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TUTA ABSOLUTA (MEYRICK) (LEPIDOPTERA: GELECHIIDAE): POTENTIAL FOR ENTRY, ESTABLISHMENT AND SPREAD IN BULGARIA

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Abstract

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The tomato leaf miner *Tuta absoluta*, a devastating pest of tomato in South America, was reported from Spain in 2006 and has subsequently spread throughout many European countries, causing serious damages to tomato in the invaded areas. The pest can also develop on other cultivated plants, among which are peppers, eggplants and potatoes, posing a significant threat to agriculture. The present paper describes the major pathways for entry of the pest on the territory of Bulgaria and its potential for establishment and spread in the context of the Balkan region. It analyses the endangered areas in the country with emphasis on tomato cultivation, which is most at risk, and reviews the current national situation with examples of recent outbreaks.

The steady decrease in tomato production in Bulgaria has led to an increase in import of tomatoes in order to meet the consumer demands. This contributes to a higher risk of entry of *T. absoluta*, as 65% to 99% of the imported fresh tomatoes come from countries where outbreaks of the pest have been observed during the past 5 years. Packing materials for import of tomatoes, peppers and eggplants, as well as imported planting material also present a risk and are considered in detail. *T. absoluta* has repeatedly entered Bulgaria through import from Turkey and Greece and it is very likely that it will continue to threaten the national vegetable production. The analysis of the available data through climatic modeling shows that the pest cannot permanently establish in the country outdoors, as it cannot survive the cold winter conditions. However, the establishment of transient field populations, developing 2 – 5 generations per year during the growing season, and permanent populations in greenhouses is a likely scenario. These facilitate the spread of *T. absoluta* to adjacent areas through flight and to distant locations through human-assisted means.

Key words: Tuta absoluta, distribution, entry, establishment, Bulgaria

Introduction

The tomato leafminer *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is one of the most devastating pests of tomato in South America (CIP, 1996; Barrientos et al., 1998; Miranda et al., 1998; Filho et al., 2000; Gomide et al., 2001). Adults are active at night and females lay eggs on the aerial parts of the host plants. The maximal lifetime fecundity is 260 eggs per female (Uchoa-Fernandes et al., 1995). There are four larval instars and pupation takes place in the soil, on the leaf surface or in the mines, created by the insect. The pest can overwinter as egg, pupa or adult stage (EPPO, 2005).

The species is thought to originate from Chile and to have spread to South America on different solanaceous crops after developing resistance to the commonly used plant protection products (Siqueira et al., 2000; 2001; Lietti et al., 2005). In Europe, *T. absoluta* was initially reported from Eastern Spain in late 2006 (Urbaneja et al., 2007), and has subsequently spread throughout many European countries, including the Balkan and Mediterranean regions (EPPO, 2009a; 2009b; EC Report, 2009, Potting et al., 2009, Desneux et al., 2010). Since its initial detection, *T. absoluta* has caused serious damages to tomato in the invaded areas (Torres et al., 2001, Germain et al., 2009). Therefore, it is currently considered a key agricultural threat to European and North African tomato production. Without adequate controls, infestations can result in 90 to 100 % loss of field-produced tomatoes (Vargas, 1970; Estay, 2000).

Although tomato (*Lycopersicon esculentum* Mill.) is the preferred host plant of *T. absoluta*, its larvae can also de-

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velop on other cultivated plants such as *Solanum tuberosum* L. (potato), *Solanum melongena* L. (eggplant), *Solanum muricatum* Aiton (sweet pepper), *Nicotiana tabacum* L. (tobacco), *Phaseolus vulgaris* L. (bean) and *Physalis peruviana* L. (cape gooseberry) (Desneux et al., 2010). The most severe European outbreaks have been reported on tomato, but there are reports of significant damage to eggplant in Italy (EPPO, 2009c) and potatoes in France (Maiche, 2009). Viggiani et al. (2009) reported that in Italy the tomato leafminer causes direct and indirect damage to the production of tomato, potato, eggplant, and pepper. The larvae of *T. absoluta* can also be found on wild hosts such as *Datura stramonium* L., *Datura ferox* L., *Lycium chilense* (Coralillo), *Lycopersicum hirsutum* L., *Nicotiana glauca* (Graham), *Solanum lyratum* Thumberg, *Solanum puberulum* Nuttal ex Seemann, and *Solanum nigrum* L. (EPPO, 2007).

The aim of the present paper is to describe the major pathways for entry of the pest on the territory of Bulgaria and its potential for establishment and spread in the context of the Balkan region.

Material and Methods

Data from the literature was used to create a map of reported *T. absoluta* outbreaks in the EU and the Mediterranean region.

The results from sampling in greenhouses and fields in Central and Southwestern Bulgaria performed by Plant Protection Institute and the analyses of samples provided by producers were used to create a map of *T. absoluta* outbreaks in the country for the period 2009 – 2011.

A CLIMEX model for *T. absoluta* developed by Desneux et al. (2010) was used to predict the number of generations of the pest, which can develop outdoors in Bulgaria in order to evaluate establishment potential.

Data on the volume and frequency of import of plants and plant products – hosts of *T. absoluta* for the past 5 years obtained from EUROSTAT, FAOSTAT and AGROSTATISTICA were analyzed to determine the potential pathways for introduction of the pest in Bulgaria. Data from the National Service for Plant Protection (NSPP) for the period 2005 – 2007 were also utilized.

Data on the total cropping area in Bulgaria in 2009 for hosts of *T. absoluta* was obtained from the Ministry of Agriculture and Food in order to assess the potential of transfer of the pest to a suitable host in relation to the major pathways.

Results and Discussion

Endangered areas

In order to assess the total cultivated area where *T. absoluta* can find a suitable host, data on production areas for the major hosts of the pest in the Balkans was collected. Table 1 presents the approximate cropping areas in Bulgaria and its neighboring countries over the past 20 years. The analysis of the data shows that the tomato growing areas have not changed in Serbia, Macedonia and Romania, while they have significantly decreased to 25 000 ha in Greece and have almost doubled in acreage in Turkey to 300 000 ha. There is a two-fold increase in the pepper growing areas in Turkey to 90 000 ha, while in Romania they have decreased to 19 917 ha. These areas have almost remained unchanged in the rest of the investigated countries. The areas for cultivation of eggplants are significantly smaller, when compared to those for the other two crops. Their size is decreasing in almost all investigated countries, except for Macedonia, where the area for eggplant cultivation, although small, has increased 10-fold to reach 50 ha.

Specifically for Bulgaria, the areas for cultivation of the three host plants have decreased as follows: for tomatoes –

Table 1
Changes of harvested area of tomato, pepper, chillies and eggplant in Bulgaria and the neighbouring countries in the period 1989-2009 (in ha x 10^3)

country / year	Tomato						Pepper and chillies							Eggplant						
	1989	1992	2006	2007	2008	2009	1989	1992	1993	2006	2007	2008	2009	1989	1992	1993	2006	2007	2008	2009
Bulgaria	30	18	7	5	3	3	18	17	14	9	5	4	5	1.3	0.8	0.7	0.3	0.4	0.3	0.7
Greece	43	52	34	33	25	25	4	4	4	5	5	4	4	2.9	2.9	2.9	3.2	3.1	2.9	2.9
Romania	52	53	50	46	51	49	30	21	18	23	19	20	20	12.3	5.7	6.0	11.4	9.7	10.5	9.9
Serbia			21	21	20	20				19	19	19	19				0.1	0.1	0.1	
F.Y.R. Macedonia		7	6	5	5	6		9	8	8	8	8	8		0.01	0.01	0.1	0.1	0.1	0.1
Turkey**	157	172	270	270	300	300	48	56	53	88	88	88	90	36	34	29	35	33	31	31

*after FAOSTAT last entered 3.05.2011
**data for Turkey includes total production , not only that from European part of the country.

from 30 240 ha to 3007 ha which has led to an 8.4-fold reduction in yield; for peppers – 3.5-fold decrease in the area for cultivation; for eggplants – 1.8-fold decrease in the area for cultivation. The decrease in national production has led to an increase in imported volumes in order to meet the demands of the market and has contributed to a higher risk of entry of invasive species.

Table 2 presents the production areas for some hosts of *T. absoluta* in Bulgaria by regions. The data show that the major cropping areas are located in the Southwestern and South Central part of the country.

Entry of T. absoluta in Bulgaria

After the first report of *T. absoluta* in Europe (Spain) in 2006, in the following 5 years the pest has had outbreaks in protected tomato cultivation and open field crops in 22 countries from the Mediterranean basin, the Arabian Peninsula and Europe (Figure 1).

T. absoluta is not listed in Plant Health Directive 2000/29/EC. Therefore, no measures for the pest are justified including the plant health inspection. Based on experiences in South America and Europe, the spread of the leafminer can be greatly facilitated through agricultural trade. Because of the unrestricted movement of tomato fruit and plants between the MS of the European Union (EU), the pest has rapidly spread in the EU.

T. absoluta was detected in Bulgaria during routine inspections of NSPP in the period June – August, 2009. The species was found on field and greenhouse tomatoes in the town of Rakovski and the village of Parvenets (Plovdiv area), on field tomatoes in the village of Yunatsite (Pazardzhik area) and in a warehouse of a vegetable market in Sofia. Harizanova et al. (2009) considered that *T. absoluta* was most likely imported with Spanish tomatoes. During this period, there were no official reports of the presence of the pest in Greece and Turkey. All findings from Bulgaria in 2009, however, are reported from markets and areas located in proximity to Trakiya highway (E80), which is the main transport corridor for import of vegetables from Turkey and to a less extent from Greece. In 2010 the moth was also found in vegetable markets and warehouses in the region of Blagoevgrad on tomatoes imported from Crete, Greece. Blagoevgrad is located near the main surface route connecting Bulgaria and Greece – E79. During the period May – July 2011, an outbreak of *T. absoluta* on tomato plantings and in their vicinity was observed in the Southwestern region of Bulgaria. Figure 2 presents a map of recent outbreaks in the country. In August 2011, the pest also spread to greenhouses in East and North Bulgaria.

The most relevant pathways for entry of *T. absoluta* in Bulgaria are as follows: 1) Import of tomato fruits intended for consumption from countries where the pest is present; 2) Packing materials (boxes, crates, pallets, etc.) for import of

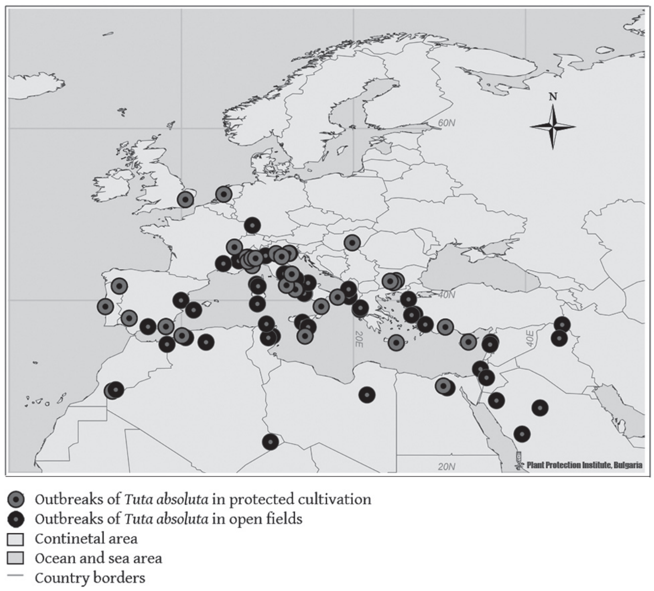

Fig. 1. Outbreaks of Tuta absoluta in the EPPO region in the period 2006 - 2010

Table 2
Cropping area of potential host of *T. absoluta* in different regions of Bulgaria in 2009*

Regions	Tomatoes	Peppers	Eggplants	Potatoes	Onions	Beans
	ha					
Northwestern	120	112	1	295	93	70
North Central	193	114	7	186	50	87
Northeastern	260	1211	40	278	62	228
Southeastern	258	281	15	400	741	34
Southwestern	626	495	314	5968	5	833
South Central	1550	2800	318	6875	228	439

*After AGROSTATISTICA (2010).

tomatoes, eggplants and peppers from countries where the pest is present; 3) Planting material originating from countries where the pest is present (mainly tomatoes).

Pathway 1. Tomato fruit

The detection of *T. absoluta* in tomato (re)packing stations in the Netherlands and the United Kingdom, believed to have arrived on imported Mediterranean tomatoes, emphasizes the risk of moving infested tomato fruit (Potting et al., 2009; Desneux et al., 2010). Tomato imports are a pathway for the entry of the pest in many countries. Larvae of *T. absoluta* attack leaves, buds, stems, flowers, calyces and tomato fruit (Vargas, 1970). Since they are internal feeders, there is a risk that an early infestation could remain undetected in tomato consignments at ports of entry. In addition, the fruit calyx when attached to the developing fruit, usually exhibits greater larval damage than the fruit (FERA, 2009). This information suggests that vine or truss tomatoes represent a great risk for the entry of *T. absoluta* than tomatoes without stems and calyces.

In the last 20 years the production of tomatoes in Bulgaria has shown an 8.4-fold decrease from over 800 000 t in 1989 to less than 100 000 t in 2009. In 2009, the consumption of fresh and processed tomatoes in Bulgaria amounted to 19 051 t and 174 427 t, respectively (Branthôme, 2010). Evidently, the national production cannot satisfy the consumer demand, setting the need for an increase in import, which, in turn, contributes to a higher risk of entry of *T. absoluta* through its main pathway – infested tomato fruit.

Tomato fruit is a likely pathway since the volume moving along it to Bulgaria is massive and 65 to 99% of it originates from countries where outbreaks of the pest have been observed during the past 5 years (Table 3). Furthermore, 50% of the import of tomatoes occurs during the period March – June (Figure 3). This period coincides with the time for transplanting outdoor vegetables, which would facilitate transfer of the pest to a suitable host. In general, the transfer of *T. absoluta* to a suitable host is most likely during the period March – September.

⊙ Outdoors cultivation
✱ Warehouses and markets
★ Greenhouses
✪ Protected and outdoor cultivation

Fig. 2. Outbreaks of *Tuta absoluta* in Bulgaria

Pathway 2. Tomato, eggplant and pepper packing materials

Larvae, pupae, and adults of *T. absoluta* could also survive in tomato, eggplant and pepper packing materials. As an example, the most severe problem facing UK growers is the arrival of infested crates at clean tomato growing sites (Sixsmith, 2010). Therefore, it is reasonable to consider that reused and infested crates and boxes might be a pathway for *T. absoluta*. If larvae, pupae or adults are imported in tomato packing materials, adults might be able to fly away when tomatoes, eggplants and pepper are unpacked. Larvae and pupae could complete their development and escape from infested boxes or crates, particularly if they are discarded outdoors. Alternatively, non-returnable packing boxes can be used and should be assembled and stored in an area of the packing station away from infested crates (Sixsmith, 2010).

Packing materials (boxes, crates, pallets, etc.) for import of tomatoes represent the biggest threat, since the intensity of movement and the volume along the pathway are identical to those for Pathway 1.

The major exporters of peppers to Bulgaria for the past five years have been Turkey (37-71%), Macedonia (21-69%) and Greece (2 – 9%) (Table 3). Practically, import occurs throughout the year, but is most active at the end of the summer season and in autumn, from September to the first decade of November (Figure 4).

Mainly Turkey (70 – 90%), Greece (7 – 18%) and Jordan (2 – 7%) exported eggplants to Bulgaria during the past years. The volumes are much smaller than these of tomatoes and peppers are, but 50% of the import occurs during March – June (Figure 5). This period is suitable for transfer of the pest on suitable hosts and establishment of transient populations in local fields.

Pathway 3 Planting material

Only a small number of countries export vegetable planting material to Bulgaria. There is a trend of increase in the share of import from Greece (1 – 74.5%) (Table 4). The import of transplants occurs during the most suitable period for establishment of transient populations of *T. absoluta* outdoors – March to May (Figure 6). Also planting infested transplants in greenhouses increases the risk of outbreaks in protected cultivation.

In the past few years, in connection to the intensification of tomato production in some greenhouses in South – Central Bulgaria, a large volume of tomato plants for planting was imported from Greece. Producers preferred to import transplants rather than relying on own production in order to optimize greenhouse area use. The infestation of two greenhouses

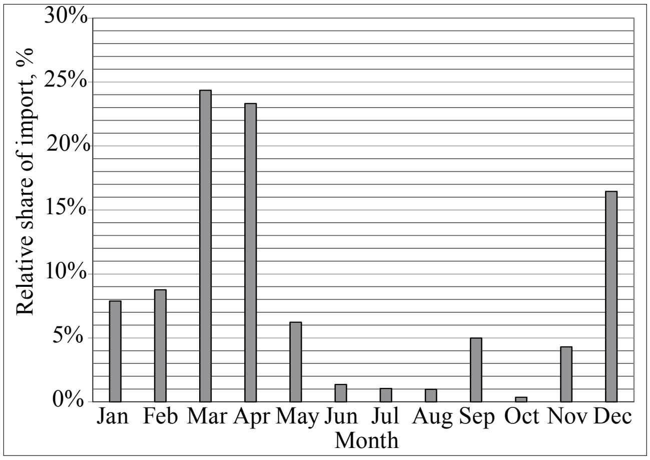

Fig. 3. Import of tomato fruits during different months of the year - relative share based on average values for 2005-2007 (after NSPP, Bulgaria)

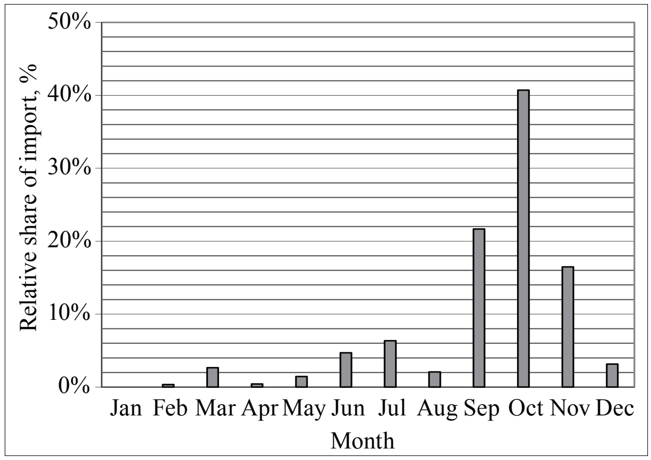

Fig. 4. Import of pepper and chillies during different months of the year - relative share based on the average values for 2005-2007 (after NSPP, Bulgaria)

Table 3
Import of fresh tomato, pepper and eggplant in Bulgaria for the last 5 years, t*

Year / Country of origin	Tomato					Pepper					Eggplant				
	2006	2007	2008	2009	2010	2006	2007	2008	2009	2010	2006	2007	2008	2009	2010
Albania		58	41	409	2 223				13	15	:	:	:	1	3
Czech Republic											:	2	:	2	1
Cyprus					6										
Egypt	3				25	15				9					
F.Y.R. Macedonia	13	11 659	16 704	11 125	9 624	640	8 544	10 993	6 757	12 009	:	6	77	:	18
France					42		1		0.1		:	0	:	0	:
Greece	688	1 191	1 097	1 718	7 432	148	53	561	1 045	1 492	10	38	88	66	137
Israel	2			282		1			13						
Italy	26	48	320	7	123		3	19	3	0,3	:	7	12	0	:
Jordan	9	919	2 221	2 205	2 281	1	7	44	363	168	1,9	16	18	50	54
Kosovo		197	35		30		19								
Lebanon	1					4					3,5				
Montenegro		301	185												
Morocco	2														
The Netherlands	108	90	75	58	209	11	40	55	38	30	1,7	12	5	3	13
Romania		16	0	682	415		7		29	282	:	1	:	8	8
Serbia		2 090	769	361	1 138	56	388	152	95	3					
Slovenia			17												
Spain	138	136	557	166	324	11			14	6	14	:	:	13	16
Syrian Arab Republic	87	183	74	2 368	32	1	3		180	4	:	:	:	34	3
Turkey	8 848	22 796	35 232	60 287	21 788	2 131	5 274	17 388	12 191	3 429	528	485	503	516	522
Total	9 925	39 684	57 327	79 669	45 691	3 020	14 339	29 211	20 741	17 447	559	567	704	694	774

*after EUROSTAT - last entered on 22.06.2011 in South Central Bulgaria in the region of Harmanli in 2010 is probably a result of usage of Greek tomato transplants.

After the analysis of the pathways of entry, we can conclude that *T. absoluta* has most likely been introduced in Bulgaria on tomatoes and packing material along the E80 highway in 2009 from Turkey and Greece. Additionally, there has been a continuous import of infested products and packing materials through road E79 from Greece in 2010 and 2011, which led to the introduction of the pest in greenhouses and outdoors along the road.

Potential for establishment and spread of Tuta absoluta in Bulgaria

It is evident that *T. absoluta* has a high potential for further entry in Bulgaria and therefore an assessment of its potential for establishment and spread is necessary. Climatic comparison is a useful tool for evaluating where the introduced species might become permanently established within a new geographic region (Mack et al., 2002), especially taking into account the influence of low temperatures on the survival of *T. absoluta*.

T. absoluta is a multivoltine species with a high reproductive potential. Larvae do not enter diapause when food is available and depending on the environmental conditions up to 12 generations per year may be able to develop (EPPO, 2005). In the laboratory (at a constant temperature of 25°C and 75 % R.H.), *T. absoluta* completes a generation in 28.7 days (Vargas, 1970). Under the field conditions in Chile, *T. absoluta* could complete seven to eight generations per year (Vargas 1970). Temperature thresholds for egg larva and pupa were estimated at 6.9 ± 0.5, 7.6 ± 0.1 and 9.2 ± 1.0 °C. The total thermal constant from egg to adult was estimated at 453.6 ± 3.9 Degree Days (DD) (Desneux et al., 2010).

A Climex model was used to predict the potential distribution of *T. absoluta* in Europe (Desneux et al., 2010). A map of Ecoclimatic indices (EI) was created to show the climatic suitability (Figure 7). The higher the EI value, the most suitable the climate at that location (EI 10: species could survive, 30: very favorable, (Sutherst et al., 2007)). According to the model, the pest can establish only in areas of the Mediterranean basin, where the climatic conditions are similar to those in the native area of species. The EI for Bulgaria is 0, so **the pest cannot survive winter temperatures and establish permanent populations outdoors**. However, the model does not include the possibility of transient populations occurring outdoors during favorable periods of the year. The pest can also establish in protected cultivation where the conditions are suitable and remain relatively unchanged throughout the year. Such infestations indoors may become sources of

Table 4
Import of vegetable and strawberry planlets in Bulgaria for the last 5 years, t*

Country of origin	2006	2007	2008	2009	2010
Germany					0.1
France				1.0	1.0
Greece	1.3	18.0	1.7	78.2	74.5
Italy	36.9	38.0	56.0		0.6
Netherlands	17.7	7.3	11.3		0.2
Serbia			0.3	20.7	
Total	55.9	63.3	69.3	99.9	76.4

*after EUROSTAT - last entered on 2.05.2011

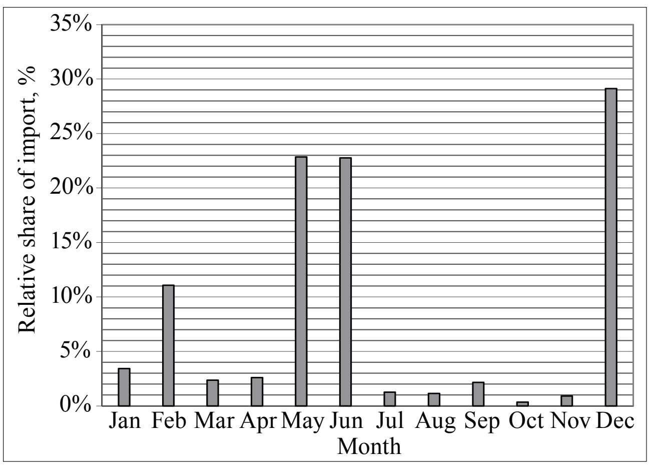

Fig. 5. Import of eggplant during different months of the year - relative share based on the average values for 2005-2007 (after NSPP, Bulgaria)

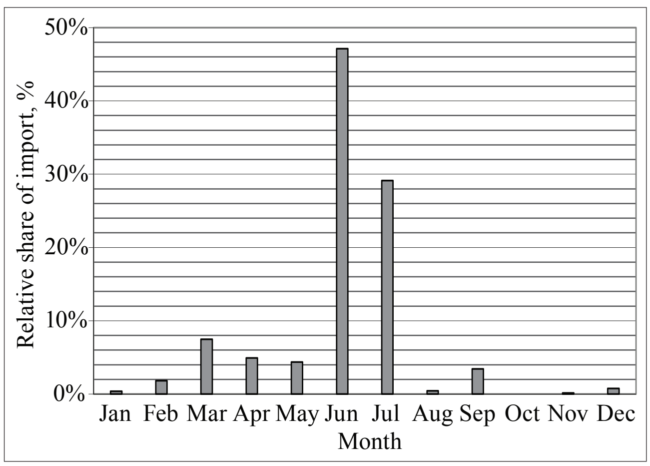

Fig. 6. Import of vegetable plantlets during different months of the year - relative share based on average values for 2005-2007 (after NSPP, Bulgaria)

transient outdoor populations in the summer. Based on the Climex model, a map of the number of generations per year on the territory of Bulgaria was created (Figure 8). It shows that in different areas *T. absoluta* could develop from 2 to 5 generations.

Tomato is the main and most suitable host for the pest. Therefore, to assess the potential for establishment and increase in the level of infestation we need to consider the major tomato growing areas in the country, which are located in South Central and Southwestern Bulgaria (Table 2). Most of the greenhouses for tomato production in the country are also located in these areas. They have favorable conditions for establishment of transient populations outdoors (for up to 5 generations), outbreaks and infestation of adjacent greenhouses. The species could overwinter in protected areas and develop up to 12 generations per year. Therefore, greenhouses represent reservoirs for regular re-infestation of plants grown outdoors. Moreover, the first reports of the pest in Bulgaria were from these particular areas. In the other parts of the country the climatic conditions are either less suitable for the development of the pest outdoors or the tomato growing areas are relatively small, which decreases the risk of establishment and spread.

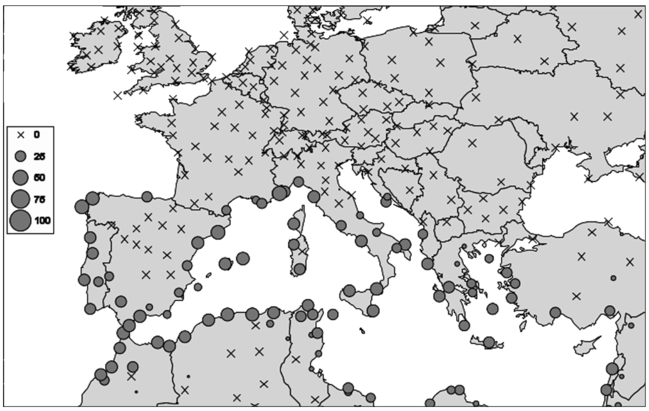

Fig. 7. Ecoclimatic index (EI) map of *Tuta absoluta* in Europe

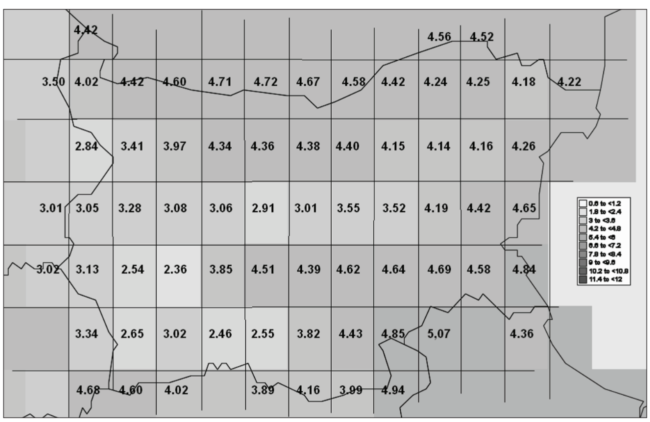

Fig. 8. Number of generations of *Tuta absoluta* in Bulgaria

The major production areas for other hosts of the pest, grown in the country (eggplants, potatoes, onions, beans) are located in the same regions as for tomatoes, except for peppers, which are also cultivated in Northeastern Bulgaria (Table 2). According to the Climex model, this area is also suitable for the pest and it could develop up to 4 generations outdoors.

Once introduced to a new area, *T. absoluta* has the potential to spread naturally through adult flight. The adults can fly actively for several kilometers, which allows for short distance spread (field-to-field, field to glasshouse and *vice versa*) (Stol et al., 2009). Long-distance spread can occur through human assisted means (Potting et al., 2009).

Importantly, infestations in Europe have not been confined to warm regions where *T. absoluta* is expected to survive outdoors. Greenhouse production and tomato packing houses have been subjects to outbreaks across Europe. Protected environments are capable of supporting *T. absoluta* in regions that would otherwise be considered too cold for establishment.

Since its introduction into Europe in 2006, *T. absoluta* has continued to spread through the European and Mediterranean regions. By July 2009, the pest was intercepted 56 times at 13 packing stations and 61 times at 24 greenhouses in the neighborhood of infected packing stations in the Netherlands (Potting et al., 2009). In the UK as of January 2010, 21 packing sites and 11 growing areas have reported outbreaks of *T. absoluta* (Sixsmith, 2010). More recently, *T. absoluta* has spread to Germany where it was detected at a central market, a packing station, and at four tomato production sites (EPPO, 2010). Adults of *T. absoluta* have also been detected in tomato greenhouses and vegetable warehouses in Lithuania (Ostrauskas and Ivinskis, 2010).

Suitable solanaceous host plants exist in South Bulgaria (Table 2) so establishment and spread of transient populations are possible if appropriate pest management is not in place. In addition to crop plants , solanaceous weeds could serve as host reservoirs for the pest.

Conclusions

The total tomato yield in Bulgaria has shown an 8.4-fold decrease for the past 20 years, which has led to an increase in the volumes of tomatoes for import, contributing to a higher risk of entry of *T. absoluta*;

T. absoluta has most likely been introduced in Bulgaria on tomato fruits and packing material in the spring of 2009 from Turkey and Greece. The import of infested fruit consignments in 2010 and 2011 has led to the introduction and establishment of the pest in greenhouses and transient populations outdoors in the Southwestern and South Central part of the country. The climatic conditions in Bulgaria and the tradition of cultivating field vegetables in proximity to greenhouses allow migration of the pest from protected cultivation to the field and *vice versa*;

The repeated use of packing materials by the Bulgarian producers leads to additional spread of the pest outdoors and in the greenhouses.

Under the current climatic conditions, *T. absoluta* will not be able to overwinter outdoors in Bulgaria. However, transient populations outdoors, developing 2 – 5 generations per year during the growing season, may establish and damage susceptible hosts. In tomato greenhouses, the pest can develop more than 10 generations per year.

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