 F deg.

2.7.3. Screen storage area from the outside to keep out PTMs.

2.7.4. If potato sacks, crates or other containers are used, they should be new or thoroughly sanitized.

2.8. Biological control

Natural enemies of potato tuber moth can be used as a part of an IPM program. The parasitoids, *Copidosoma koehleri* and *Bracon gelechiae* Ashmead (Hymenoptera: *Braconidae*) have been used with some success in South America and Australia, respectively (Symington, 2003, Alvarez *et al.*, 2005).

2.9. Bio-pesticides and natural chemicals

Bacillus thuringiensis (Bt) formulations have proved effective for potato tuber moth control in various parts of world (Alvarez *et al.*, 2005).In several South American countries, PhopGV-based biopesticides (*Phthorimaea operculella* granulovirus (PhopGV) genus: Betabaculovirus of the arthropod-infecting Baculoviridae) are used to control either *Phthorimaea operculella* or *Tecia solanivora* (Zeddam *et al.,* 2013).

***3. Tecia solanivora* - economic importance and hosts**

The Guatemalan potato moth, *Tecia solanivora* (Povolny) (Lepidoptera: *Gelechiidae*), is the most important insect pest of potato, *Solanum tuberosum* L., worldwide. It was described by Povolný in 1973. Larvae attack tubers and are difficult to control. *Tecia solanivora,* has a narrow host range with only potato identified so far.

3.1. Insect description and life cycle

Adults are rather stout moths with lanceolate front wings and larger rear wings with many fringes. The female is bright brown, the first pair of wings having three marks and bright brown longitudinal lines. The male is dark brown, with two marks on the first pair of wings and scarcely visible longitudinal lines. The female is larger than the male, measuring approximately 13 x 3.4 mm, whereas the male measures 9.7 x 2.9 mm (Barroso, 1974; Torres, 1989; Sotelo, 1996).

Eggs are ovoid in form, 0.53 x 0.41 mm, pearly white when freshly laid, turning yellow during incubation and dark brown when close to hatching.

Larvae are eruciform, with three pairs of true legs (thoracic) and five pairs of pseudolegs (four abdominal and one anal pair). After hatching, larvae measure 1.2-1.4 mm in length and are transparent white, with the head and prothoracic shield dark brown. Second-instar larvae are cream, with darker, coffee-coloured spots. Third-instar larvae are yellow-green; the spots along the body are more visible and the head and prothoracic shield are dark brown. Final stage larvae measure 12-15 x 2.5 mm and are purple on the dorsal side and green ventrally.

The pupa is fusiform, measures on average 8.52 x 2.95 mm (female) or 7.83 x 2.42 mm (male) and is a pale coffee colour at first, which later darkens. Pupation may occur on the ground, on the walls of storerooms, in sacking or within the tuber itself.

3.2. Presence and distribution of *Tecia solanivora*

The first reports of *T. solanivora* indicate that it was originated in Guatemala (Povolny, 1973), where it is found in the western highlands from altitudes of 1830 to 3050 m. In 1970, it was accidentally introduced into Costa Rica in potatoes for consumption imported from Guatemala (Povolny, 1973). In 1982, the pest was already established in the main potato-producing zones of the country (Barroso, 1974). It is now established in almost all the central American countries: El Salvador, Honduras, Nicaragua, Costa Rica and Panama (PRECODEPA, 1988, 1989).

At the end of 1983, *T. solanivora* was introduced to Venezuela from Costa Rica via the state of Tachira (Torres, 1989). It is now present in Tachira, Merida, Trujillo (reported in 1986), and in Ara (reported in 1987), with the most affected areas lying above 2000 m. In 1985, *T. solanivora* arrived in Colombia from Venezuela via the Department Norte de Santander and spread rapidly within the country, due to the brisk trade in tubers for consumption between different parts of the country.

In 1997, *T. solanivora* was reported in Ecuador, in the province of Carchi (Gallegos *et al.*, 1997) and later, in 1998, it was reported in the province of Cotapaxi at the south of Quito (INIAP/PNRT, 1997).

3.3. Damage and symptoms

Damage is similar to that caused by other tuber moths. Larvae attack tubers and can completely destroy them. Damage is caused by larval galleries that contain residues of food, frass, and the cast skins of larvae (exuviae). Holes and galleries produced by *T. solanivora* are larger than those produced by other Lepidoptera species that attack potato tubers (OEPP/EPPO, 2006). The entry holes may remain inconspicuous. No external symptoms are seen until larvae leave the tuber through circular exit holes of 2 to 3 mm.

3.4. Impact

T. solanivora is an aggressive pest that damages up to 100% of stored potato seeds (Vargas *et al.*, 2004). *T. solanivora* also produces important losses in field conditions by entering the potato tubers under the ground.

Larvae feed exclusively on potato tubers, in the field and in store. Tuber quality is much reduced and heavily infested tubers can no longer be used for human or animal consumption. Stocks can be totally destroyed in less than 3 months. The temperature at which potatoes are stored influences thedevelopment of the pest population and subsequent damage. More damage occurs as the store temperature increases, allowing faster population growth and more generations.Damage up to 95% is commonly reported in America. In Ecuador, a crop may be destroyed in 2–3 months. Damage can reach 40% of the yield of a field in Central America. In 1994, Colombia attributed losses of 276 323 t to *T. solanivora* In Colombia during 1995 there was 4.4% damage to field potatoes and 11.3% damage to potatoes in store (Arias *et al.*, 1996). In Costa Rica, *T. Solanivora*, is so important that 12–24 insecticide applications against it each year are justified, raising the likelihood that resistance may appear (Hilje, 1994). Spanish local newspapers reported that, in 2001, potato production was reduced by 50% in the north of Tenerife because of *T. Solanivora* and a severe drought, leading to economic losses of 900 000 EUR. The situation is considered serious and discussions are reported in the newspapers abot financial compensation for the growers.

3.5. Phytosanitary measures

T. solanivora is a quarantine pest for the CPPC and also for Peru that is trying to avoid introduction of the pest.*T. solanivora* has also been identified as an 'Alert pest' by NAPPO. In 2002, it was added to the EPPO A2 action list, and endangered EPPO member countries are thus recommended to regulate it as a quarantine pest. Import of potatoes should be prohibited from countries where the pest is present, and absence of the pest from other countries should be demonstrated by detection survey. Under EPPO Standard PM 8/1 Commodity-specific Phytosanitary Measures for potato (OEPP/EPPO, 2004), other measures could be considered under transitional arrangements. Tubers should be: 'practically free from soil' (0.1% and 1% tolerance for seed and ware potatoes, respectively); packed in containers which are new, or cleaned and disinfected; free from larvae, pupae or adults of insects by visual inspection. It should be noted that there seems to be very few potato-producing areas which are free from *T. solanivora* in Central and South American countries where it occurs, so pest-free areas do not appear to be a practical option.

3.6. Cultural control

In the field, good management practices to control T. solanivora are deep planting, timely and high earthing-up or hilling, defoliation when the crop is mature, opportune harvesting, not leaving harvest residues and the use of healthy seed and crop rotations when infestations are severe. In storage, cleanliness and diffused lighting are recommended (Marroquin, 1981; Leal, 1983; Torres,1994). Covering tuber seed to a depth of 5-10 cm prevents female moths from ovipositing in seed tubers and keeps larvae from migrating to tubers from infested sprouts above ground. High hilling of growing plants protects the developing tubers from ovipositing females and reduces the possibility of larvae reaching the bulking tubers. Adequate watering and prevent cracks from forming in the soil. These allow female moths to reach potato tubers for oviposition and provide shelter for adult moths. Female moths become active in the evening and most eggs are laid at that time. Harvested tubers should therefore not remain exposed to ovipositing females overnight, and if they cannot be stored immediately, must at least be covered.

3.7. Biological control

Copidosoma koehleri, an encyrtid polyembryonic parasitoid of *Phthorimaea operculella*, was also shown to parasitize *T. solanivora* in controlled conditions (Torres and Antolinez, 1995). Tests with the virus *Baculovirus phthorimaea*, also a pathogen of *P. operculella*, have shown that it also affects *T. solanivora* larvae (Torres and Antolinez, 1993; Trillos,

1996). This granulosis virus now plays a key role in the management of potato tuber moth in storage. The methodology of mass multiplication of *B. phthorimaea* in larvae of *T. solanivora*, and its preparation in powder form, have been developed for the mass commercialization of a bioinsecticide (Trillos, 1996; Sotelo, 1997). The dust formulation is produced by selecting and grinding virus-infected larvae from damaged potato tubers and then mixing them with ordinary talc. In Venezuela, the potential of the entomopathogenic nematode *Steinernema feltiae* as a biocontrol agent has been studied (Fan and Maggiorani, 1995).

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