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CROP PROTECTION

Spacial distribution and suitability for *Panonychus ulmi* (Tetranychidae) in Brazil

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ABSTRACT. Predictive studies project the geographic distribution of species and can be used to infer climatic niches. However, only a few studies have been conducted on mites. This approach helps map areas with potential for the occurrence of endemic, threatened, or potentially invasive species. *Panonychus ulmi* (Tetranychidae) is of global economic importance, commonly associated with apple orchards and grapevines. Potential distribution modeling is used to predict areas with environmental suitability for the distribution of a species and/or group. Considering that predictive models on national or regional scales present better data reliability, the present study aimed to analyze the distribution of *P. ulmi* in Brazil through bioclimatic inferences. The presence of species, bioclimatic variables, and MaxEnt algorithm were used to define a predictive model. The median performance rate of the model was 0.992, indicating its robustness. The variable that made the greatest contribution to the model was the average temperature of the coldest quarter (Bio11). The predictive model of the ecological niche indicated that the southern region of Brazil is environmentally favorable for the adaptation of this mite. The data obtained helped us understand the geographical distribution of *P. ulmi* in Brazil, and climatically suitable areas for its occurrence were inferred. We believe that this tool can offer indirect assistance to the agricultural sector, especially the producers of apples and grapes in Brazil regarding the presence of *P. ulmi*.

Keywords: European red mite; adventive mite species; apple orchard; biogeography; spatial distribution.

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Introduction

Globally, Brazil is among the ten largest apple producers, and its southern region stands out for the cultivation and production of this fruit. It is an important source of income for local producers and the regional economy, particularly in the states of Santa Catarina and Rio Grande do Sul (Kist, 2015; Kist et al., 2019). In addition to apple production, the region stands out in viticulture, with the production of grapes, wine, and its derivatives (Mattuela & Mello, 1999). Viticulture is an essential source of income for wine producers and cooperatives in several states of Brazil (Mello, 2008; Instituto Brasileiro do Vinho [IBRAVIN], 2019; Mello, 2019).

Among tetranychids, *Panonychus ulmi* (Koch), known as the European red mite, is economically important in apple orchards and wineyards in Asia, America, Europe, and Oceania (Migeon & Dorkeld, 2020). The first record of *P. ulmi* in Brazil was on apple trees of Argentinian origin (Flechtmann, 1967). In 1972, Bleicher (1974) reported an infestation of this species in an apple orchard in Fraiburgo (state of Santa Catarina, Brazil). However, the first record of grapevine infestation in Brazil was in the 2005–2006 growing season, causing damage to the *Vitis vinifera* L. [Vitaceae] cultivar Merlot in Bento Gonçalves (state of Rio Grande do Sul, Brazil) (Ferla & Botton, 2008), and the second record was in 2006 in Pirapora (state of Minas Gerais, Brazil) by Mendonça (2009). The late occurrence in grapevines may have occurred due to the geographical proximity of apple and grapevine-growing areas in Rio Grande do Sul State, where apple trees present better reproductive performance. According to Flechtmann (1967), this may have occurred because of the transit of contaminated plant material.

In Brazil, abamectin is often used to control spider mites (Andrei, 2005). Biological control can also be applied using predatory mites (Phytoseiidae) (Lindquist, 1996; McMurtry, Moraes, & Sourassou, 2013), especially *Neoseiulus californicus* (McGregor) (Phytoseiidae), a species present on the vines in Rio Grande do Sul that is mainly associated with populations of *P. ulmi* (*eg*., Johann & Ferla, 2012). With favorable environmental conditions and the absence of natural enemies, *P. ulmi* can cause significant damage to crops (Monteiro, 2002). This phytophagous mite causes damage by feeding on the cytoplasmic content of plant cells, leading to the loss of chlorophyll in the affected areas, tanning, and reddish spots on the adaxial surface of the leaves. Severe attacks can result in defoliation, and in extreme cases, a reduction in fruit size and even death (Kovaleski & Vendramin, 1993; Ferla & Botton, 2008; Moraes & Flechtmann, 2008).

Studies predicting the potential geographic distribution of environmental niches of mites are scarce. This methodology could be used to map environmentally suitable areas for the occurrence of these species. Direct or indirect climatic factors can contribute to the distribution patterns of economically important species, thereby generating information for control decisions (Lu, Ma, Chen, Lu, & Xu, 2012; Amaro & Moraes, 2013; Meynard, Migeon, & Navajas, 2013; Parsa et al., 2015; Navia, Hamada, Gondim, & Benito, 2016; Litskas, Migeon, Navajas, Tixier, & Stavrinides, 2019; Corrêa, Silva, Nascimento, Oliveira, & Ferla, 2021). Considering that the distribution of most organisms is associated with environmental conditions at a given location or region (Soberón, 2010; Townsend, Begon, & Harper, 2010), this approach can be used to assess the potential distribution of species at the pest level (Parsa et al., 2015; Corrêa et al., 2021).

Considering that predictive models at national or regional scales present better data reliability, the present study aimed to analyze the potential distribution of *P. ulmi* in Brazil through bioclimatic inferences, aiming at delimiting areas with viable environmental suitability for the establishment of this species.

Material and methods

Occurrence data

Data on the occurrence of *P. ulmi* in Brazil was obtained from previous studies by Monteiro, Souza, and Pastori (2006), Ferla and Botton (2008), Mendonça (2009), Ferla, Johann, Klock, Majolo, and Botton (2011), Johann & Ferla (2012), and Johann, Horn, Carvalho, and Ferla (2014); the online database SpeciesLink (http://www.splink.org.br/); the online database Spider Mites Web (https://www1.montpellier.inra.fr/CBGP/spmweb/) (Migeon & Dorkeld, 2020), and information available from the Laboratory of Acarology, University of Vale do Taquari (Univates), Brazil. The data from the Laboratory of Acarology were obtained from research conducted over more than 15 years in southern Brazil. Only one record of *P. ulmi* per city was considered to eliminate data overlap bias. The records were georeferenced in geographic coordinates according to the collection location and/or center of the municipality in a satellite image of high spatial resolution in Google Earth in the format of decimal degrees, Datum WGS-84, for further analysis.

Data analysis

We obtained the bioclimatic variables (from Bio1 to Bio19) from the WorldClim database (https://www.worldclim.org/), which includes bioclimatic information from 1960 to 2018. The variables available were the average minimum temperature (°C), average maximum temperature (°C), and total precipitation (mm) (Fick & Hijmans, 2017). The layers were cut according to the geographic space of Brazil using a conversion tool in Quantum GIS for subsequent analysis. Although the potential for the translocation of invasive species is known, distinctions can be made regarding the inferences of geographical barriers with the risk of colonization of new environments. In a more restricted analysis, the risks of errors and misinterpretation of the results are lower in the elaboration of models of geographic distribution (Barve et al., 2011).

To perform environmental suitability analysis for *P. ulmi*, we used the MaxEnt algorithm (*maximum entropy*). To perform this analysis, we selected all the bioclimatic variables (Bio1–Bio19) (Phillips, Anderson, & Schapire, 2006; Phillips & Dudik, 2008). We used 80% of the points as training data and 20% as test data (Anderson, Lew, & Peterson, 2003). They were selected from ten replicates using a bootstrapping method with standard software functions (Phillips et al., 2006; Phillips & Dudik, 2008). In this study, the variables that contributed to the development of the predictive model for *P. ulmi* in the Brazilian territory were Annual Mean Temperature (Bio1), isothermality (Bio3), Temperature Seasonality (Bio4), minimum temperature of the coldest month (Bio6), Mean Temperature of Driest Quarter (Bio9), Mean Temperature of Coldest Quarter

(Bio11), Precipitation of Driest Month (Bio14), and Precipitation Seasonality (Bio15). Using these bioclimatic variables, we performed a new round of analysis following the same procedure mentioned above.

Through a model executed using the MaxEnt algorithm (using points of presence and bioclimatic variables), a file (*asc*) was made available and converted into a predictive map. Final editing was performed using Quantum GIS. The model presents the average rating of the area under the curve (AUC), which provides the performance, where values close to one indicate high performance (Elith et al., 2006; Soberón, 2007). The geographical distribution of *P. ulmi* in Brazilian states involved in the cultivation and production of apples and grapes is shown in Figure 1 (Mattuela & Mello, 1999; Mello, 2008; Kist, 2015; IBRAVIN, 2019; Kist et al., 2019; Mello, 2019).

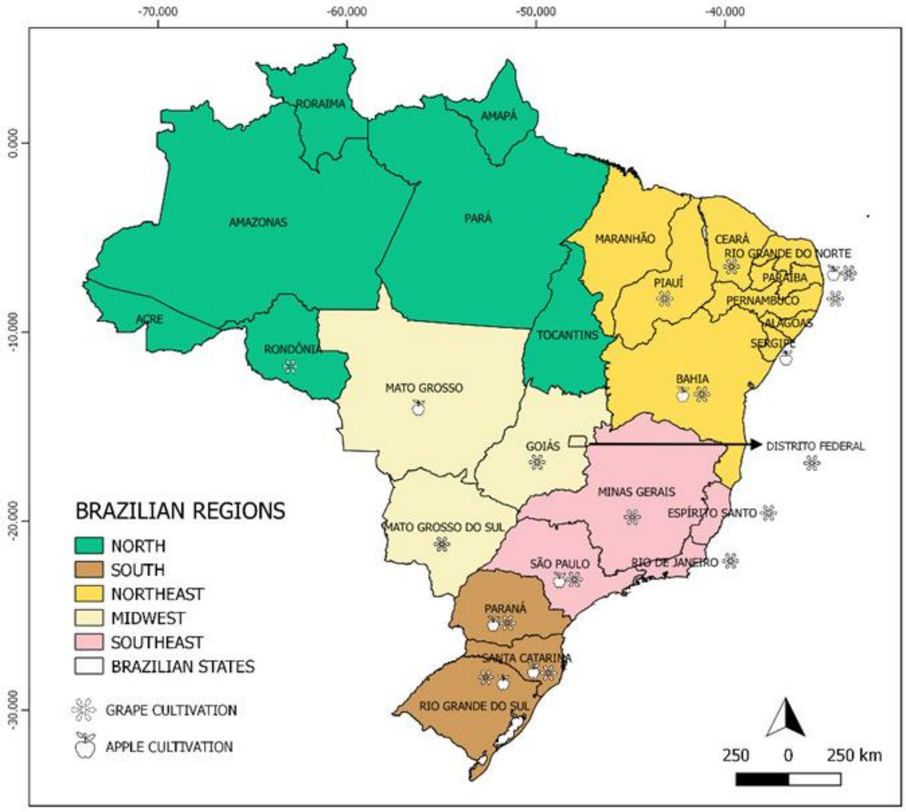

Figure 1. Map indicating the Brazilian regions and states that present commercial cultivation of apples and grapevines.

Results and discussion

According to the data obtained, *P. ulmi* occurs in 29 municipalities in Brazil and is distributed among the states of Minas Gerais, Paraná, Rio Grande do Sul, Santa Catarina, and São Paulo. The use of the predictive modeling tool through bioclimatic inferences indicated a potential scenario in which the southern region of the Brazilian territory presents greater environmental suitability for this species. However, the model also indicated that the southeastern and central-western regions had potential environmental characteristics suitable for the presence of *P. ulmi* (Figure 2). Of the bioclimatic variables evaluated, the mean temperature of the coldest quarter (Bio11) was the bioclimatic variable with the highest percentage contribution, indicating greater suitability for its distribution (Table 1). The average predictive performance rate was 0.992. As shown in Figure 1, the southern, southeastern, and northeastern regions present high concentrations of areas under cultures of apples and grapevines in Brazil.

The analysis of bioclimatic inferences indicated climatically suitable areas for the distribution of *P. ulmi* in the Brazilian territory, where the southern region showed high environmental suitability. Regions with the occurrence of *P. ulmi* in Brazil are within a temperate to subtropical climate, where annual mean temperatures can vary between 12 and 24°C and annual mean precipitation between 1000 and 2500 mm (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). However, in these regions of Brazil, succinct variations in temperature and precipitation between the four seasons can occur during some periods due to climate change (Mota & Agendes, 1986; Nery, 2005; Conti, 2011; Alvares et al., 2013). In the southern region for example, between the states of Paraná, Santa Catarina and Rio Grande do Sul (Mota & Agendes, 1986; Nery, 2005), where of *P. ulmi* occurrence is mostly reported (Ferla & Botton, 2008; Ferla et al., 2011; Johann & Ferla, 2012; Johann et al., 2014). Winter is the coldest season, and the most representative month is July when the mean daily minimum varied between 6 and 12°C (Nery, 2005).

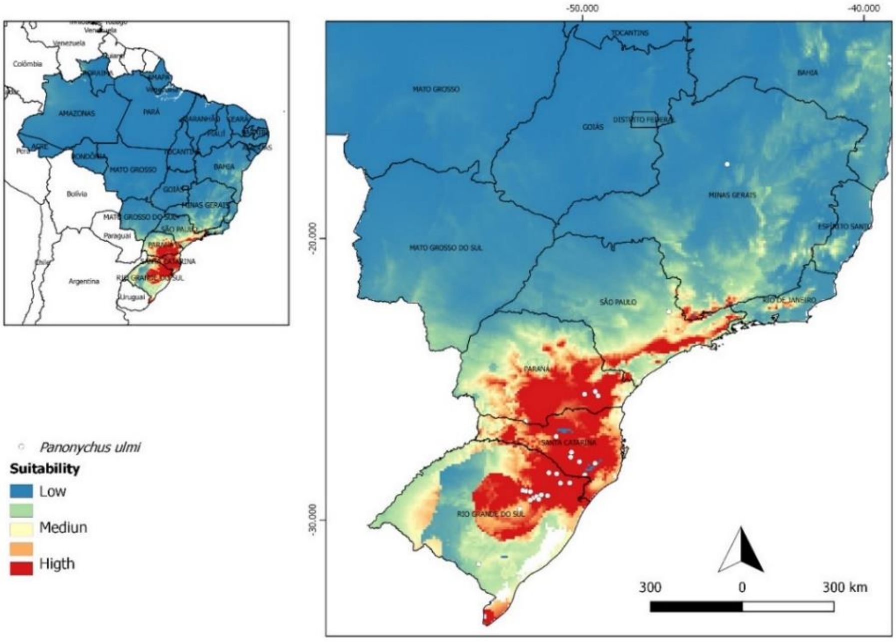

Figure 2. Distribution of environmental suitability for *Panonychus ulmi* in Brazil indicating points of presence of the species at the borders or in adjacent areas. Warm colors indicate a high probability of environmental suitability for *P. ulmi*.

Table 1. Predictive variables used in the environmental suitability model for *Panonychus ulmi* in Brazilian territory and their contributions (%).

Data	Type	%
Bio11_br	Mean Temperature of Coldest Quarter	62,5
Bio9_br	Mean Temperature of Driest Quarter	13,7
Bio14_br	Precipitation of Driest Month	8,1
Bio15_br	Precipitation Seasonality	7,1
Bio6_br	Min Temperature of Coldest Month	3,1
Bio4_br	Temperature Seasonality	2,6
Bio1_br	Annual Mean Temperature	2,5
Bio3_br	Isothermality	0,5

This region may reach temperatures close to 0°C during this period, and negative temperature records may occur, which differs from other regions of the Brazilian territory (Mota & Agendes, 1986; Conti, 2011; Alvares et al., 2013). This temperature pattern corroborated the bioclimatic variable (mean temperature of the coldest quarter), which had the greatest contribution in this study to the model of environmental adequacy for *P. ulmi*. Therefore, we can consider this region favorable for the species, even as a producer of perennial fruits such as apples and grapes. *P. ulmi* can survive in these places because of its diapause (winter eggs deposited on the branches of the plant and summer eggs on the leaves without interruption) (Cuthbertson & Murchie, 2010).

Geographic distribution models have been used to determine patterns of areas with aptitude for the occurrence of several species (Anderson et al., 2003; Soberón & Peterson, 2005; Soberón, 2007; Migeon et al., 2009; Soberón, 2010; Meynard et al., 2013, Parsa et al., 2015; Litskas et al., 2019), and to determine whether a location or region is satisfactory for the species under different environmental conditions. Such models do not necessarily state whether a region is currently occupied by the species but are more appropriate for determining the bioclimatic conditions suitable for its occupation (Phillips et al., 2006; Phillips, 2008; Phillips & Dudik, 2008; Soberón, 2010).

However, for mites of economic importance, climatically suitable areas may promote infestation (Lu et al., 2012; Amaro & Moraes, 2013; Parsa et al., 2015; Navia et al., 2016; Corrêa et al., 2021). Considering that the distribution of these organisms is associated with abiotic factors (Rabbinge, 1976), climate change may interfere with their distribution patterns, which may be beneficial or limited (Migeon et al., 2009; Meynard et al., 2013; Navia et al., 2016; Litskas et al., 2019; Corrêa et al., 2021). However, even with these environmental factors, climatic limitations on distribution may coincide with host plant occurrence (Ragusa & Tsolakis 2000). The presence of mites and their patterns of occurrence are correlated with environmental factors (Rabbinge, 1976; Johann & Ferla, 2012; Amaro & Moraes, 2013; Corrêa et al., 2021), indicating that *P. ulmi* is established in the southern region of Brazil (Ferla & Moraes, 2002; Ferla & Botton, 2008). However, we cannot ignore other conditions that may be associated with this adaptation, such as the constant use of phytosanitary products which might eliminate natural control agents and, consequently, allow a population increase in phytophagous mites (Ferla & Moraes, 2002; Duso, Pozzebon, Kreiter, Tixier, & Candolfi, 2012; Gräff, Johann, Souza, & Ferla, 2017).

Some Brazilian states, such as Mato Grosso do Sul, Sergipe, and Paraíba, which also have areas of apple production (Kist, 2015; Kist et al., 2019), and the states of Ceará, Goiás, Piauí, Rondônia, and Mato Grosso do Sul (Mattuela & Mello, 1999; Mello, 2008; IBRAVIN, 2019; Mello, 2019), which presently have grapevine production, do not present reports in the literature indicating the presence of *P. ulmi*. The geographic model built in this study indicated a low or nonexistent probability of this phytophagous mite in these regions. Considering that the distribution of some mite species may be associated with the host plant (Ragusa & Tsolakis, 2000), *P. ulmi* may have reached these regions through vegetative material transit. However, even in the presence of an appropriate host plant (apple tree or grapevine), it cannot be established because of unfavorable environmental conditions. Considering that these regions have distinctions in minimum temperatures when compared to the states of Santa Catarina, Paraná, and Rio Grande do Sul (Nery, 2005; Conti, 2011; Alvarez et al., 2013), this could be a viable explanation for the absence of *P. ulmi* in other regions of Brazil. However, we cannot ignore an additional factor: the presence of predatory mites that might act as biological controls that prevent *P. ulmi* from achieving pest status.

Considering the scarcity of studies that mention patterns in the potential distribution of phytophagous mites at the regional level, geographic modeling is an essential tool that can contribute to such studies. In this study, we identified areas with environmental suitability for *P. ulmi* in Brazil, delimiting some factors that would assist in understanding areas that are suitable for accommodating the species. Based on this information, apple and grapevine producers would remain alert in these regions and plan preventive actions by implementing management and control measures to minimize possible damage to production. For example, several biological control measures can be applied in such areas. However, this information is of great importance for future academic studies on this species, particularly in the southern region of Brazil.

Conclusion

The median performance rate of the model was 0.992, indicating its robustness. The variable that made the greatest contribution to the model was the average temperature of the coldest quarter (Bio11). The predictive model of the ecological niche indicated that the southern region of Brazil is environmentally favorable for the adaptation of this mite. The data obtained helped us understand the geographical distribution of *P. ulmi* in Brazil, and climatically suitable areas for its occurrence were inferred. We believe that this tool can offer indirect assistance to the agricultural sector, especially the producers of apples and grapes in Brazil regarding the presence of *P. ulmi*.

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References

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*(6), 711-728. DOI: https://doi.org/10.1127/0941-2948/2013/0507

Amaro, G., & Morais, E. G. F. (2013). Potential geographical distribution of the red palm mite in South America. *Experimental and Applied Acarology*, *60*(30), 343-355. DOI: https://doi.org/10.1007/s10493-012-9651-9

Anderson, R. P., Lew, D., & Peterson, A. T. (2003). Evaluating predictive models of species' distributions: criteria forselecting optimal models. *Ecological Modelling*, *162*(3), 211-232. DOI: https://doi.org/10.1016/S0304-3800(02)00349-6

Andrei, E. (2005). *Compêndio de defensivos agrícolas* (7. ed.). São Paulo, SP: Editora Andrei.

Barve, N., Barve, V., Jiménez-Valverde, A., Lira-Noriega, A., Maher, S. P., Peterson, A. T., … Villalobos, F. (2011). The crucial role of the accessible area in ecological niche modeling and species distribution modeling. *Ecological Modelling*, *222*(11), 1810-1819. DOI: https://doi.org/10.1016/j.ecolmodel.2011.02.011

Bleicher, E. (1974). Ocorrência do ácaro *Panonychus ulmi* (Koch, 1836) Tuttle & Baker (1966) no estado de Santa Catarina. *O Solo*, *66*(1), 64.

Conti, J. B. (2011). *Clima e meio ambiente*. São Paulo, SP: Atual Editora.

Corrêa, L. L. C., Silva, D. E., Nascimento, J. M., Oliveira, S. V., & Ferla, N. J. (2021). Predictive distribution of *Aculus schlechtendali* (Acari: Eriophyidae) in southern Brazil. *International Journal of Acarology*, *47*(1), 1-4. DOI: https://doi.org/10.1080/01647954.2020.1870548

Cuthbertson, A. G., & Murchie, A. K. (2010). *A brief life history of Panonychus ulmi (red spider mite) in apple orchards*. Applied Plant Science Division, DARD, Newforge Lane, Belfast BT9 5PX, UK. Retrieved on Jan. 15, 2021 from https://eservices.ruralni.gov.uk/pdfs/crops/Red%20spider%20mite.pdf

Duso, C., Pozzebon, A., Kreiter, S., Tixier, M. S., & Candolfi, M. (2012). Management of phytophagous mites in European vineyards. In *Arthropod management in vineyards* (p. 191-217). Dordrecht, NT: Springer. DOI: https://doi.org/10.1007/978-94-007-4032-7_9

Elith, J., Graham, C. H., Anderson, R. P., Dudik, M., Ferrier, S., Guisan, A., … Zimmermann, N. E. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, *29*(2), 129-151. DOI: https://doi.org/10.1111/j.2006.0906-7590.04596.x

Ferla, N. J., & Botton, M. (2008). Ocorrência do ácaro vermelho europeu associado à cultura da videira no Rio Grande do Sul, Brasil. *Ciência Rural*, *38*(6),1758-1761. DOI: https://doi.org/10.1590/S0103-84782008000600042

Ferla, N. J., Johann, L., Klock, C., Majolo, F., & Botton, M. (2011). Phytoseiid mites (Acari: Phytoseiidae) from vineyards in Rio Grande do Sul State, Brazil. *Zootaxa*, *2976*(1), 15-31. DOI: https://doi.org/10.11646/zootaxa.2976.1.2

Ferla, N. J., & Moraes, G. D. (2002). Ácaros (Arachnida, Acari) da seringueira (*Hevea brasiliensis* Muell. Arg.) no Estado do Mato Grosso, Brasil. *Revista Brasileira de Zoologia*, *19*(3), 867-888. DOI: https://doi.org/10.1590/S0101-81752002000300025

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302-4315. DOI: https://doi.org/10.1002/joc.5086

Flechtmann, C. H. W. (1967). Phytoseiidae do Estado de São Paulo (Acarina: Mesostigmata). *Anais da Escola Superior de Agricultura Luiz de Queiroz*, *24*, 247-248. DOI: https://doi.org/10.1590/S0071-12761967000100023

Gräff, C. A, Johann, L., Souza, C. F. V., & Ferla, N. J. (2017). Patogenicidade de *Isaria fumosorosea* sobre o ácaro vermelho europeu em laboratório. *Biotemas*, *30*(1), 73-78. DOI: https://doi.org/10.5007/2175-7925.2017v30n1p73

Instituto Brasileiro do Vinho [IBRAVIN]. (2019). *Panorama da vitivinicultura brasileira – 46ª Reunião ordinária da câmara setorial da cadeia produtiva da viticultura, vinhos e derivados*. Brasília, DF: IBRAVIN Retrieved on Jan. 1, 2021 from http://www.agricultura.gov.br/assuntos/camaras-setoriais-tematicas/documentos/camaras-setoriais/viticultura-vinhos-e-derivados/2018/47aro/2-5-comercializacao.pdf

Johann, L., & Ferla, N. J. (2012). Mite (Acari) population dynamics in grapevines (*Vitis vinifera*) in two regions of Rio Grande do Sul, Brazil. *International Journal of Acarology*, *38*(5), 386-393. DOI: https://doi.org/10.1080/01647954.2012.657240

Johann, L., Horn, T. B., Carvalho, G. S., & Ferla, N. J. (2014). Diversity of mites (Acari) in vineyard agroecosystems (*Vitis vinifera*) in two viticultural regions of Rio Grande do Sul State, Brazil. *Acarologia*, *54*(2), 137-154. DOI: https://doi.org/10.1051/acarologia/20142122

Kist, B. B. (2015). *Anuário Brasileiro da maçã 2015*. Santa Cruz do Sul, RS: Editora Gazeta.

Kist, B. B, Vencato, A. Z., Santos, C., Carvalho, C., Reetz, E. R., Poll, H., & Beling, R. R. (2019). *Anuário Brasileiro da maçã 2019*. Santa Cruz Sul, RS: Editora Gazeta.

Kovaleski, A., & Vendramim, J. D. (1993). Biologia de *Panonychus ulmi* (Kock, 1836) (Acari: Tetranychidae) em macieira. *Revista de Agricultura*, *68*(1), 27-41.

Lindquist, E. E. (1996). External anatomy and notation of structures. In *Eriophyoid mites-their biology, natural enemies and control* (v. 6, p. 1-30). Amsterdam, NT: Elsevier.

Litskas, V. D., Migeon, A., Navajas, M., Tixier, M. S., & Stavrinides, M. C. (2019). Impacts of climate change on tomato, a notorious pest and its natural enemy: small scale agriculture at higher risk. *Environmental Research Letters*, *14*(8), 1-10. DOI: https://doi.org/10.1088/1748-9326/ab3313

Lu, H., Ma, Q., Chen, Q., Lu, F., & Xu, X. (2012). Potential geographic distribution of the cassava green mite *Mononychellus tanajoa* in Hainan, China. *African Journal of Agricultural Research*, *7*(7), 1206-1213. DOI: https://doi.org 10.5897/AJAR11.1784

Mello, L. M. R. (2008). Vitivinicultura Brasileira: Panorama 2007. *Jornal da Fruta*, *16*(196), 21-22.

Mello, L. M. R. (2019). *Vitivinicultura Brasileira: Panorama 2018*. Bento Gonçalves, RS: Embrapa Uva e Vinho. (Comunicado Técnico, 210).

Mello, L. M. R., & Mattuela, J. L. (1999). Abordagem prospectiva: da cadeia produtiva da uva e do vinho do Rio Grande do Sul. *Revista de Política Agrícola*, *8*(2),1-11.

Mendonça, R. S. D. (2009). Estudos taxonômicos de ácaros *Tetranychidae* no Brasil e filogenia e estrutura genética do ácaro rajado, *Tetranychus urticae* Koch, inferidas a partir de sequências do DNA ribossômico e mitocondrial. Retrieved on Jan. 10, 2021 from https://repositorio.unb.br/handle/10482/4580.

Meynard, C. N., Migeon, A., & Navajas, M. (2013). Uncertainties in predicting species distributions under climate change: A case study using *Tetranychus evansi* (Acari: Tetranychidae), a widespread agricultural pest. *PLoS ONE*, *8*(6), 1-10. DOI: https://doi.org/10.1371/journal.pone.0066445

McMurtry, J. A., De Moraes, G. J., & Sourassou, N. F. (2013). Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. *Systematic and Applied Acarology*, *18*(4), 297-320. DOI: https://doi.org/10.11158/saa.18.4.1

Migeon, A., Ferragut, F., Escudero-Colomar, L. A., Fiaboe, K., Knapp, M., Moraes, G. J., & Navajas, M. (2009). Modelling the potential distribution of the invasive tomato red spider mite, *Tetranychus evansi* (Acari: Tetranychidae). *Experimental and Applied Acarology*, *48*, 199-212. DOI: https://doi.org/10.1007/s10493-008-9229-8

Migeon, A., & Dorkeld, F. (2020). *Spider mites web*: a comprehensive database for the Tetranychidae. Retrieved on Dec. 18, 2020 from http://www.montpellier.inra.fr/CBGP/spmweb

Monteiro, L. B. (2002). Manejo integrado de pragas em macieira no Rio Grande do Sul II. Uso de *Neoseiulus californicus* para o controle de *Panonychus ulmi*. *Revista Brasileira de Fruticultura*, *24*(2), 395-405. DOI: https://doi.org/10.1590/S0100-29452002000200024

Monteiro, L. B., Souza, A., & Pastori, P. L. (2006). Comparação econômica entre controle biológico e químico para o manejo de ácaro-vermelho em macieira. *Revista Brasileira de Fruticultura*, *28*(3), 514-517. DOI: https://doi.org/10.1590/S0100-29452006000300038

Moraes, G. D., & Flechtmann, C. H. W. (2008). *Manual de acarologia. Acarologia básica e ácaros de plantas cultivadas no Brasil*. Ribeirão Preto, SP: Holos Editora.

Mota, F. S. D., & Agendes, M. D. O. (1986). *Clima e agricultura no Brasil*. Porto Alegre, RS: Sagra.

Navia, D., Hamada, E., Gondim Jr, M. G. C., & Benito, N. P. (2016). Spatial forecasting of red palm mite in Brazil under current and future climate change scenarios. *Pesquisa Agropecuária Brasileira*, *51*(5), 586-598. DOI: https://doi.org/10.1590/S0100-204X2016000500020

Nery, J. T. (2005). Dinâmica climática da região sul do Brasil. *Revista Brasileira de Climatologia*, *1*(1), 61-75. DOI: https://doi.org/10.5380/abclima.v1i1.25233

Parsa, S., Hazzi, N. A., Chen, Q., Lu, F., Campo, B. V. H., Yaninek, J. S., & Vásquez-Ordóñez, A. A. (2015). Potential geographic distribution of two invasive cassava green mites. *Experimental and Applied Acarology*, *65*(2), 195-204. DOI: https://doi.org/10.1007/s10493-014-9868-x

Phillips, S. J, Anderson, R. P, & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological modelling*, *190*(3-4), 231-259. DOI: https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips, S. J., & Dudík, M. (2008). Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, *31*(2), 161-175. DOI: https://doi.org/10.1111/j.0906-7590.2008.5203.x

Phillips, S. J. (2008). Transferability, sample selection bias and background data in presence-only modelling: a response to Peterson et al. (2007). *Ecography*, *31*(2), 272-278. DOI: https://doi.org/10.1111/j.0906-7590.2008.5378.x

Rabbinge, R. (1976). *Biological control of fruit-tree red spider mite*. Wageningen, NT: Pudoc.

Ragusa, S., & Tsolakis, H. (2000). Notes on the adaptation of some phytophagous and predacious mites to various ecological parameters in the Mediterranean countries. *Web Ecology*, *1*(1), 35-47. DOI: https://doi.org/10.5194/we-1-35-2000

Soberón, J., & Peterson, A. T. (2005). Interpretation of models of fundamental ecological niches and species' distributional areas. *Biodiversity Informatics*, *2*, 1-10. DOI: https://doi.org/10.17161/bi.v2i0.4

Soberón, J. (2007). Grinnellian and Eltonian niches and geographic distributions of species. *Ecology Letters*, *10*(12), 1115-1123. DOI: https://doi.org/10.1111/j.1461-0248.2007.01107.x

Soberón, J. (2010). Niche and area of distribution modeling: A population ecology perspective. *Ecography*, *33*(1), 159-167. DOI: https://doi.org/10.1111/j.1600-0587.2009.06074.x

Townsend, C. R., Begon, M., & Harper, J. L. (2010). *Fundamentos em ecologia*. Porto Alegre, RS: Artmed Editora.