Phenology modeling and regional risk assessments for *Tecia solanivora*

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Abstract

The Guatemalan potato tuber moth, *Tecia solanivora* (Lepidoptera: Gelechiidae) is a serious pest in potato (*Solanum tuberosum*) production as larvae feed on potato tubers in field and storage and destroy them completely. Native in Guatemala, *T. solanivora* spread within the last 25 years to Venezuela, Colombia, Ecuador and Tenerife, Canary Islands, Spain. Exact understanding of pest ecology, specifically its temperature-dependent development, is helpful for targeting control efforts to the most affected and threatened regions. Life-tables describing development time and mortality of immature life stages, sex ratio, longevity of adults and oviposition of *T. solanivora* at constant temperatures ranging from 9.9 to 29.9°C were established. Functions were fitted to the observed data points and compiled to a temperature based phenology model. The model was validated with development data collected under fluctuating temperature regimes before it was linked to geographic information systems in order to produce maps indicating the risk of *T. solanivora* establishment and population growth potential in the Andean region. The indices chosen for mapping were the generation index (number of generations per year) and the activity index (potential population growth within one year). The maps were compared with available data on the distribution of *T. solanivora* in Colombia, Ecuador and Venezuela. The maps indicate that multiplication of *T. solanivora* is possible in various potato growing zones of all South American countries and that there is a high risk of further distribution of *T. solanivora* to Peru.

Keywords: potato production, pest management, Guatemalan potato tuber moth, insect modeling

Introduction

The Guatemalan potato tuber moth, *Tecia solanivora* Povolny (Lepidoptera: Gelechiidae) is a potato pest whose larvae feed on potato (*Solanum tuberosum* L.) tubers during the cropping period as well as in storage making them unsuitable for consumption. Losses of up to 60% at harvest and of 100% during storage were observed in Ecuador (Suquillo 2004); for Colombia harvest losses of 10 to 50% were reported (Palacios *et al.* 1997). Originating in Guatemala, *T. solanivora* was unintentionally introduced into Venezuela in 1983 (Salasar & Escalante 1984) and into Colombia in 1985 (Durán 2001). In 1996 it reached Ecuador (Gallegos 1997) and in 1999 it was detected in Tenerife, Canary Islands (Trujillo *et al.* 2004).

Further distribution of the pest has to be prevented. In order to develop an appropriate strategy for managing the pest it is important to identify those potato growing areas that are most affected or threatened by *T. solanivora*. A *T. solanivora* phenology model based on temperature was developed and linked to Geographic information systems in order to produce risks maps indicating the pest's activity potential in the Andean region and South America in general.

Materials and Methods

Insect modeling and model validation

Development time and mortality of immature life stages, sex ratio and longevity of adults as well as fecundity of *T. solanivora* were determined at constant temperatures ranging between 9.9 and 29.9°C. Hereby, we followed the methods for life-table studies of the potato tuber moth *Phthorimaea operculella* (Zeller) as described by Sporleder et al. (2004). Functions were fitted to the distribution of development, median development rate, mortality and fecundity (Table 1).

Table 1. Functions and their estimated parameters fitted to *T. solanivora* development distribution, development rate, mortality of immature life stages and fecundity

Distribution of development and senescence time

	intercept (=a)							slope (=b)
temp.(°C) life stage	9.9	15.2	17.4	20.4	25.4	27.8	29.9	
eggs	-184.27	-132.78		-104.45	-84.22	-78.64	-86.96	49.37
larvae	-43.79	-33.18		-30.02	-27.15	-27.64		9.53
female pupae	-44.56	-33.92		-28.20	-23.94	-22.38	-23.99	10.50
female adults	-13.01	-10.27	-9.27	-10.68	-8.00	-7.82	-8.82	3.62

Development or senescence rate

life stage	P	To	Ha	Tl	Hl	Hh	Th
eggs	0.07349	289.006	18297.32	282.573	-206259	90647.2	303.131
larvae	0.03861	291.710	10260.36	283.148	-194683	161978.7	302.506
female pupae	0.104	298.303	12903.94	283.228	-57865.9	212441.4	303.810
female adults	0.06359	290.976	8850.484	282.974	-1629230	1138448	303.190

Mortality

life stage	Model	x0	Y0	a	b	C
eggs	y ~ y0 + a * exp(-0.5 * (log(x/x0)/b)^2)	64.57364	0.094914	30107.52	0.168595	
larvae	y ~ a * sqrt(x) + b * x + c			-2.67494	0.32969	5.76309
pupae	y ~ a * x^2 + b * x + c			0.00468	-0.17646	1.90151

Fecundity

	Model	x0	y0	a	B
total oviposition	y ~ y0 + a * exp(-0.5 * ((x - x0)/b)^2)	15.376	50.278	255.653	3.931
accumulated oviposition rate	y ~ pgamma(x, a, b)			2.542	5.624

For the variation of development time in eggs, larvae and senescence of female adults the logit model was used:

$$F(x) = \frac{1}{1 + \exp(-(a + b * \ln x)}.$$

For female pupae, we used a complementary log-log model:

$$F(x) = 1 - \exp\left(-\exp\left(a_i + b \ln x\right)\right).$$

For the development or senescence rate, the Sharpe & DeMichele model was applied (Sharpe and DeMichele, 1977).

A female ratio of 1:0.88 was established for all temperatures studied. The functions were compiled to an overall temperature-driven (computer-based) phenology model which uses rate summation and a cohort up-dating algorithm for simulating population growth. For considering temperature fluctuations within one day a cosine function was fitted in between the daily minimum and maximum temperatures and a 15 minute interval was used for calculating the population development as described by Sporleder *et al.* (2008). Development data collected under eleven different fluctuating temperatures were used for validating the overall model. Model outputs were compared to observed development data and the deviation was found to be low enough to accept the model (Table 2).

Table 2. Deviation of simulated to observed values on *T. solanivora* development parameters

development parameters	deviation: simulated-observed values	
total immature development time (days)	-6.8	(±2.40)
mortality in immature life stages (%)	-16.5	(±3.06)
total oviposition per female	+33.5	(±4.76)

Values in parenthesis indicate the standard error.

Risk mapping

ILCYM 2.0 software (Sporleder *et al.* 2009) was used to generate *T. solanivora* risk maps based on the validated model. Spatial simulation was conducted using climatic data (WorldClim, http://www.worldclim.org) on a resolution of 2.5 min for South America or 30 seconds for Ecuador. The indices used for mapping were the Generation Index and the Activity Index.

Generation Index: The Generation index represents the estimated number of generations per year. The program calculates the mean duration of one generation for each day of the year (*Tx*; x = 1 to 365), which are summed up and divided by the number of days of the year for estimating the mean number of generations per year:

$$\text{Generation Index} = \frac{\sum 365/Tx}{365}$$

where *Tx* = development time of eggs + larvae + pupae (days) + survival time of female adults (days) * 0.42 (normalized age of females when 50% of eggs are laid)

Activity Index: The Activity Index indicates the decimal power of the estimated population growth potential within a given year. It considers the development time, immature mortality and fecundity and is based on the finite rate of population increase modelled for each day of the year. The index is calculated by using the following formula:

$$\text{Activity Index} = \log \Pi\, (\exp[\ln(\text{fecundity}_i * \text{immature survival}_i/2)/T_i]) \quad i = 1, 2, \ldots 365$$

Results and discussion

The *Tecia solanivora* risk maps developed for Ecuador and South America with climatic data for the year 2000 indicate that the regions with the highest number of generations also have the highest activity and growth of the pest population (Fig. 1, 2). Colombia, Venezuela and Ecuador are already infested with *T. solanivora*. Five or more generations per year might develop in large parts of Venezuela and Colombia leading to a multiplication of the population of up to 10^{22} times within one year. *T. solanivora* infestation is possible in almost the complete potato growing area. In Ecuador the pest severity is less, only up to three generations might develop in the major potato growing zones in the northern and central provinces. Potentially, population increase might be in some small areas up to 10^{18} fold within one year; however, more than half of the central and northern potato growing zones are not at risk of *T. solanivora* because high altitudes and low temperatures render population growth. Literature data on the number of generations per year or the annual population growth are not available, therefore only figures about infestation levels from reports and literature can be used for validating (evaluating) the simulated resulting risk maps. In case of Venezuela, the whole Andean region is reported to be infested (Niño 2005), which coincides with the information of the maps. In Colombia, *T. solanivora* is distributed in the provinces Norte de Santander, Santander, Boyacá, Antioquia, Cundinamarca, Tolima and Nariño (Palacios *et al.* 1997), which are the same regions as indicated in the maps. In Ecuador, *T. solanivora* monitoring data also confirm the simulation results for all potato growing zones with exception of the Pichincha region where an annual population growth of up to 10^{14} is predicted but no moths were detected during monitoring (PUCE-PROMSA 2004). This difference might be caused by high precipitation (1350 mm, Izobamba, INAMHI) as heavy rainfalls impede *T. solanivora* population growth (Barragán *et al.* 2004) and only temperature was considered for mapping.

Peru, Bolivia, Brazil, Argentina, Chile Uruguay and Paraguay are still *T. solanivora* free. The maps however show that the temperature conditions in these countries would favor the pests' population growth. Peru as neighboring country to *T. solanivora* infested Ecuador is especially at risk and preventive measures for early detection are taken since 1997 (Naccha and Villar 2005). Up until now *T. solanivora* was not introduced into Peru probably because southern Ecuador and northern Peru are no commercial potato growing zones and potato fields are small and sparse. Furthermore distribution occurred mainly through human influence; to Costa Rica, Venezuela and Colombia *T. solanivora* was introduced with infested seed tubers (Palacios *et al.* 1997). No potato trade from Ecuador to Peru was registered since 1994 because Peru most of the years does not import potatoes and furthermore potato prices in Ecuador are usually higher than in Peru since the dollarization of Ecuador in 2000 (FAOSTAT, 2009).

Conclusion

The fact that *T. solanivora* reached Tenerife, Canary Islands, shows that the pest might be introduced and also further distributed within Europe and other potato growing regions outside of Latin America. This should be reason for alert for all countries where potato cultivation plays a major role and where the maps indicate a high potential of population growth. Worldwide maps, which are still to be produced, will help to identify those zones in order to create awareness of the risk of *T. solanivora* introduction. Further factors important for the pests' population growth and infestation (e.g., rainfall, crop management etc.), which are not considered for risk mapping yet, have also to be taken in account to define those areas especially at risk.

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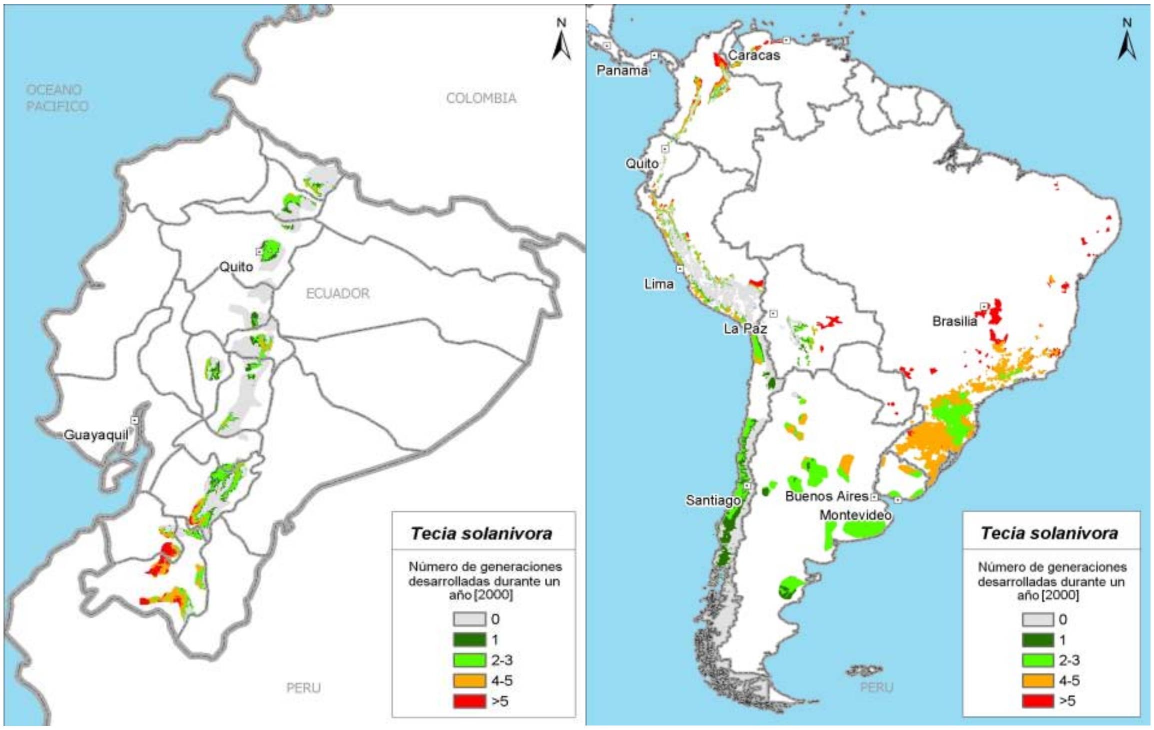

Figure 1. Simulated numbers of *Tecia solanivora* generations for the year 2000 in the potato growing zones of Ecuador (resolution: 30 sec.) and South America in general (resolution 2.5 min.)

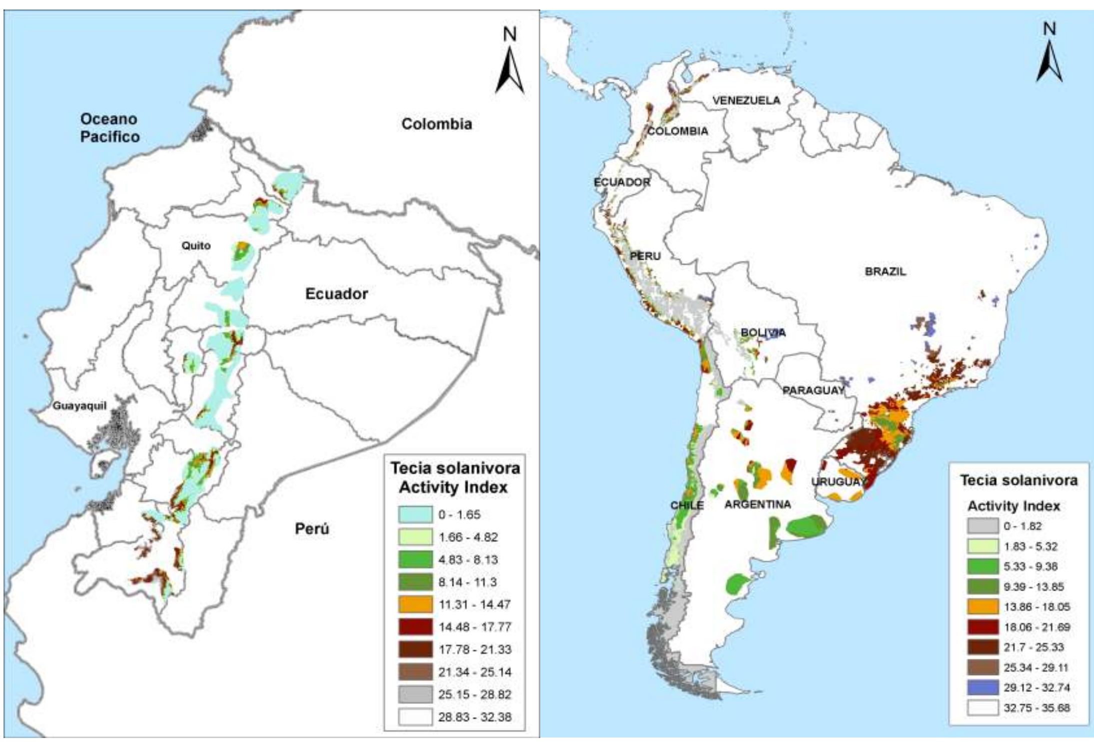

Figure 2. Estimated population growth (activity index) of *Tecia solanivora* within the year 2000 in the potato growing zones of Ecuador (resolution: 30 sec.) and South America (resolution: 2.5 min.)

References

Barragán, A., A. Pollet, M. Prado, A. Lagnaoui, G. Onore, I. Aveiga, X. Lery and J-L. Zeddam 2004. La polilla guatemalteca *Tecia solanivora* (Povolny) (Lepidoptera: Gelechiidae) en Ecuador. Diagnóstico y perspectivas de manejo bajo un método de predicción. In: Memorias - II Taller Internacional de Polilla Guatemalteca. Pontificia Universidad Católica del Ecuador. pp. 5-23.

Durán, O. 2001. La polilla guatemalteca de la papa y su manejo. Plagas y enfermedades de la papa. Boletín de Sanidad Vegetal, ICA, Caldas, Colombia.

Gallegos, 1997. La polilla de la papa *Tecia solanivora* en Ecuador. In: Primer seminario taller internacional sobre manejo integrado de *Tecia solanivora*. Ibarra, Ecuador. CIP, INIAP, PNRT-Papa, FORTIPAPA. pp. 27-28.

Naccha, J. and A. Villar 2005. Acciones preventivas del sistema de vigilancia fitosanitaria del SENASA-Peru contra la polilla guatemalteca de la papa Tecia solanivora (Povolny)(Lepidoptera: Gelechiidae). In: Memorias: III Taller Internacional sobre la polilla guatemalteca de la papa, *Tecia solanivora*. Cartagenas de Indias, Colombia. 16 - 17 de octubre 2003. Centro Internacional de la papa (CIP), Lima, Perú. pp. 9-15.

Niño, L. 2005. Antecedentes de la investigacion y manejo integrado de la polilla guatemalteca *Tecia solanivora* (Lepidoptera: Gelechiidae) en Venezuela. In: Memorias: III Taller Internacional sobre la polilla guatemalteca de la papa, *Tecia solanivora*. Cartagenas de Indias, Colombia. 16 -17 de octubre 2003. Centro Internacional de la papa (CIP), Lima, Perú. pp. 107-114.

Palacios, M., G. Sotelo, E. Saenz 1997. La polilla de la papa *Tecia solanivora* (Povolny). In: Primer seminario taller internacional sobre manejo integrado de *Tecia solanivora*. Ibarra, Ecuador. CIP, INIAP, PNRT-Papa, FORTIPAPA. pp. 1-22.

PUCE-PROMSA 2004. Proyecto Polilla Guatemalteca: Mapas de distribucion de la plaga – Distribución de *Tecia solanivora* in Ecuador. CD interactivo; © PROMSA-MAG-PUCE.

Salasar, J., and W. Escalante. 1984. La polilla guatemalteca de la papa, *Scrobipalpopsis solanivora*, nueva plaga del cultivo de la papa en Venezuela. Sociedad Venezolana de Ingenieros Agronomos 9: 24-28.

Sporleder, M., J. Kroschel, M. R. Gutierrez Quispe, A. Lagnaoui 2004. A temperature-based simulation model for the potato tuber worm, *Phthorimaea operculella* Zeller (Lepidoptera; Gelechiidae). Environmental Entomology 33 (3): 477-486.

Sporleder, M., R. Simon, H. Juarez, J. Kroschel 2008. Regional and seasonal forecasting of the potato tuber moth using a temperature-driven phenology model linked with geographic information systems. In: Tropical Agriculture - Advances in Crop Research Vol. 10: Integrated Pest Management for the Potato Tuber Moth, *Phthorimaea operculella* (Zeller) - Potato Pest of Global Importance Margraf Publishers GmbH, Weikersheim, Germany. pp.15-30.

Sporleder, M., R. Simon, J. Gonzales, D. Chavez, H. Juarez, F. de Mendiburu, J. Kroschel 2009. Insect Life Cycle Modeling (ILCYM) A software package for developing temperature-based insect phenology models with applications for regional and global risk assessments and mapping. http://research.cip.cgiar.org/confluence/display/ilcym/Downloads)

Sharpe, J. H., and DeMichele, D. W. (1977). Reaction kinetics of poikilotherm development. *J. Theor. Biol.* 64, 649-670.

Suquillo, J. 2005. Alternativas culturales y biológicas en el control de *Tecia solanivora* en campo y almacenamiento. Escuela politécnica del ejército, Sangolquí, Quito, Ecuador. Master thesis. pp. 86.

Trujillo, E., D. Rios, R. Cabrera 2004. Distribución de *Tecia solanivora* (Povolny) (Lepidoptera: Gelechiidae) en Tenerife, Islas Canarias, España. In: Memorias - II Taller Internacional de Polilla Guatemalteca. Pontificia Universidad Católica del Ecuador. p. 191.