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Original Article

Climatic risk for Asian soybean rust occurrence in Mato Grosso, Rio Grande do Sul and Paraná states[1]

Risco climático para ocorrência da ferrugem asiática da soja no Mato Grosso, Rio Grande do Sul e Paraná

Aline U. Henck[2*], Sidinei Z. Radons[3], Julio R. Pellenz[3], Joelson N. Haas[3] & Patrícia Pivetta[2]

[1] Research developed at Universidade Federal da Fronteira Sul, Campus Cerro Largo, Cerro Largo, RS, Brazil
[2] Universidade Federal de Santa Maria/Departamento de Fitotecnia, Santa Maria, RS, Brazil
[3] Universidade Federal da Fronteira Sul/Campus Cerro Largo, Cerro Largo, RS, Brazil

HIGHLIGHTS:

During the soybean growing months, climatic risks escalate in Mato Grosso compared to Rio Grande do Sul and Paraná states.
The southern region faces higher risks than Mato Grosso during the soybean-free period, making its implementation crucial.
Air temperature and relative air humidity influence the climatic risk of Asian soybean rust occurrence.

ABSTRACT: Asian soybean rust is a primary factor affecting soybean production. Climate risk knowledge optimizes agricultural management, reduces pesticide use, and promotes environmental sustainability. The objective of this study was to evaluate the climatic risk of the occurrence of Asian soybean rust in the states of Mato Grosso, Rio Grande do Sul, and Paraná, Brazil, verifying the months with temperature and relative air humidity that are more favorable for disease development. Hourly meteorological data were obtained from the National Institute of Meteorology, collected from 36 automatic weather stations in Mato Grosso state, 44 in Rio Grande do Sul state, and 26 in Paraná state, from the beginning of the operation until December 31, 2021. The climatic risk values for Asian soybean rust occurrence were calculated daily, obtained by the product of the response functions to leaf wetness duration and air temperature during this period. The average total climatic risk of Asian soybean rust occurrence in Mato Grosso, Rio Grande do Sul, and Paraná states, was 44, 30, and 36%, respectively. Relative air humidity was the meteorological element with the greatest climatic risk for the development of the disease in the states of Rio Grande do Sul and Paraná, Brazil, and air temperature was the most limiting, the opposite was observed for the state of Mato Grosso, where air temperature was favorable and relative air humidity was more limiting.

Key words: *Glycine max* (L.), disease forecasting systems, air temperature, relative air humidity

RESUMO: A ferrugem-asiática da soja é um dos principais fatores que afetam a produção de soja. O conhecimento dos riscos climáticos otimiza o manejo agrícola, reduz o uso de agrotóxicos e promove a sustentabilidade ambiental. O objetivo deste estudo foi avaliar o risco climático para a ocorrência da ferrugem-asiática da soja nos Estados de Mato Grosso, Rio Grande do Sul e Paraná, Brasil, verificando os meses com temperatura e umidade relativa do ar mais favoráveis ao desenvolvimento da doença. Os dados meteorológicos horários foram obtidos através do Instituto Nacional de Meteorologia, coletados de 36 estações meteorológicas automáticas do estado de Mato Grosso, 44 no Rio Grande do Sul e 26 no Paraná, desde a data de início de funcionamento até 31 de dezembro, 2021. Os valores de risco climático para a ocorrência da ferrugem-asiática da soja foram calculados diariamente, obtidos pelo produto das funções de resposta à duração do molhamento foliar e a temperatura do ar durante esse período. O risco climático total de ocorrência da ferrugem asiática da soja, em média, em Mato Grosso, Rio Grande do Sul e Paraná, foi 44, 30 e 36%, respectivamente. A umidade relativa do ar foi o elemento meteorológico de maior risco climático para o desenvolvimento da doença no Rio Grande do Sul e Paraná, no Brasil e a temperatura do ar foi o mais limitante, o oposto foi constatado para o estado de Mato Grosso, a temperatura do ar foi favorável e a umidade relativa do ar foi limitante.

Palavras-chave: *Glycine max* (L.), sistema de previsão de doenças, temperatura do ar, umidade relativa do ar

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* Corresponding author - E-mail: alineulzeferhenck@gmail.com
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Introduction

Soybean (*Glycine max* (L.) Merrill) is a dicotyledonous legume that originates from the Asian continent. In the 2021/2022 growing season, Brazil produced approximately 125.5 million tons, cultivated over 41.5 million hectares concentrated primarily in the southern and midwestern regions of the country (CONAB, 2023).

Asian soybean rust (ASR) is caused by the biotrophic fungus *Phakopsora pachyrhizi* Syd. & P. Syd. Reported for the first time in Brazil in 2001 (Yorinori et al., 2005), it is considered the most serious among the diseases that affect crops (Langenbach et al., 2016) and can cause yield reductions of up to 90% (Silva et al., 2020), particularly in places with suitable conditions for leaf wetness and air temperature for the pathogen (Beruski et al., 2020).

For disease management, most growers use resistant cultivars and chemical control with scheduled fungicidal sprays (Zambolim et al., 2022), which do not consider the interactions between the pathogens and the environment. An alternative is the use of disease forecasting systems based on weather variables, as reported for potatoes (Bosco et al., 2010), and coffee trees (Hinnah et al., 2020). Engers et al. (2024) developed and validated a prediction system for ASR based on meteorological variables, and verified that it is possible to reduce fungicidal applications without affecting productivity.

Forecasting systems applied to a series of climatic data allow the assessment of the risk of disease occurrence in a given region. According to Radons et al. (2021), these help in planning management practices for the crop, reduce the use of chemical control methods, and increase sustainability, as applications are only made when necessary. This study found that planting late-cycle cultivars and late sowing increased the risk of disease occurrence, leading to greater use of fungicides, especially during El Niño events.

Therefore, the aim of this study was to evaluate the climatic risk for ASR occurrence in the states of Mato Grosso, Rio Grande do Sul, and Paraná, Brazil, verifying the months of the year with air temperature and relative air humidity most favorable for disease development.

Material and Methods

Climatic data for air temperature and relative air humidity were obtained from the website of the National Institute of Meteorology (INMET, 2019), with hourly records collected from 36 automatic weather stations located in the states of Mato Grosso, 44 in Rio Grande do Sul, and 26 in Paraná (Figure 1) from the start record date until December 31, 2021.

According to the Köppen climate classification, the predominant climates in Mato Grosso are Am (forest climate, with a short dry season and heavy rains during the remainder of the year) and Aw (savannah climate, with a dry season typically defined in winter). Rio Grande do Sul and Paraná are classified as Cfa (subtropical, without a defined dry season and hot summers) and Cfb (temperate, without a defined dry season and moderately hot summers), respectively (Alvares et al., 2013).

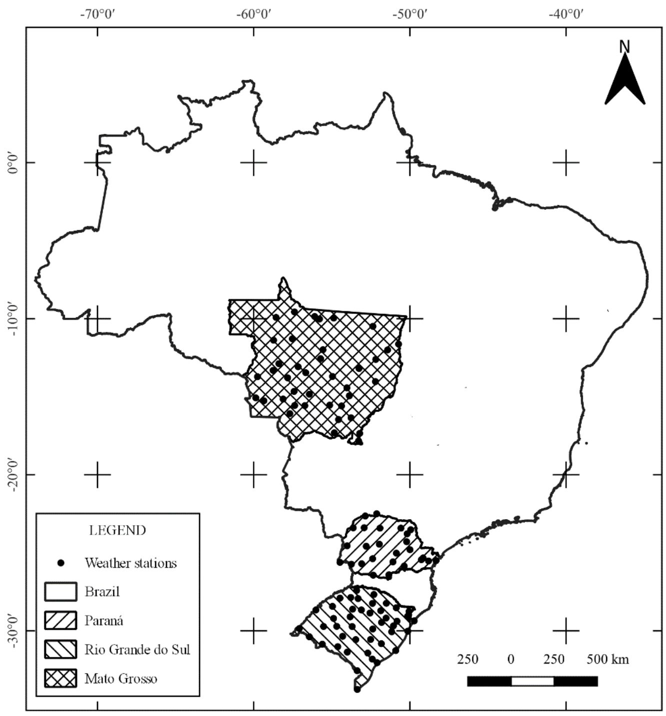

Figure 1. Spatial distribution of automatic weather stations used in the study, located in the states of Mato Grosso, Rio Grande do Sul, and Paraná, Brazil

Data were organized into electronic spreadsheets for each weather station, invalid data were identified, and the percentage of failures was determined. The total climatic risk of disease occurrence was calculated using the method described by Engers et al. (2024). The response function to the leaf wetness duration (f(W)) represents the disease occurrence risk as a function of time when the relative air humidity is > 85%, according to Eq. 1:

$$f(W) = \frac{1}{1 + e^{(W-12)}} \tag{1}$$

where:

W - daily leaf wetness duration (hours).

The response function to air temperature (f(T)) represents the disease occurrence risk as a function of the average daily air temperature during the period when the relative air humidity is > 85%, according to Eqs. 2 and 3:

$$f(T) = \frac{2(T-8)\alpha(22.75-8)\alpha - (T-8)2\alpha}{(22.75-8)2\alpha} \tag{2}$$

$$\alpha = \frac{\ln 2}{\ln\left[\frac{(42-8)}{(22.75-8)}\right]} \tag{3}$$

where:

T - daily average air temperature when leaf wetness occurs (°C).

The values of 42, 22.75, and 8 in the equation indicate the maximum, optimal, and minimum air temperatures (°C) for disease development, respectively.

The total climatic risk values for disease occurrence were obtained as the product of the response functions to the duration of leaf wetness and air temperature during this period, ranging from 0 to 1 (0-100%). Climatic risk data by air temperature, relative air humidity, and total risk were organized into monthly and annual averages and analyzed using boxplot graphs (5, 25, 50, 75, and 95%).

Results and Discussion

In Mato Grosso, the average annual climatic risk of ASR, considering relative air humidity, was 30%. This value varied among months, being higher from December to April, with a maximum in February (54%), and showed high variability among different weather stations. From July to September, it was lower, with a minimum in August (2%) and low variability (Figure 2A). This can be understood because this region is characterized by two well-defined seasons: a dry season from May to September and a rainy season that occurs between October and April (Carvalho et al., 2022), the latter being when the greatest climatic risks are verified.

On average, throughout the year, 98% of the analyzed periods posed climatic risk for disease occurrence considering only air temperature, which was high during all months, with low variability between weather stations (Figure 2B). The total climatic risk of ASR occurrence was 44%, on average, in the state of Mato Grosso. The highest disease potential was observed in summer (maximum 64% in March) and the lowest in winter, from July to September (minimum 8% in August) (Figure 2C). The greater the climatic risk in a given location, the greater is the chance of ideal air temperature and relative air humidity for germination and penetration of the pathogen into the host. Minchio et al. (2018) also found an increasing number of occurrences of the disease throughout the harvest in this state.

Thus, although air temperature was a meteorological element favorable for pathogen development in Mato Grosso throughout the year, relative air humidity was limited during the winter period, which was decisive for the total risk. Periods with high relative air humidity can increase leaf wetness time, which is essential for pathogen urediniospore germination and penetration processes in plant tissues (Agrios, 2004). When meteorological conditions do not provide continuous periods of leaf wetness, disease development does not occur either (Melching et al., 1989), regardless of whether the air temperature is favorable.

The greatest disease potential was observed during the crop cultivation period because of the combination of temperature and relative air humidity suitable for pathogen development. According to Del Ponte (2006a), ASR can be extremely aggressive under favorable weather conditions, resulting in early defoliation of plants and significant damage to grain production. Godoy et al. (2016) emphasized that the pathogen affects most producing regions and can survive throughout the year in the presence of a host. Therefore, soybean producers should intensify their disease management and control practices during periods of greater climatic risk. During the growing season, when the greatest disease potential occurs,

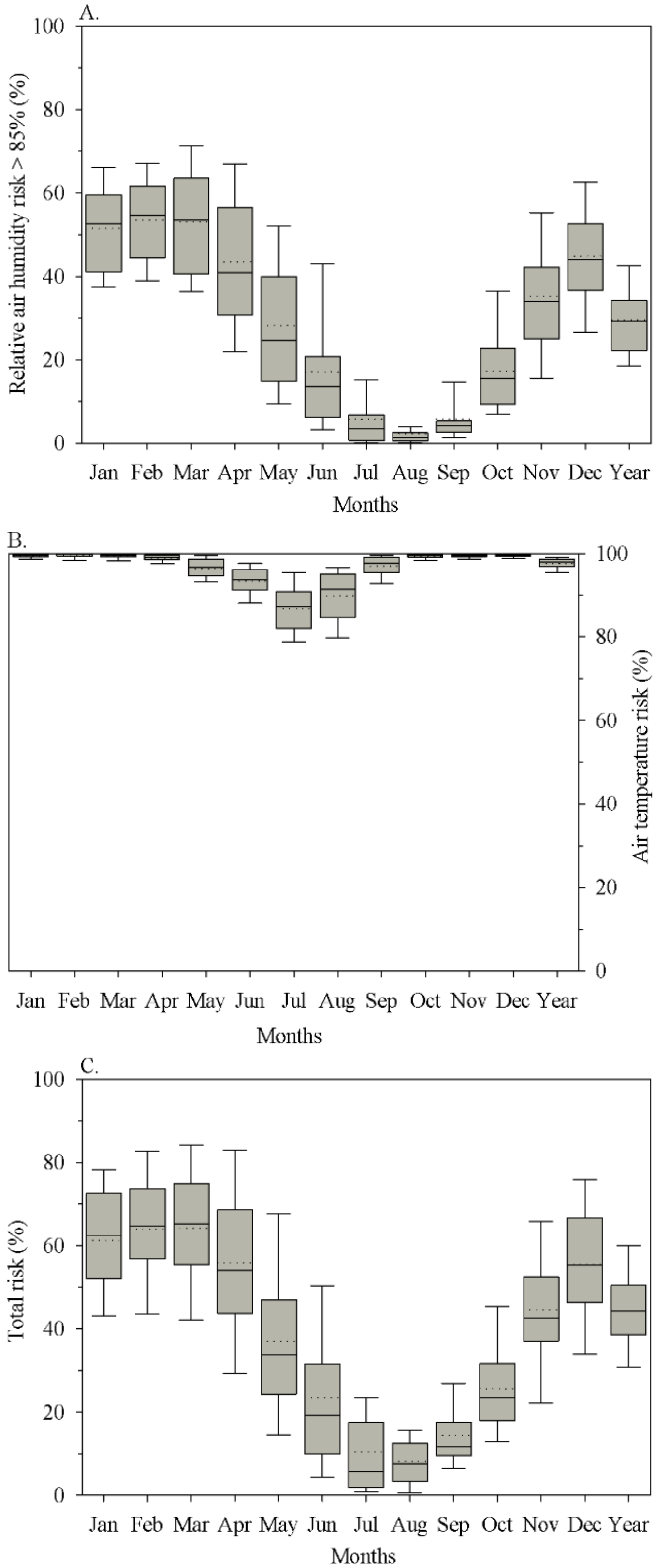

Figure 2. Boxplot analysis (5, 25, 50, 75, and 95%) and means (dotted line) of risk by relative air humidity > 85% (RH > 85%) (A), air temperature (B), and total risk (C) for the occurrence of ASR, throughout the months of the year for the Mato Grosso state, Brazil

alternatives, such as sowing date anticipation and the use of early cycle cultivars, which provide an escape from greater risk periods, can be used (Ogoshi et al., 2019; Radons et al., 2021).

Although the model exhibited reduced favorability from June to September owing to lower humidity during these months, soybeans can only be sown in Mato Grosso with irrigation, which can help improve conditions, as temperature is no longer a limiting factor. This period coincides with that recommended by the Ministry of Agriculture, Livestock, and Supply for applying the soybean-free period in the state from June 15 to September 15 (MAPA, 2023), highlighting the need for it to be conducted.

In Rio Grande do Sul, the average annual climatic risk of ASR occurrence, considering the relative air humidity, was 33%, with favorable conditions throughout the year and intensifying during winter (Figure 3A). Although soybeans are not grown during winter in southern Brazil, the biotrophic pathogen *Phakopsora pachyrhizi* requires living cells to survive the off-season. This is made possible by the presence of volunteer plants ("guax plants") and alternative hosts, such as kudzu (*Pueraria lobata*) and perennial soybean (*Neotonia witwigii*) (Zambolim et al., 2022), which have already been reported in the country. Thus, it is essential to assess the climatic risk of disease occurrence throughout the year and not just during the crop-growing period.

Air temperature analysis showed that, on average, there was a 72% risk of disease occurrence. The risks were high during the first and last months of the year, with low variability among weather stations. After autumn, the trend decreased until July, when the lowest average climatic risk was verified (42%) with high variability (Figure 3B). Therefore, the average total climatic risk of ASR occurrence is 30% in the state of Rio Grande do Sul. May showed the highest climatic risk (36%) and August had the lowest (22%) (Figure 3C), with some variability between meteorological stations.

Radons et al. (2021), in a study conducted in Rio Grande do Sul, described that the climatic risk of ASR occurrence in the state varied between different locations, corroborating the results of this study. It was also verified that the use of early cultivars and sowing at the beginning of the period recommended by Agricultural Zoning of Climate Risk, provided lower climatic risks, as well as fewer fungicidal applications. Other researchers have also found that by using disease prediction systems based on meteorological variables, it is possible to reduce the number of fungicidal applications, as described by Bosco et al. (2010) for potato late blight and Hinnah et al. (2020) for coffee rust.

In Paraná state, the average annual climatic risk for ASR occurrence, considering relative air humidity, was 33%, ranging from 26% (September) to a maximum of 42% (June). Furthermore, it is important to highlight the considerable variability, indicating that some weather stations presented very high risks, whereas others presented very low risks during the same month (Figure 4A). Del Ponte et al. (2006a) reported that rainfall can affect disease progression. Thus, the results can be explained by the fact that the northern and northwestern regions of the state are characterized as transition regions for the monsonic rainfall regime, in which the rains are concentrated from September to April. In contrast, other regions have an isoigro rainfall regime and do not have a defined dry season (Ely & Dubreuil, 2017).

Brazil's southern region is characterized by an isoigro rainfall regime, where rainfall is well distributed throughout the year (Back et al., 2020), unlike central Brazil. Thus, the

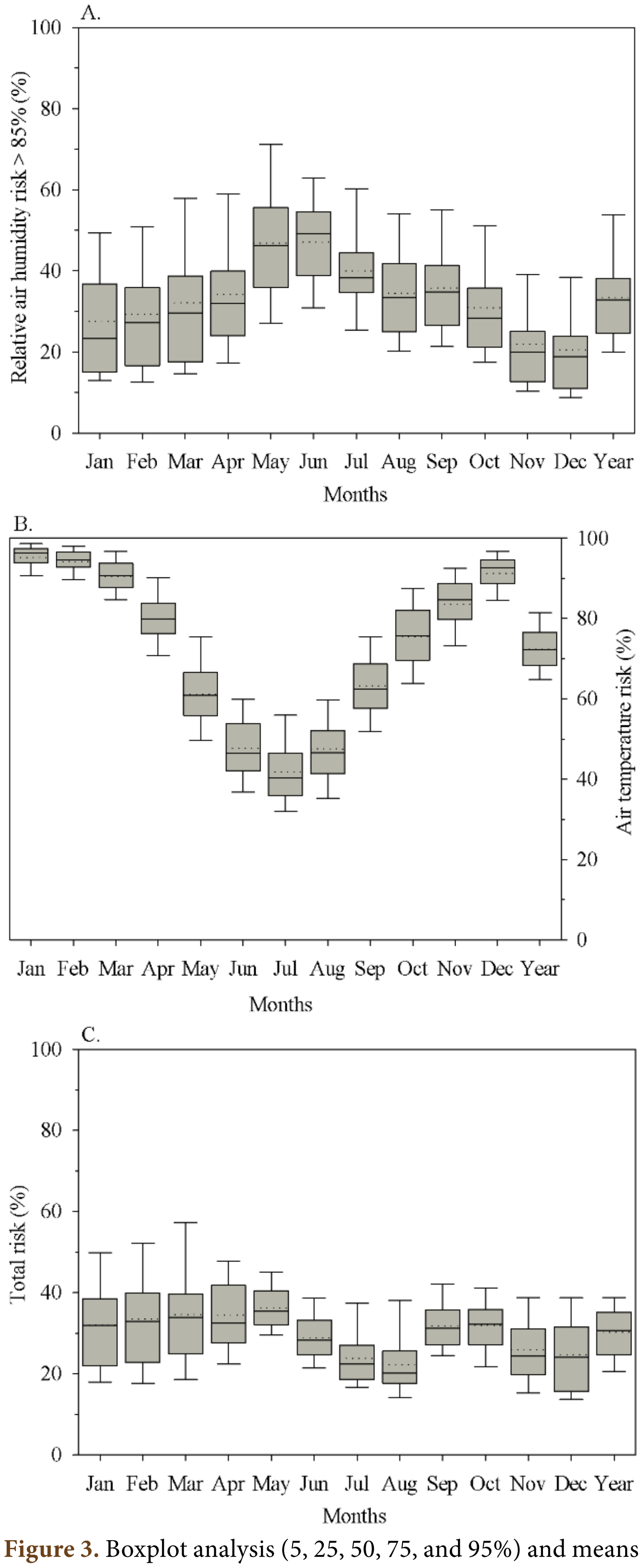

Figure 3. Boxplot analysis (5, 25, 50, 75, and 95%) and means (dotted line) of risk by relative air humidity > 85% (RH > 85%) (A), air temperature (B), and total risk (C) for the occurrence of ASR, throughout the months of the year for the Rio Grande do Sul state, Brazil

relative humidity conditions were conducive to disease development throughout the study period. Studies conducted in the state of Rio Grande do Sul point to the importance of considering the influence of the El Niño Southern Oscillation phenomenon, which interferes with rainfall patterns in the

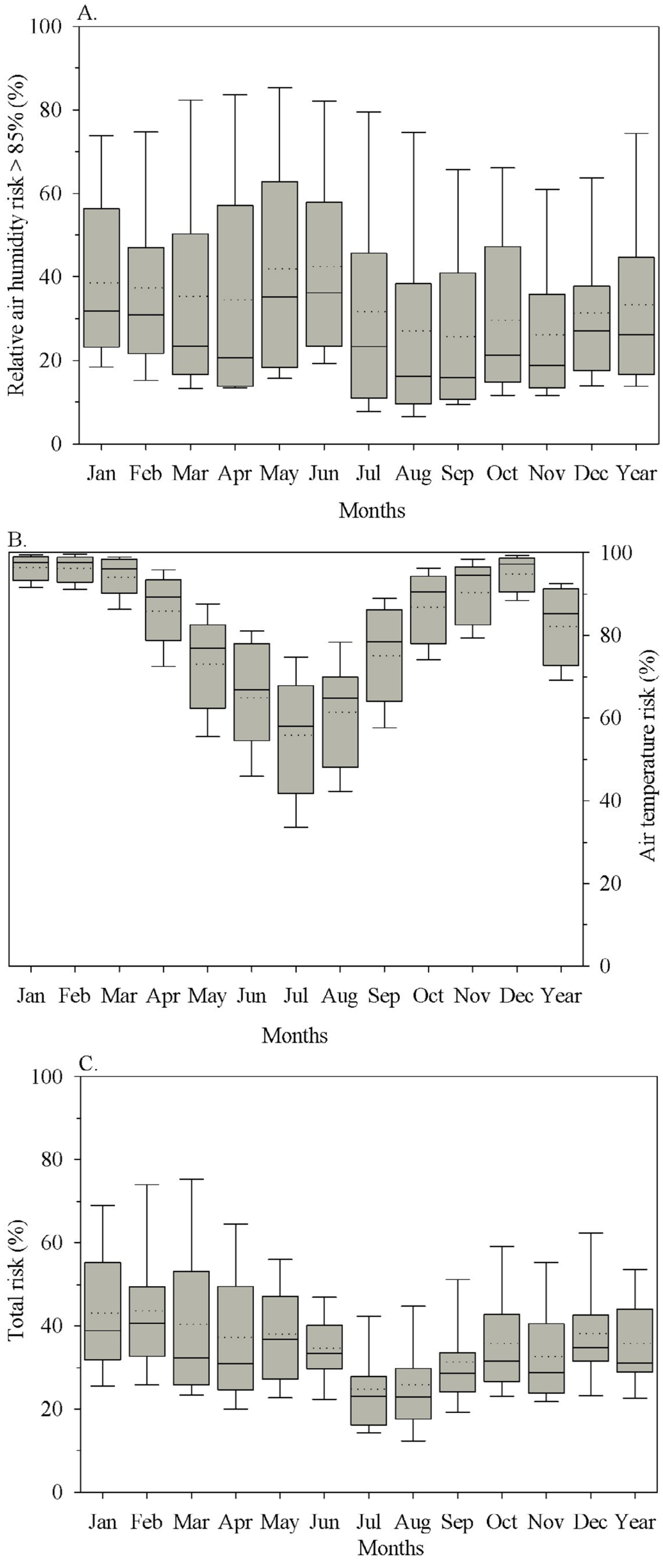

Figure 4. Boxplot analysis (5, 25, 50, 75, and 95%) and means (dotted line) of risk by relative air humidity > 85% (RH > 85%) (A), air temperature (B), and total risk (C) for the occurrence of ASR, throughout the months of the year for the Paraná state, Brazil

region and the climatic risk of the disease occurring over the years (Radons et al., 2021). In central Brazil, this phenomenon does not have a significant impact on the development of ASR or soybean yield (Fattori Junior et al., 2022).

Air temperature analysis revealed that on average, disease risk occurrence in Paraná was 82%. Risks were high during the first and last months of the year for most weather stations. After the onset of autumn, a reduction was observed, reaching a midyear minimum (56% in July) with high variability (Figure 4B).

The average total climatic risk of ASR occurrence was 36% in Paraná. February presented the highest climatic risk (44%), whereas July had the lowest (25%) (Figure 4C). Forecast systems based on meteorological variables were used to predict the occurrence of diseases daily, considering the interaction between leaf wetness duration and air temperature during this period. According to Del Ponte et al. (2006b), they can be used to predict monthly periods of favorable climatic conditions and indicate regions at greater climatic risk.

Therefore, although the southern region presented favorable and essential relative air humidity conditions for pathogen spore germination and penetration into the host during the year, the air temperature was limiting during the off-season, lowering total climatic risks. Minchio et al. (2016) reported that low air temperature in winter was a limiting factor for pathogen survival in volunteer plants in Rio Grande do Sul, Brazil. Studies indicate that the pathogen can develop when the leaves are wet for a long time and the air temperature is in the ideal range from 18 to 26.5 °C. When the air temperature is < 9 °C or > 28.5 °C, the disease does not develop (Melching et al., 1989).

However, although this was the most limiting variable, even during the recommended soybean-free period (July 13-October 10 for the Rio Grande do Sul and June 10-September 10 for Paraná) (MAPA, 2023), climate risks varied from 22 to 32% (July-October) in Rio Grande do Sul and from 25 to 35% (June-September) in Paraná (Figure 3C). Thus, the results proved the possibility of the disease occurring during the soybean off-season and the importance of implementing this management practice in this region.

When the soybean-free period was not conducted, there was an increase in spores owing to the presence of the pathogen primary host, volunteer soybean plants. This, combined with optimal environmental conditions, allows the fungus to survive and initiate new reproductive cycles (Rosa et al., 2023). Minchio et al. (2016) highlighted the importance of a soybean-free period in the state of Rio Grande do Sul. In this state, this practice was not conducted for many years, as it was justified that frost formation during this period was sufficient to eliminate voluntary soybeans (Godoy et al., 2016).

Conclusions

1. The total climatic risk of Asian soybean rust occurrence, on average, over the year was highest in the state of Mato Grosso, followed by the states of Paraná and Rio Grande do Sul. During the months of crop cultivation, the most significant risks were observed in the state of Mato Grosso, whereas during the off-season, they were higher in the states of Rio Grande do Sul and Paraná.

2. Relative air humidity was the meteorological element with the greatest climatic risk for disease development in the states of Rio Grande do Sul and Paraná, Brazil, and air

temperature was limiting in this region. The opposite trend was observed in Mato Grosso. Air temperature was favorable for pathogen development throughout the year, and relative air humidity was limiting.

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Literature Cited

Agrios, G. N. Plant pathology. 5th ed. San Diego: Academic Press, 2004. 922p.

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C; Gonçalves, J. D. M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Back, Á. J.; Sônego, M.; Pereira, J. R. Índices de concentração de chuvas da região sul do Brasil. Revista Brasileira de Climatologia, v.27, p.57-72, 2020. http://dx.doi.org/10.5380/abclima.v27i0.65466

Beruski, G. C.; Del Ponte, E. M.; Pereira, A. B.; Gleason, M. L.; Câmara, G. M.; Araujo Junior, I. P.; Sentelhas, P. C. Performance and profitability of rain-based thresholds for timing fungicide applications in soybean rust control. Plant Disease, v.104, p.2704-2712, 2020. https://doi.org/10.1094/PDIS-01-20-0210-RE

Bosco, L. C.; Heldwein, A. B.; Blume, E.; Trentin, G.; Grimm, E. L.; Lucas, D. D. P.; Loose, L. H.; Radons, S. Z. Sistemas de previsão de requeima em cultivos de batata em Santa Maria, RS. Bragantia, v.69, p.649-660, 2010. https://doi.org/10.1590/S0006-87052010000300017

Carvalho, M. A. C. C. de; Uliana, E. M.; Silva, B. F. P. da; Martins, C. A. da S.; Cruz, I. F. da; Aires, U. R. V.; Mendes, M. A. dos S. A. Precipitação e produtividade de grãos em zonas de transição Cerrado-Amazônia no Brasil: probabilidade, distribuição espacial e sistemas sinóticos. Geo UERJ, p.1-25, 2022. http://dx.doi.org/10.12957/geouerj.2022.52331

CONAB - Companhia Nacional de Abastecimento. Série histórica das safras. Available on: <https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=30>. Accessed on: Jun. 2023.

Del Ponte, E. M.; Godoy, C. V.; Canteri, M. G.; Reis, E. M.; Yang, X. B. Models and applications for risk assessment and prediction of Asian soybean rust epidemics. Fitopatologia Brasileira, v.31, p.533-544, 2006a. https://doi.org/10.1590/S0100-41582006000600001

Del Ponte, E. M.; Godoy, C. V.; Li, X.; Yang, X. B. Predicting severity of Asian soybean rust epidemics with empirical rainfall models. Phytopathology, v.96, p.797-803, 2006b. https://doi.org/10.1094/PHYTO-96-0797

Ely, D. F.; Debreuil, V. Análise das tendências espaço-temporais das precipitações anuais para o estado do Paraná-Brasil. Revista Brasileira de Climatologia, v.21, p.553-569, 2017. https://doi.org/10.5380/abclima.v21i0.48643

Engers, L. B. de O.; Radons, S. Z.; Henck, A. U.; Bortoluzzi, M. P. Evaluation of a forecasting system to facilitate decision-making for the chemical control of Asian soybean rust. Tropical Plant Pathology, p.1-8, 2024. https://doi.org/10.1007/s40858-024-00649-1

Fattori Junior, I. M.; Sentelhas, P. C.; Marin, F. R. Assessing the impact of climate variability on asian rust severity and soybean yields in different Brazilian Mega-Regions. International Journal of Plant Production, v.16, p.17-28, 2022. https://doi.org/10.1007/s42106-021-00169-x

Godoy, C. V.; Seixas, C. D. S.; Soares, R. M.; Marcelino-Guimarães, F. C.; Meyer, M. C.; Costamilan, L. M. Asian soybean rust in Brazil: past, present, and future. Pesquisa Agropecuária Brasileira, v.51, p.407-421, 2016. https://doi.org/10.1590/S0100-204X2016000500002

Hinnah, F. D.; Sentelhas, P. C.; Patrício, F. R. A.; Paiva, R. N.; Parenti, M. V. Performance of a weather-based forecast system for chemical control of coffee leaf rust. Crop Protection, v.137, e105225, 2020. https://doi.org/10.1016/j.cropro.2020.105225

INMET - Instituto Nacional de Meteorologia. Histórico de dados meteorológicos. 2019. Available on: <https://portal.inmet.gov.br/dadoshistoricos>. Accessed on: Jul. 2022.

Langenbach, C.; Campe, R.; Beyer, S. F.; Mueller, A. N.; Conrath, U. Fighting Asian soybean rust. Frontiers in Plant Science, v.7, e797, 2016. https://doi.org/10.3389/fpls.2016.00797

MAPA - Ministério da Agricultura, Pecuária e Abastecimento. Brasília: MAPA, 2023. Available on: <https://www.in.gov.br/en/web/dou/-/portaria-sda-n-781-de-6-de-abril-de-2023-475808852>. Accessed on: Jun. 2023.

Melching, J. S.; Dowler, W. M.; Koogle, D. L.; Royer, M. H. Effects of duration, frequency, and temperature of leaf wetness periods on soybean rust. Plant Disease, v.73, p.117-122, 1989. https://doi.org/10.1094/PD-73-0117

Minchio, C. A.; Canteri, M. G.; Fantin, L. H. Epidemias de ferrugem asiática no Rio Grande do Sul explicadas pelo fenômeno ENOS e pela incidência da doença na entressafra. Summa Phytopathologica, v.42, p.321-326, 2016. https://doi.org/10.1590/0100-5405/2219

Minchio, C. A.; Fantin, L. H.; Caviglione, J. H.; Braga, K.; Silva, M. A. A.; Canteri, M. G. Predicting Asian soybean rust epidemics based on offseason occurrence and El Niño southern oscillation phenomenon in Paraná and Mato Grosso states, Brazil. Journal of Agricultural Science, v.10, p.562-571, 2018. https://doi.org/10.5539/jas.v10n11p562

Ogoshi, C.; Zanon, A. J.; Junior, D. F. U.; Bittecourt, C. R. C.; Ulguim, A. da R.; Carlos, F. S. Progresso temporal da ferrugem asiática em função de épocas de semeadura e de cultivares de soja em terras baixas. Brazilian Journal of Development, v.5, p.17102-17114, 2019. https://doi.org/10.34117/bjdv5n9-231

Radons, S. Z.; Heldwein, A. B.; Puhl, A. J.; Nied, A. H.; Silva, J. R. da. Climate risk of Asian soybean rust occurrence in the state of Rio Grande do Sul, Brazil. Tropical Plant Pathology, v.46, p.435-442, 2021. https://doi.org/10.1007/s40858-021-00431-7

Rosa, G. F. da; Olin, P. E.; Piazer, A. M.; Nadalon, H. F.; Silva, B. da R. da; Farias, G. W. de; Bolzan, G. B.; Goulart, V. da S. Monitoramento do inóculo para controle de ferrugem asiática no estado do Rio Grande do Sul durante a safra 2021/2022. Revista Científica Multidisciplinar, v.4, p.1-12, 2023. https://doi.org/10.47820/recima21.v4i2.2738

Silva, E.; Graça, J. P. da; Porto, C.; Prado, R. M. do; Hoffmann-Campo, C. B.; Meyer, M. C.; Nunes, E. de O.; Pilau, E. J. Unraveling Asian Soybean Rust metabolomics using mass spectrometry and Molecular Networking approach. Scientific Reports, v.10, p.1-11, 2020. https://doi.org/10.1038/s41598-019-56782-4

Yorinori, J. T.; Paiva, W. M.; Frederick, R. D.; Costamilan, L. M.; Bertagnolli, P. F.; Hartman, G. E.; Godoy, C. V.; Nunes Junior, J. Epidemics of soybean rust (*Phakopsora pachyrhizi*) in Brazil and Paraguay from 2001 to 2003. Plant Disease, v.89, p.675-677, 2005. https://doi.org/10.1094/PD-89-0675

Zambolim, L.; Reis, E. M.; Guerra, W. D.; Juliatti, F. C.; Menten, J. O. M. Integrated management of Asian soybean rust. European Journal of Applied Sciences, v.10, p.602-633, 2022. https://doi.org/10.14738/aivp.102.12215