Impact of environmental conditions on the distribution of insect pests in Nitra region vineyards (Slovakia)

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Abstract: *The presented study introduces the most common and significant insect pests of the grapevine (Vitis vinifera) in Slovakia, specifically the occurrence of the European grapevine moth (Lobesia botrana) and the American grapevine leafhopper (Scaphoideus titanus). Historical records set prerequisites to studying the complex interactions between the pests and their host plant. If they are not understood sufficiently, they may have devastating consequences on the grape-growing. The research was carried out in the model vineyards in Jelenec, Ladice and Topoľčianky during the period from April to September 2019 and 2021. Jelenec and Ladice had six monitoring sites, Topoľčianky had seven monitoring sites. Data were collected in approximately 30-day cycles. The aim of research was to monitor the incidence of insect pests in selected vineyards and identify their relation to environmental conditions. Pheromone traps were used throughout the research. The insect traps in combination with species-specific pheromone represent a reliable method for the pest monitoring. Based on aim studying the link between insect pests and climate conditions, traps were dispersed at the place of installation of the microclimatic dataloggers and the automatic stations. Data on the occurrence of the pests were subsequently evaluated in the context of the climate variability (temperature, wind speed, precipitation) and distance of the locality from the forest using Redundancy Analysis. It was confirmed that the insect pests are unequally distributed in the studied region and also inside the vineyards. Using Redundancy Analysis, we were able to explain the bonds in a maximum of 40% insect pests-environmental factors relationships. This research results show the need for regular monitoring of insect species, taking into account microclimatic as well as other ecological factors to optimize agrotechnical interventions.*

Keywords: *Vineyard insect pests, Slovak viticulture, Environmental conditions, Lobesia botrana, Scaphoideus titanus*

Introduction

Vitis vinifera and viticulture as such are hugely influenced by various climatic factors and characteristics of the physical environment (Van Leeuwen 2010). These characteristics were instrumental in the formation of the famous winemaking regions, especially in Europe. However, apart from abiotic environmental factors, many biotic interactions also influence the grapevine (Biasi et al. 2019). One of these factors is the presence of various organisms being either beneficial or harmful to the grapevine (Reineke and Thiéry 2016). Likewise, many biotic and abiotic conditions influence grapevine diseases and pests (Schneider et al. 2022). Historical records set prerequisites to studying the complex interactions between the pests and their host plant. If they are not understood sufficiently, they may have devastating consequences on the grape-growing. A prime example serves the case of the phylloxera epidemic in the mid-19th century. This epidemic devastated the wine-producing industry in France and had substantial consequences on the grape-growers across Europe (Macedo 2011), reaching

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the territory of today´s Slovakia shortly after the detection in Austria (Haba 2005). Interestingly, though, the phylloxera, an insect pest native to North America (Lund et al. 2017), was unintentionally introduced into Europe with planting material intended to beat powdery mildew, an important fungal disease (Granett et al. 2001). Vineyards are agroecosystems, which can host a large number of pests (Reineke and Thiéry 2016).

The most recent grape pest species transferred to Europe from North America is the American grapevine leafhopper *Scaphoideus titanus.* Leafhoppers (e.g., *Scaphoideus titanus, Hyalesthes obsoletus, Reptalus panzeri, Oncopsis alni)* do not cause significant damage to the grapes by sucking the leaf but as phytoplasma vectors play a major role in the spread of diseases. The two most important grape yellowing diseases caused by phytoplasma in Europe are the *Bois noir* and the quarantine *Flavescence dorée*. *Scaphoideus titanus* Ball. (Hemiptera: Cicadellidae) feeds only on grapes and it is a primary vector of *Flavescence dorée*. Eggs were introduced into Europe with seeding material. The species first appeared in Slovakia in 2013 (Tóthová et al. 2015) and was collected in the Nitra wine region in 2015 (Tancik and Seljak 2017). Eggs of *S. titanus* are laid on branches between August and October. Around mid-May of the following year, the eggs start hatching. Nymphs are visible from mid-May, and adults appear from the beginning of July to mid-October, although the highest population level can be observed in July and August (Chuche and Thiéry 2014). The stage L1 larvae take up the phytoplasma from infected plants during their first feeding. An incubation period is necessary for phytoplasma to pass through cells and enter the salivary glands (Lefol et al., 1994). The infectivity of cicadas develops after 4-5 weeks, at any stage of development and remains infectious throughout their lives. The disease has catastrophic impact on the vineyard, radically decreasing the yields. The damage to the plants is progressive, and the infected grapevines typically die within a few years (Filippin et al. 2009). Delayed bud break, stunting, yellowing and curling of leaves are common symptoms of *Flavescence dorée* (Chuche and Thiéry 2014, Morone et al. 2007). However, these are shared with *Bois noir*, another disease belonging to the group identified as grapevine yellows (Belli et al. 2010). There is no direct control method against *Flavescence dorée* because the infected plants cannot be cured. The only solution is the control of *S. titanus* with insecticide treatments (Caudwell et al. 1972).

The grapevine moths (e.g., *Lobesia botrana, Eupoecilia ambiguella*) pose a big threat because they feed on the flower or fruit of host plants, most often grapes. If the moth attacks mature grape clusters, the berries can become further damaged through a potentially deadly infection of a fungus called botrytis, also known as bunch rot. The European grapevine moth *Lobesia botrana* (Denis and Schiffermüller) (Tortricidae), is one of the most destructive grape pests in the Palearctic Region. In Europe, two to four generations of the polyphagous *L. botrana* (Thiéry and Moreau 2005) occur annually, with typically two (rarely three) generations occurring in Slovakia and its surround (Svobodová et al. 2013). In Central Europe climate, *L. botrana* starts to be active at the end of April and May (daily temperature over 10 degrees Celsius). In May and June, first-generation larvae web and feed on the flower clusters. Second-generation larvae (July/August) feed on green berries. Young larvae penetrate the berry and hollow them out, leaving the skin and seeds. Third-generation larvae (August/September) cause the greatest damage by webbing and feeding inside berries and within bunches, which become contaminated with frass (Venette et al. 2003). Larvae feed on fruit, causing direct damage and enhancing secondary infection by *Botrytis cinerea* Persoon (botrytis bunch rot or gray mold). Gilligan et al. (2011) identified tortricid larvae damaging grapes in California as *L. botrana*, representing the first records of this species in North America. In recent years, *L. botrana* was accidentally transmitted and found in the vineyards of Chile (2008), California (2009) and Argentina (2010) (Ioriatti et al. 2012). It was declared eradicated from California in 2016. Each larva is capable of damaging between 2 and 10 berries, and up to 20-30 larvae per cluster may occur in heavily attacked vineyards (Thiery et al. 2018). If conditions are suitable for fungal or acid rot development, a large number of berries may be also affected by *Botrytis cinerea*, *Aspergillus carbonarius* and *Aspergillus niger*., which results in severe qualitative and quantitative damage (Delbac and Thiery 2016). Damage is variety-dependent: generally, it is more severe on grapevine varieties with dense grapes, because this increases both larval installation and rot development. Individuals from the last generation overwinter as diapausing pupae from autumn to the next spring, located under vine bark.

Other significant insect pests in the vineyards include *Harmonia axyridis* (harlequin ladybird**)** and *Vespula* (social wasps). The ladybird feeds on damaged grapes in late summer and autumn. As they cannot be removed, they get harvested and processed together with the grapes. It creates a typical off-flavor scent in the wine and must, the so-called "ladybird taint" (Bátor and Bozsik 2017). Lastly, *Vespula* (Hymenoptera: Vespidae) is a small genus of social wasps. In Slovakia, the common wasp (*Vespula vulgaris*) is the most common in vineyards (Jósvai et al. 2011). In spring, they chew up weathered wood and build honeycombs in which they lay eggs. The wasps, which hatch after several larval moults, sting the grapes, and eat the contents, leaving only the berry skin. As secondary damage, the grapes are attacked by fungi or bacteria, which can further develop into vinegar and green rot.

The spatial distribution of insect pests in vineyards, especially invasive species, has received considerable attention in the past years (Sciaretta et al. 2008, Ifoulis and Savopoulou-Soultani 2006, Leach and Leach 2020, Chireceanu et al. 2020, Comșa et al. 2022). Early detection and monitoring are essential practices in preventing the spread of invasive species, as well as adopting the most appropriate management measures for established populations (Britton et al. 2010). One of the most important reasons of invasive species spreading is the increasing impact of climate change on agriculture (Kocmánková et al. 2010, Skendžić et al. 2021). It directly impacts pests' reproduction, development, survival and dispersal, whereas indirectly it affects the relationships between pests, their environment and other insect species such as natural enemies, competitors, vectors and mutualists (Prakash et al. 2014).

As of 31.7.2021, more than 14 600 hectares of vineyards were registered in Slovakia, with wine production of approximately 0.3 mhl per year. Slovakia is not yet amongst the leading vineyard growers, however, viticulture has a long tradition. Although research on insect pests in vineyards is relatively limited in Slovakia, several studies have been carried out (Svobodová et al. 2013, Tancík et al. 2014, Tóthová et al. 2015, Tancik and Seljak 2017).

In this paper, we provide a monitoring of the incidence of insect pests (especially *L. botrana* and *S. titanus*) in selected vineyards of the Nitra region. The research was undertaken from April to September 2019 and 2021. Selected vineyards are the predominant cultivation, mostly surrounded by forests, rarely by small fields. The main purpose of the study was to investigate the spatial dynamics of insect pests inside vineyards and to evaluate the effect of environmental parameters on its distribution. The chosen environmental parameters were minimum, maximum temperature, amount of precipitation, wind speed and distance from the forest. The temperatures were chosen on the basis of the detected temperature differentiation within the selected vineyards in the previous research of the sites (Mosná 2019, Oršulová et al. 2019). Precipitation and wind speed have a direct effect on the distribution of insect pests. The high moisture content decreases the rate of development of insect which may even be completely halted (Schowalter 2016, Comșa et al. 2022). Choosing forest distance was based on assumption, that the forest might harbour alternative host plants of the insect pests and therefore represent possible sources of spreading of the pests into the vineyard, or conversely, the forest can produce predators of insect pests.

Materials and methods

Study area

Three vineyards in Nitra region were selected for this research, where the oldest historic evidence of the existence of vine growing and winemaking in Slovakia was found (Domin et al. 2017). Two of them are located in Nitra wine sub-region (Jelenec – 48.381 N, 18.211 E and Ladice – 48.394 N, 18.248 E) and one in Zlaté Moravce wine sub-region (Topoľčianky – 48.434 N, 18.400 E). The total area of the studied vineyards is 152.2 ha (Jelenec – 42.4 ha, Ladice – 43.1 ha, Topoľčianky – 66.7 ha). The sub-regions are located at the interface of the geomorphological units of the Danube Uplands and the Tríbeč Mountains (Fig. 1).

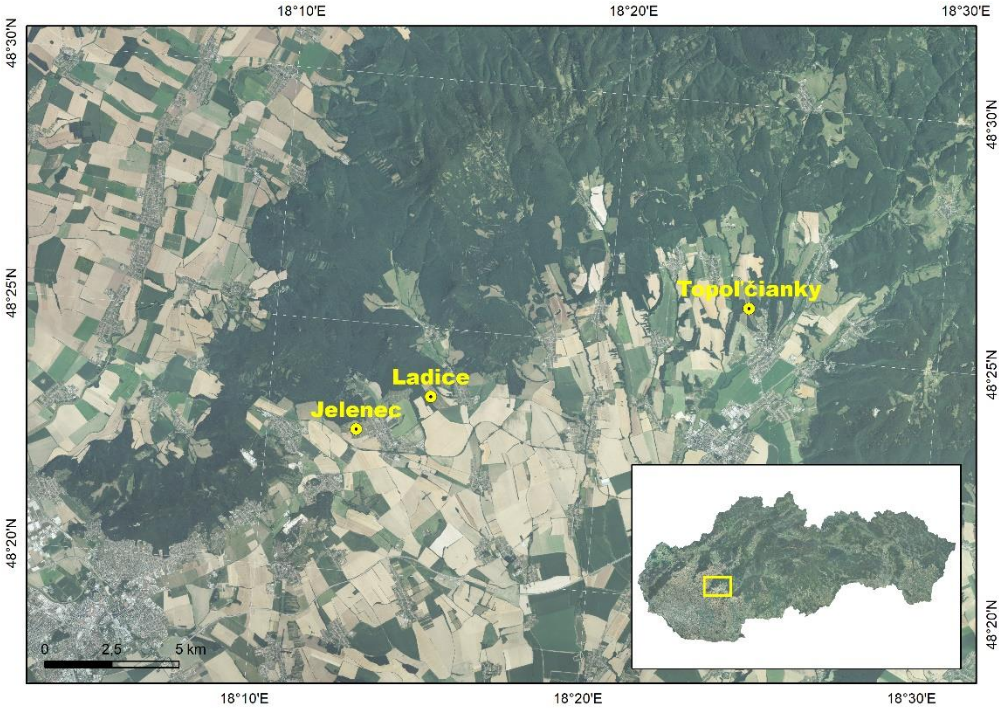


Fig. 1. *Studied vineyards and their location within Slovakia*

Data and instrumentation

The placement of traps in the field was performed on different dates between April and the end of August 2019 and 2021. The season was set according to the time with the highest vineyard threat to pests. In 2019 the research in Jelenec took 91 days (start date 23rd May), in Ladice 70 days (start date 28th June) and 104 days in Topoľčianky (start date 25th May). In 2021 exact durations were set, resulting in 143 research days (start date 9th April). Jelenec and Ladice had five monitoring sites in 2019 and six in 2021, Topoľčianky had seven monitoring sites during both years (Fig. 2). Data were collected in approximately 30-day cycles.

Based on the link between insect pests and climate conditions, traps were dispersed at the place of installation of the microclimatic datalogger (Solinst Levelogger 3001, Fig. 3) and the automatic station (iMETOS® 3.3 IMT300 by Pessl Instruments). The datalogger, as well as the insect trap, was located in the leaf wall of the vineyard – about 80 centimetres above the ground.

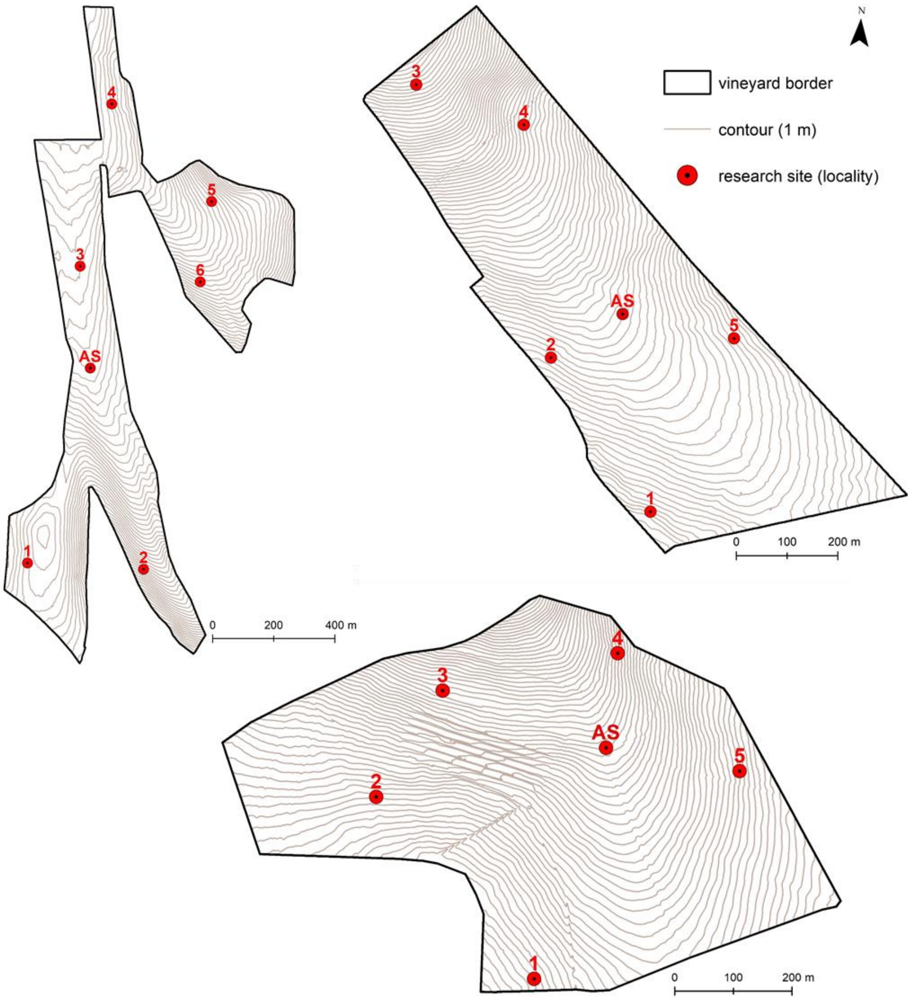


Fig. 2. *Studied vineyards with the designation of studied localities*

Pheromone traps DeltaStop by Propher (Czech Republic) were used throughout the research. The insect trap in combination with species-specific pheromone represents a reliable method for the pest monitoring and capture. These traps are a sensitive tool to monitor the flight of males exclusively but can be useful to time an ovicidal treatment, and to properly schedule scouting activities in the vineyard. It has now been shown that the *L. botrana* sex pheromone is a blend of 15 compounds (Arn et al. 1988). For economic reasons though commercial traps contain only the major pheromone compound, which has a satisfactory trapping specificity for *L. botrana*. A major limitation of *L. botrana* sexual trapping is the lack of a clear relationship between the number of males trapped and the damage done by their offspring, given the high number of other uncontrolled ecological factors involved (Roehrich et al. 1983, Pérez-Aparicio et al. 2019).

Climatic data obtained from microclimatic dataloggers, and automatic weather stations were applied to the period of individual cycles; the average, maximum and minimum temperature was determined for the period. Data about total precipitation and wind speed were obtained from the automatic weather station. The last data entry was the distance of the locality from the forest, which was measured by Trimble Geo 7x GPS receiver.

Fig. 3. *Environment and setting of the dataloggers and traps*

Statistical analysis

The relationship between taxonomical heterogeneity of the insect community and environmental conditions of vineyards was examined using a Redundancy Analysis (RDA). The selection procedure (forward selection of environmental predictors) was based on pseudo-F criteria (999 permutations) and acceptance threshold $\alpha = 0.05$ at each step. The hierarchical design of permutations was set. At the level of vineyards and plots, data were freely permuted. Within plots, data permutations reflected the time transect of the samples taken.

Response curves of the two most frequent taxa to significant environmental gradients were constructed using Poisson distribution. Assumptions of Poisson distribution of the data were assessed based on diagnostic plots.

All analyses were computed in R software (R Core Team 2016) using the package "Vegan 2.5-7" (Oksanen et al. 2020), "nlme" (Pinheiro et al. 2012), "geepack" (Halekoh et al. 2006). "effects" (Fox and Weisberg 2018), "car" (Fox and Weisberg 2019), "ggplot2" (Wickham 2016).

Results and Discussion

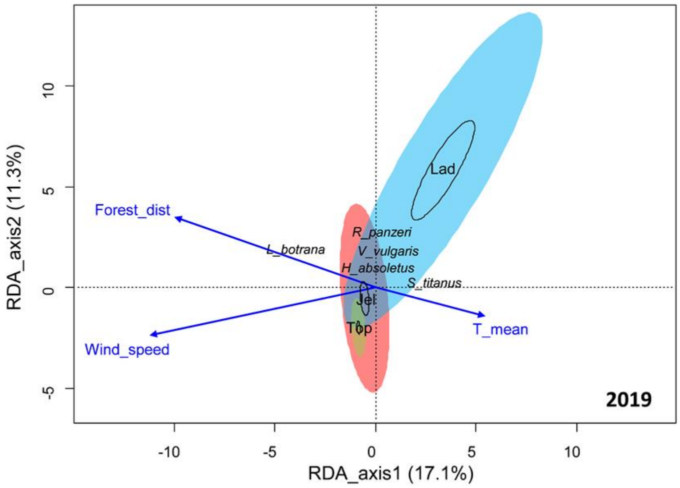
The following eight insect species were detected during the research: two species of grapevine moths (*L. botrana* and *E. ambiquella*), four species of leafhoppers (*S. titanus, H. obsoletus, R. panzeri* and *O. alni*), common wasp (*V. vulgaris*) and harlequin ladybird (*H. axyridis*) (Tab. 1). Monitoring was focused on *L. botrana*, but high numbers of *S. titanus* were also recorded, despite the collection method specific to *L. botrana*. As specific pheromone evaporators were used, the most widespread pest was *L. botrana* (776 caught individuals). A high incidence of *S. titanus* has been reported (649 individuals). Due to the small number of captured other species, we will continue to address *L. botrana* and *S. titanus*.

Tab. 1. *Number of catched individuals*

Caught Species	Number of individuals
Lobesia botrana [Denis and Schiffermüller] (Tortricidae)	776
Scaphoideus titanus Ball (Hemiptera: Cicadellidae)	649
Hyalesthes obsoletus Signoret (Hemiptera: Cixiidae)	13
Vespula vulgaris (Hymenoptera: Vespidae)	4
Reptalus panzeri Löw (Hemiptera: Cixiidae)	2
Harmonia axyridis Pallas (Coleoptera: Coccinellidae)	2
Oncopsis alni Schrank (Auchenorrhyncha: Cicadellidae)	1
Eupoecilia ambiquella Hubner (Tortricidae)	1

Environmental parameters influencing the incidence of insect pests

According to the RDA (Fig. 4), four environmental variables were statistically significant (threshold level $\alpha = 0.05$) predictors of the pests community structure: forest distance, average temperature and wind speed, and in 2021, the minimum temperature. After performing the RDA with 2019´s data, we retained the first two axes that explained 28.4% of the total variation in pest's community composition. RDA for 2021´s data explained 39.9% of the total variation in pest's community composition. Other environmental parameters (precipitation, maximum temperature) became statistically insignificant. From both ordination diagrams, it is obvious that the abundance of *S. titanus* and *H. obsoletus* increased with the increase of temperature at the studied localities. On the other hand, the abundance of *L. botrana* was the highest on the plots furthest from the forest. In both studied years, the vineyard in Ladice had the highest variability in the structure of the pest community composition, while the vineyard in Topoľčianky the lowest.



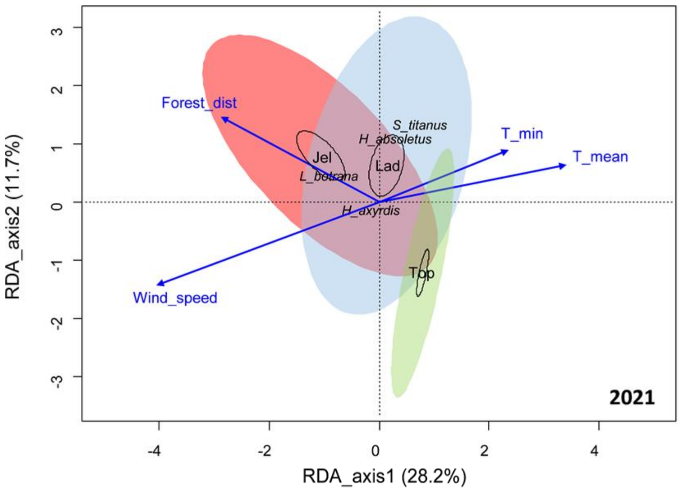


Fig. 4. *RDA diagrams showing the ordination of species along the first two axes and their correlation with significant environmental variables selected through forwarding selection (at $p < 0.05$, based on 999 permutations); Explanation: The size of the coloured ellipse means predicted variability of the pest community composition on the locality. The black-line ellipse means the confidence interval for the position of the locality centroid. Abb. Forest_dist – air distance from the forest, T_min – minimal air temperature, T_mean – mean air temperature*

Response curves to significant gradients of the environment (Fig. 5) were constructed for the two most numerous species. In Jelenec and Ladice vineyard, species *L. botrana* showed the highest abundances at temperatures of 12 – 14ºC with a gradual decrease in abundance with temperature increase. Species *S. titanus* shows the highest abundances at temperatures of 19 – 21ºC, in Jelenec and Ladice this pest started to get active around 14 – 15ºC. In Topoľčianky vineyard there is a sharp increase of this species at a temperature of 21ºC, but the presumed reason is the generally low abundance of the species compared to two other localities. A positive correlation of abundance in *L. botrana* with increase of forest distance was found in the Ladice vineyard, whilst on other two localities, this relationship was not relevant. Similarly, in *S. titanus* only a slight abundance increase with the increase of distance from the forest was observed. The increase of *L. botrana* abundance especially in Ladice vineyard may be due to the declining number of potential forest predators with the increase of distance from the forest. In the Jelenec and Ladice vineyard, the peak in *L. botrana* abundance was reached at a wind speed of 1.2 to 1.4 m/s. In *S. titanus* the highest abundances were observed during the season where the wind speed was lower than 0.8 m/s.

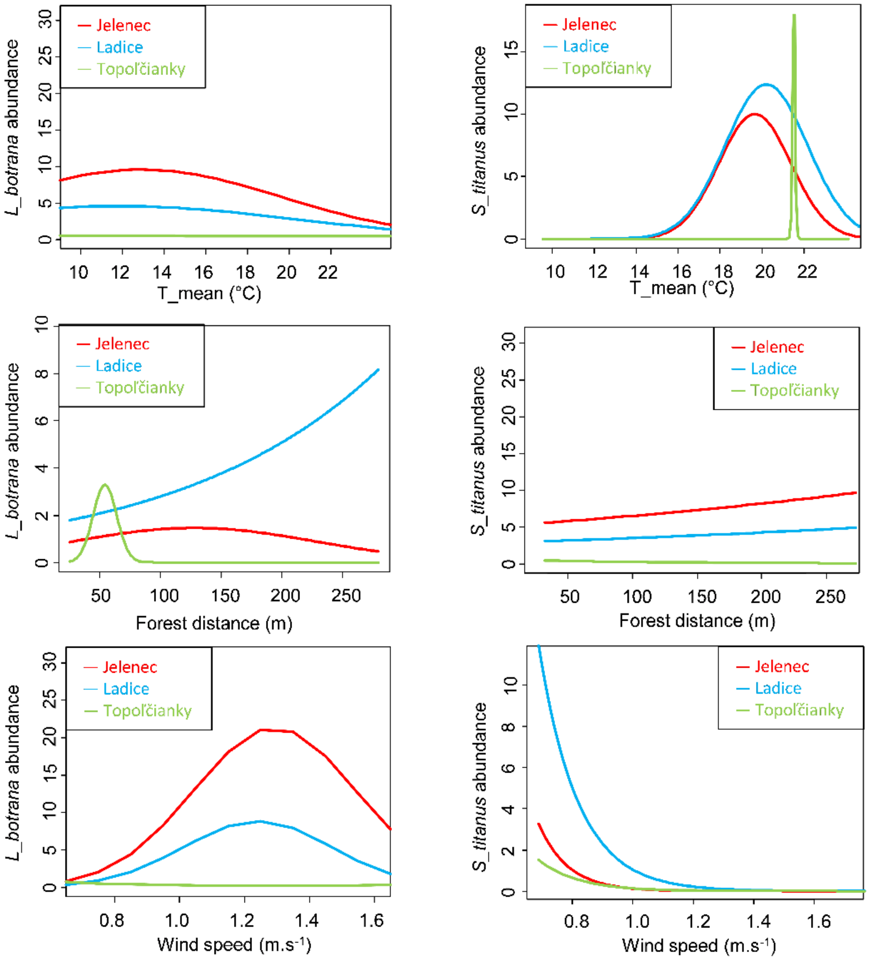


Fig. 5. *Response curves showing the relationship between in abundances of L. botrana and S. titanus and significant (threshold level α = 0.05) environmental gradients identified in the Redundancy analysis; Explanation: Response curves were constructed using a Poisson distribution with ln (μ) link function*

Empirical analysis of the spatial distribution of L. botrana and S. titanus

During the research, significant differences in the number of detected insect pests were found between individual vineyards (Tab. 2). Although in 2019 the data collection cycles were of different lengths, the vineyard with the longest cycle showed the lowest incidence and, conversely, the vineyard with the shortest cycle had the highest incidence of pests. The assumption that the Topoľčianky will be the least affected by insect pests was also confirmed in the homogenized season of 2021. Both, *L. botrana* and *S. titanus* appeared to be significantly different over the localities and years. However, only two years of monitoring do not allow any precise appreciation of variability effects.

Tab. 2. *Abundance of L. botrana and S. titanus in studied vineyards*

	2019			2021		
	Jelenec (91)	Ladice (70)	Topoľčianky (104)	Jelenec (143)	Ladice (143)	Topoľčianky (143)
L. botrana	27	21	28	433	219	48
S. titanus	40	230	18	59	173	129

Number in parentheses – number of monitored days

Within the environmental parameters (Tab. 3), individual sites do not show significant temperature differences. These can be seen in the precipitation and the average distance of monitoring sites from the forest.

Tab. 3. *Environmental parameters during the research*

	2019			2021		
	Jelenec (91)	Ladice (70)	Topoľčianky (104)	Jelenec (143)	Ladice (143)	Topoľčianky (143)
Forest_dist	83.20	59.60	71.29	83.20	59.60	71.29
T_mean	21.52	21.42	21.79	16.57	18.14	16.46
T_min	7.29	7.47	7.51	-4.62	-5.01	-5.88
T_max	36.12	36.41	37.66	37.57	36.56	37.21
Prec_sum	221.60	154.60	201.80	no data	282.00	433.60
Wind_speed	0.88	0.70	0.79	1.18	1.13	1.26

Number in parentheses – number of monitored days; Abb. Forest_dist – average air distance from the forest (m), T_mean – mean air temperature (°C), T_min – minimal air temperature (°C), T_max – maximal temperature (°C), Prec_sum – sum of precipitation (mm)

Evaluation of the pests occurrence in individual vineyards

Significant differences in the number of captured insect pests were not only detected between individual localities, but also within individual vineyards.

In Jelenec vineyard (Table 4), five research sites were set in 2019 and six in 2021 (an automatic weather station site has been added). *S. titanus* appeared to be evenly represented within the vineyard, in the central open part of the vineyard (4 and AS), the openness of the site is a prerequisite for stronger winds. *L. botrana* occurred in the largest number in locality 5, which is located near other non-forest cultures. As Ioriatti et al. (2011) declares *L. botrana* larvae feed on grapevines and up to 40 other mostly thermophilic plant species. There is no evidence of species composition of these neighbouring plots, it is possible that these plants are located there.

Five research sites were located in Ladice in 2019 and six in 2021 (an automatic weather station site has been added). The vineyard in Ladice also showed differences in the detected numbers of insect pests. *S. titanus* had the highest abundance in sites 1 and 3. Site 1 is located closest to the forest area. The highest number of captured *L. botrana* individuals was captured at site 4. The site is the warmest according to the measured temperatures, with temperature differences being insignificant.

Tab. 4. *Abundance of species within research sites in the Jelenec vineyard with environmental parameters*

Site/year	*S. titanus*	*L. botrana*	Forest_dist (m)	T_mean (ºC)	T_min (ºC)	T_max (ºC)
1	**25**	**63**	**27**	**18.44**	**-4.62**	**36.62**
2019	3	0		21.13	-7.29	35.96
2021	22	63		16.42	-4.62	36.62
2	**16**	**44**	**115**	**18.84**	**-3.19**	**36.86**
2019	12	0		21.67	-9.06	35.86
2021	4	44		16.01	-3.19	36.86
3	**32**	**43**	**74**	**18.73**	**-2.38**	**36.34**
2019	22	3		21.52	-8.69	35.51
2021	10	40		16.64	-2.38	36.34
4	**1**	**59**	**40**	**18.92**	**-2.98**	**36.57**
2019	1	3		21.73	-8.50	35.92
2021	0	56		16.82	-2.98	36.57
5	**25**	**172**	**160**	**18.76**	**-4.00**	**37.57**
2019	2	21		21.58	8.44	36.12
2021	23	151		16.64	-4.00	37.57
AS	**0**	**79**	**281**	**16.76**	**-3.40**	**36.05**
2021	0	79		16,76	-3,40	36,05

Abb. Forest_dist – air distance from the forest, T_mean – mean air temperature, T_min – minimal air temperature, T_max – maximal temperature

Tab. 5 *Abundance of species within research sites in the Ladice vineyard with environmental parameters*

Site/year	*S. titanus*	*L. botrana*	Forest_dist (m)	T_mean (ºC)	T_min (ºC)	T_max (ºC)
1	**139**	**4**	**29**	**17.87**	**-5.01**	**35.63**
2019	87	0		21.50	-7.47	35.63
2021	52	4		16.06	-5.01	35.60
2	**22**	**30**	**36**	**18.04**	**-4.10**	**36.41**
2019	20	2		21.47	-8.37	36.41
2021	2	28		16.32	-4.10	35.80
3	**135**	**48**	**54**	**18.41**	**-2.42**	**36.08**
2019	92	2		22.13	-10.41	36.01
2021	43	46		16.54	-2.42	36.08
4	**18**	**100**	**75**	**18.43**	**-0.98**	**36.56**
2019	14	16		21.72	-9.43	35.06
2021	4	84		16.79	-0.98	36.56
5	**26**	**18**	**104**	**18.34**	**-3.25**	**35.85**
2019	17	1		21.77	-8.83	35.16
2021	9	17		16.63	-3.25	35.85
AS	**63**	**40**	**172**	**16.65**	**-3.35**	**35.31**
2021	63	40		16.65	-3.35	35.31

Abb. Forest_dist – air distance from the forest, T_mean – mean air temperature, T_min – minimal air temperature, T_max – maximal temperature

In Topoľčianky, the pheromone traps were installed on seven sites. However, the pheromone traps from two sites (5 and 6) did not contain any individuals of *L. botrana*. Both sites are situated in the eastern part of the vineyard and form a continuous segment. They are isolated from the rest of the vineyard by a patch of grassy vegetation. It may represent a natural barrier to the spreading of the insects, and therefore it can possibly explain why *L. botrana* did not spread to these sites. Similarly, site 4 is separated from other segments of the vineyard by a row of trees and there only two individuals of *L. botrana* were found. Most individuals were caught in the southern part of the vineyard, in sites 1 and 2. There is no significant *L. botrana* abundance change between 2019 and 2021. *S. titanus* had a relatively low number of individuals compared to other vineyards. The exception was site 4, which is located in the northern part of the vineyard. Based on the available data, we cannot identify the cause of this abnormality.

Tab. 6. *Abundance of species within research sites in the Topoľčianky vineyard with environmental parameters*

Site/year	*S. titanus*	*L. botrana*	Forest_dist (m)	T_mean (ºC)	T_min (ºC)	T_max (ºC)
1	**3**	**21**	**77**	**18.92**	**-3.61**	**37.19**
2019	1	11		21.83	8.21	37.19
2021	2	10		16.74	-3.61	36.23
2	**25**	**39**	**39**	**18.99**	**-1.09**	**36.75**
2019	6	9		22.14	8.62	36.75
2021	19	30		15.85	-1.09	35.68
3	**0**	**7**	**83**	**18.72**	**-1.21**	**36.17**
2019	0	5		21.69	8.32	35.96
2021	0	2		15.75	-1.21	36.17
4	**108**	**2**	**68**	**18.86**	**-3.75**	**37.21**
2019	8	1		21.97	8.57	36.69
2021	100	1		16.54	-3.75	37.21
5	**3**	**0**	**88**	**18.89**	**-5.75**	**37.66**
2019	0	0		21.78	7.70	37.66
2021	3	0		16.73	-5.75	36.31
6	**5**	**0**	**78**	**18.80**	**-5.88**	**36.62**
2019	2	0		21.61	7.51	36.62
2021	3	0		16.69	-5.88	36.27
AS	**3**	**7**	**66**	**18.74**	**-3.61**	**34.69**
2019	1	2		21.53	8.19	34.69
2021	2	5		16.64	-3.61	34.55

Abb. Forest_dist – air distance from the forest, T_mean – mean air temperature, T_min – minimal air temperature, T_max – maximal temperature

Presented results shows that each plot of the vineyard is unique, and the distribution of insects' may change depending on the stage of development, the season, the phenological state of the crop, and the climatic conditions. The causes of non-uniformity in insect populations are often difficult to understand, being determined by several factors (Sciarretta and Trematerra 2014). Also, Sciaretta et al. (2008) found, in accordance with our results, a different spatial distribution of the invasive species.

L. botrana is a long-known pest in vineyards. In Slovakia, it occurs in two, rarely in three generations. The second generation, which contributes to the development of fungal diseases, is mainly considered dangerous. Treatment with sprays is always according to the occurrence signalling. The spatial analysis of the occurrence of *L. botrana* in Europe is addressed by several authors (Sciaretta et al. 2008, Ifoulis and Savopoulou-Soultani 2006, Comșa et al. 2022). Related to our research, Amo-Salas et al. (2018) also highlight the need for daily temperature monitoring and the use of pheromone traps for *L. botrana* occurrence prediction models in Spain.

According to Chuche and Thiéry (2014), the occurrence of *S. titanus* in Slovakia has not yet been reported, the closest occurrence was recorded in Austria and Hungary. The cicada appeared in Slovakia only after 2013 (Tothova 2015, Tancik and Seljak 2017). Currently, as a carrier of the quarantine disease Flavescence doréé, it is recorded in larger numbers. Factors influencing the variability of population size need to be modelled (Bertin et al. 2007, Chuche and Thiéry 2014). Even though Flavescence dorée has not yet been confirmed in Slovakia, the studies performed in other European countries indicate that the introduction of the vector often also means the introduction of the disease in the course of several years (e.g., Steffek et al. 2007). Rigamonti et al. (2018) focused on *S. titanus* investigated the effect of temperature changes for its occurrence in Switzerland. In accordance with our knowledge from Slovakia, they noted the spread of this pest in connection with global warming, as well as the need to use mesoclimatic data to monitor their occurrence and for the subsequent adoption of adequate measures.

Conclusions

The main goal of the study was to monitor the incidence of insect pests using the pheromone traps targeted on the *L. botrana* in selected vineyards of the Nitra region and to identify their relation to environmental conditions. In addition to *L. botrana*, a significant occurrence of *S. titanus* was detected. It was showed that the insect pests are unequally distributed in the studied region and also inside the vineyards. Using RDA, we were able to explain the bonds in a maximum of 40% insect pests-environmental factors relationships.

From the point of view of protection against it, it is important to know its developmental stages, the date of its hatching as well as the optimal temperatures from the point of view of receiving protective sprays. Sprays are applied once a year either against larvae around the end of June or against adults at the end of July and beginning of August. However, the listed dates are indicative, as they depend on the annual development of microclimate conditions and spatial monitoring of the population with regard to ongoing climate changes.

Spatial distribution of the species *L. botrana* and *S. titanus* with regard to microclimatic conditions and its influence of georelief, as well as other ecological factors, have not yet been investigated in detail in Slovakia. We understand the mentioned physical-geographical approach as part of the methods of precise viticulture in the conditions of Slovakia. Our research results show the need for regular monitoring of these species, taking into account microclimatic as well as other ecological factors, with the aim of optimizing the spatial protection, especially of large area vineyards, with different internal geographical conditions and subsequent individual approach to protection. This research is not only a basis for science, but monitoring is especially important for winegrowers. Future research might be based on increasing the density, duration and precision of sampling to increase the robustness of the results.

References

AMO-SALAS, M., ORTEGA-LÓPEZ, V., HARMAN, R. et al. 2011: A new model for predicting the flight activity of Lobesia botrana (Lepidoptera: Tortricidae). *Crop Protection*, 30(12), 1586-1593. DOI: https://doi.org/10.1016/j.cropro.2011.09.003.

ARN, H., RAUSCHER, S., GUERIN, P. et al. 1988: Sex pheromone blends of three tortricid pests in European vineyards. *Agriculture, Ecosystems and Environment*, 21(1-2), 111-117. DOI: https://doi.org/10.1016/0167-8809(88)90143-0.

BÁTOR, I., BOZSIK, A. 2017: Damage of *Harmonia axyridis* in vineyards at the Tokaj vine region (Hungary). In. Horváth, J., Haltrich, A., Molnár, J. eds. *63th Crop Protection Scientific Days.* Budapest (Hungarian Plant Protection Society), p. 31.

BELLI, G., BIANCO, P. A., CONTI, M. 2010: Grapevine yellows in Italy: past, present and future. *Journal of Plant Pathology*, 92(2), 303-326. https://www.jstor.org/stable/41998804.

BERTIN, S., GUGLIELMINO, C., KARAM, N. et al. 2007: Diffusion of the Nearctic leafhopper Scaphoideus titanus Ball in Europe: A consequence of human trading activity. *Genetica*. 131, 275-285. DOI: https://doi.org/10.1007/s10709-006-9137-y.

BIASI, R., BRUNORI, E., FERRARA, C. et al. 2019: Assessing Impacts of Climate Change on Phenology and Quality Traits of *Vitis vinifera* L.: The Contribution of Local Knowledge. *Plants (Basel)*, 8(5), 121. DOI: https://doi.org/10.3390/plants8050121.

BRITTON, K. O., WHITE, P., KRAMER, A. et al. 2010: A new approach to stopping the spread of invasive insects and pathogens: Early detection and rapid response via a global network of sentinel plantings. *New Zealand Journal of Forestry Science*, 40, 109-114.

CAUDWELL, A., BRUN, P., FLEURY, A. et al. 1972: Les traitements ovicides contre la cicadelle vectrice, leur intérêt dans la lutte contre la Flavescence dorée en Corse et dans les autres regions. *Vignes et Vins*, 214, 5-10.

CHIRECEANU, C., MIOARA, B., TEODORU, A. 2020: Invasive Insect Species Detected on Grapevines in Romania during 2016 – 2019 and First Record of Erasmoneura vulnerata (Fitch , 1851) (Hemiptera : Cicadellidae). *Acta Zoologica Bulgarica*, 72, 649-659.

CHUCHE, J., THIÉRY, D. 2014: Biology and ecology of the Flavescence dorée vector Scaphoideus titanus: A review. Agronomy for Sustainable Development. *Agronomy for Sustainable Development*, 34, 381-403. DOI: https://doi.org/10.1007/s13593-014-0208-7.

COMȘA, M., TOMOIAGĂ, L.L., MUNTEAN, M.D. et al. 2022: The Effects of Climate Change on the Activity of the Lobesia botrana and Eupoecilia ambiguella Moths on the Grapevine Cultivars from the Târnave Vineyard. *Sustainability*, 14, 14554. DOI: https://doi.org/10.3390/su142114554.

DELBAC, L., THIÉRY, D. 2016: Damage to grape flowers and berries by Lobesia botrana larvae (Denis & Schiffernüller) (Lepidoptera: Tortricidae), and relation to larval age. *Australian Journal of Grape and Wine Research*, 22(2), 256-261. DOI: https://doi.org/10.1111/ajgw.12204.

DOMIN, J., FURDÍKOVÁ, K., BÁLEŠ V. et al. 2017: *Hrozno a víno ekologicky*. Bratislava (VÍNO NATURAL). 352 p.

FILIPPIN, L., JOVIĆ, J., CVRKOVIĆ, T. et al. 2009: Molecular characteristics of phytoplasmas associated with Flavescence dorée in clematis and grapevine and preliminary results on the role of Dictyophara europaea as a vector. *Plant Pathology*, 58, 826-837. DOI: https://doi.org/10.1111/j.1365-3059.2009.02092.x.

FOX, J., WEISBERG, S. 2018: Visualizing Fit and Lack of Fit in Complex Regression Models with Predictor Effect Plots and Partial Residuals. *Journal of Statistical Software*, 87, 1–27. DOI: https://doi.org/10.18637/jss.v087.i09.

FOX, J., WEISBERG, S. 2019: An R Companion to Applied Regression, Sage Publications, Thousand Oaks, 608 p.

GILLIGAN, T. M., EPSTEIN, M. E., PASSOA, S. C. 2014: Screening aid: European grape berry moth, *Eupoecilia ambiguella* (Hübner). *Identification Technology Program (ITP), USDA-APHIS-PPQ-S&T*, Fort Collins, CO. 5 pp.

GILLIGAN, T. M., EPSTEIN, M. E., PASSOA, S. C. et al. 2011: Discovery of *Lobesia botrana* ([Denis & Schiffermüller]) in California: An Invasive Species New to North America (Lepidoptera: Tortricidae*). Proceedings of the Entomological Society of Washington*, 113(1), 14-30. DOI: https://doi.org/10.4289/0013-8797.113.1.14.

GRANETT, J., WALKER, M. A., KOCSIS, L. et al. 2001: Biology and Management of Grape Phylloxera. *Annual Review of Entomology*, 45, 387-412. DOI: https://doi.org/10.1146/annurev.ento.46.1.387.

HABA, J. P. 2005: La filoxera en España y su difusión espacial: 1878-1926 [Phylloxera in Spain and its spatial distribution: 1878-1926]. *Cuadernos de Geografía*, 77, 101-136.

HALEKOH, U., HØJSGAARD, S., YAN, J. 2006. "The R Package geepack for Generalized Estimating Equations." *Journal of Statistical Software*, 15(2), 1-11.

IFOULIS, A.A., SAVOPOULOU-SOULTANI, M. 2006: Use of geostatistical analysis of characterize the spatial distribution of Lobesia botrana (Lepidoptera: Tortricidae) larvae in northern Greece. *Environmental Entomology*, 35, 497-506.

IORIATTI, C., BAGNOLI, B., LUCCHI, A. et al. 2012: Vine moths control by mating disruption in Italy: results and future prospects. *Redia*, 87, 117-128.

JÓSVAI, J., VOIGT, E., TÓTH, M. 2011: Preliminary report on dominances of fruit and grape-damaging yellowjackets in Hungary (Hymenoptera: Vespidae). *Növényvédelem*, 47(7), 303-307.

KOCMÁNKOVÁ, E., TRNKA, M., JUROCH, J. et al. 2010: Impact of climate change on the occurrence and activity of harmful organisms. *Plant Protection Science*, 45, 48-52. DOI: https://doi.org/10.17221/2835-PPS.

LEACH, A., LEACH, H. 2020: Characterizing the spatial distributions of spotted lanternfly (Hemiptera: Fulgoridae) in Pennsylvania vineyards. *Scientific Reports*, 1-9. DOI: https://doi.org/10.1038/s41598-020-77461-9.

LEFOL, C., LHERMINIER, J., BOUDON-PADIEU, E. et al. 1994: Propagation of the Flavescence dorée Mycoplasma-like organism in the leafhopper vector *Euscelidius variegatus* Kbm. *Journal of Invertebrate Pathology*, 63, 285-293. DOI: https://doi.org/10.1006 /jipa.1994.1053.

LUND, K. T., RIAZ, S., WALKER, M. A. 2017: Population Structure, Diversity and Reproductive Mode of the Grape Phylloxera (*Daktulosphaira vitifoliae*) across Its Native Range. *PloS One*, 12(1), 1-21. DOI: https://doi.org/10.1371/journal.pone.0170678.

MACEDO, M. 2011: Port Wine Landscape: Railroads, Phylloxera, and Agricultural Science. *Agricultural History*, 85(2), 157-173. DOI: https://doi.org/10.3098/ah.2011.85.2.157.

MORONE, C., BOVERI, M., GIOSUÈ, S. et al. 2007: Epidemiology of Flavescence Dorée in Vineyards in Northwestern Italy. *Phytopathology*, 97(11), 1422-1427. DOI: https://doi.org/ 10.1094/PHYTO-97-11-1422.

MOSNÁ, R. 2019: *Vplyv mikroklímy ako súčasť hodnotenia terroir vinohradov. [rigorózna práca].* Bratislava (Prírodovececká fakulta UK). 98 p.

OKSANEN, J., BLANCHET, F.G., FRIENDLY, M. et al. 2020: vegan: Community Ecology Package. R package version 2.5-6. Retrieved from: https://cran.r-project.org and https://github.com/vegandevs/vegan.

ORŠULOVÁ V., MATEČNÝ I., JENČO M. et al. 2019. Vplyv georeliéfu na mikroklímu vinohradov. Prípadová štúdia: Topoľčianky (Slovensko). *Meteorologický časopis*, 22(1). 21-29.

PÉREZ-APARICIO, A., TORRES-VILA, L. M., GEMENO, C. 2019: EAG responses of adult *Lobesia botrana* males and females collected from Vitis vinifera and Daphne gnidium to larval host-plant volatiles and sex pheromone. *Insects*, 10(9). DOI: https://doi.org/ 10.3390/INSECTS10090281.

PICKERING, G., LIN, J., RIESEN, R., REYNOLDS, A. et al. 2004: Influence of Harmonia axyridis on the Sensory Properties of White and Red Wine. *American journal of enology and viticulture*, 55(2), 153-159.

PINHEIRO, J., BATES, D., DEBROY, S. et al. 2012: nlme: Linear and Nonlinear Mixed Effects Models. R Package Version 3.1-105. Retrieved from: https://CRAN.R-project.org/package=nlme.

PRAKASH, A., RAO, J., MUKHERJEE, A. K. et al. 2014: *Climate Change: Impact on Crop Pests*. Odisha, India (AZRA: Applied Zoologists Research Association, Central Rice Research Institute).

REINEKE, A., THIÉRY, D. 2016: Grapevine insect pests and their natural enemies in the age of global warming. *Journal of Pest Science*, 89, 313-328. DOI: https://doi.org/ 10.1007/s10340-016-0761-8.

RIGAMONTI, I. E., MARIANI, L., COLA, G. et al. 2018: Abrupt and gradual temperature changes influence on the climatic suitability of Northwestern Alpine grapevine-growing regions for the invasive grape leafhopper Scaphoideus titanus Ball (Hemiptera, Cicadellidae). *Acta Oecologica*, 91, 22-29. DOI: https://doi.org/10.1016/j.actao.2018.05.007.

ROEHRICH, R., CARLES, J. P., DREUILHE, A. Et al. 1983: Captures of *Lobesia botrana* Den. & Schiff. (Lepidoptera, Tortricidae) in sex traps in relation to the dosage of pheromone in the dispenser. *Agronomie*, 3(9), 925-929. DOI: https://doi.org/ 10.1051/agro:19830915.

SCIARETTA.A., ZINNI, A., MAZZOCHETTI, A et al. 2008: Spatial Analysis of *Lobesia botrana* (Lepidoptera: Tortricidae) Male Population in Mediterranean Agricutural Landscape in Central Italy. *Environmental Entomology*, 37(2), 382-390.

SCIARRETTA, A., TREMATERRA, P. 2014: Geostatistical Tools for the Study of Insect Spatial Distribution: Practical Implications in the Integrated Management of Orchard and Vineyard Pests. *Plant Protection Science*, 50, 97–110. DOI: https://doi.org/10.17221/40/2013-PPS.

SCHNEIDER, L., REBETEZ, M., RASMANN, S. 2022: The Effect of Climate Change on Invasive Crop Pests across Biomes. *Current Opinion in Insect Science*, 50. DOI: https://doi.org/10.1016/j.cois.2022.100895.

SCHOWALTER, T. D. 2016: *Insect Ecology – An Ecosystem Approach*. 4th Edition. Cambridge (Academic Press). 774 p.

SKENDŽIĆ, S., ZOVKO, M., ŽIVKOVIĆ, I. P. et al. 2021: The Impact of Climate Change on Agricultural Insect Pests. *Insects*, 12, 1-31. DOI: https://doi.org/10.3390/insects12050440.

STEFFEK, R., REISENZEIN, H., ZEISNER, N. 2007. Analysis of the pest risk from Grapevine flavescence dorée phytoplasma to Austrian viticulture. *EPPO Bulletin*, 37, 191-203. DOI: https://doi.org/10.1111/j.1365-2338.2007.01102.x.

SVOBODOVÁ, E., TRNKA, M., ŽALUD, Z. et al. 2013: Climate variability and potential distribution of selected pest species in south Moravia and north-east Austria in the past 200 years – Lessons for the future. *The Journal of Agricultural Science*, 152, 225-237. DOI: https://doi.org/10.1017/S0021859613000099.

TANCÍK, J., KORBELOVÁ, E., TAMAŠEK, Z. 2014: Effect of Applications of Isonet L Plus, the Controlled-Release Dispenser in the Protection of Vineyards Against Lobesia botrana and Eupoecilia ambiguella in the Southern Slovakia. *Acta Horticulturae et Regiotecturae.* 17, 8–12. DOI: https://doi.org/10.2478/ahr-2014-0003.

TANCIK, J., SELJAK, G. 2017: Occurrence of Scaphoideus titanus Ball and some other Auchenorrhyncha in the vineyards of western Slovakia. *Plant Protection Science*, 53(2), 96-100. DOI: https://doi.org/10.17221/40/2016-PPS.

THIÉRY, D., MOREAU, J. 2005: Relative performance of European grapevine moth (Lobesia botrana) on grapes and other hosts. *Oecologia*, 143, 548–557. DOI: https://doi.org/10.1007/s00442-005-0022-7.

THIÉRY, D., LOUÂPRE, P., MUNERET, L. et al. 2018: Biological protection against grape berry moths. A review. *Agronomy for Sustainable Development,* 38(2), 15. DOI: https://doi.org/10.1007/s13593-018-0493-7

TÓTHOVÁ, M., BOKOR, P., CAGÁŇ, L. 2015: The first detection of leafhopper *Scaphoideus titanus* Ball (Hemiptera, Cicadellidae) in Slovakia. *Plant Protection Science,* 51(2), 88-93. DOI: https://doi.org/10.17221/64/2014-PPS.

VAN LEEUWEN, C. 2010: Terroir: the effect of the physical environment on vine growth, grape ripening and wine sensory attributes. *Managing Wine Quality,* 273-315. DOI: https://doi.org/10.1533/9781845699284.3.273.

VENETTE, R. C., DAVIS, E. E., DACOSTA, M. et al. 2003: Mini Risk Assessment – Grape berry moth Lobesia botrana (Denis & Schiffermüller) [Lepidoptera: Tortricidae]. USDA-APHIS, Center for Plant Health Science and Technology (Internal Report). Raleigh, NC. 38 p.

WICKHAM, H. 2016: *ggplot2: Elegant Graphics for Data Analysis*. New York (Springer-Verlag). Retrieved from: https://ggplot2.tidyverse.org.

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