# Efficacy of different chemical control strategies against Asian soybean rust

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**Abstract –** This study aimed to compare different decision-making tools for adopting chemical control in Asian soybean rust management. For this purpose, experiments were carried out during the 2022/23 and 2023/24 crop seasons, using the following decision-making strategies: preventive fungicides applications, spore monitoring, climate vulnerability system (Agroconnect Platform), and curative fungicide applications based on field observations of symptoms. The results highlighted the importance of fungicide applications, especially as preventive measures, as an effective and reliable method to protect soybean plants against Asian soybean rust. These strategies promoted greater production stability in the production systems and enhanced farmers' profitability.

**Index terms:** *Phakopsora pachyrhizi*; Severity; Spore monitoring; Climate vulnerability; Curative applications.

## Eficácia de diferentes estratégias de controle químico da ferrugem asiática da soja

**Resumo –** O objetivo deste estudo foi comparar diferentes ferramentas de tomada de decisão no controle da ferrugem asiática da soja. Para isso, foram realizados experimentos nas safras de 2022/23 e 2023/24 usando as seguintes estratégias de tomada de decisão: i) aplicações preventivas de fungicidas, ii) caça esporos, iii) sistema de vulnerabilidade climática (Plataforma Agroconnect) e iv) aplicações curativas de fungicidas após constatação de sintomas. Os resultados sugerem a importância das aplicações de fungicidas, especialmente de forma preventiva, como medida ainda eficaz e confiável para proteger as plantas de soja contra a ferrugem-asiática-da-soja, garantindo assim uma maior estabilidade na produção e rentabilidade dos produtores.

**Termos para indexação:** *Phakopsora pachyrhizi*; Severidade; Caça esporos; Vulnerabilidade climática; Aplicações curativas.

The increase in the area planted with soybeans (*Glycine max* L.) in the last 10 years in Brazil established the country as the global leader in this grain production (CONAB, 2024), with an average yield of 3,786 kg ha$^{-1}$, generating up to BRL 72.7 billion per harvest (SAP, 2023). Soybean yield is directly linked to photoassimilates production, meaning that biotic and abiotic factors that reduce leaf area can affect the grain production, with Asian soybean rust standing out for its severity. Caused by the fungus *Phakopsora pachyrhizi*, Asian soybean rust develops in environments with an average temperature of 25°C and high relative humidity, making Brazil especially suitable for its occurrence. Rust causes early defoliation, preventing the plant from carrying out its physiological processes, which can result in productivity losses of up to 90%. Deciding on the correct timing for chemical control applications is essential for treatment efficiency, since delays in adopting control measures can render them as ineffective (Beruski *et al.*, 2020). This study aimed to compare decision-making strategies for controlling Asian soybean rust.

The experiments were conducted during the 2022/23 and 2023/24 agricultural harvests in Chapecó, SC, Brazil (27°06´34´´S, 52°40'18''W, altitude 623m), in an area with typical dystroferric Red Latosol soil. According to the Köppen climate classification, the region has a humid mesothermal climate with hot summers (Humid subtropical climate – Cfa). The soybean "cultivar Zeus IPRO" was sown at a density of 18 seeds m$^{-1}$ in a No-Tillage System on corn stover (*Zea mays* L.). Fertilization was performed with 400kg ha$^{-1}$ of 0-20-20 ($N$-$P_2O_5$-$K_2O$), according to soil analysis, and distributed in the sowing furrow. The experimental design was a randomized block design with five replicates. Experimental plots measured 1.8m x 4m, with four sowing rows spaced 0.45m apart. Five decision-making strategies were evaluated for soybean rust control (Table 1): Control (no fungicide application); Preventive (preventive and biweekly fungicide applications starting at the R1 stage - 4 applications per cycle); Spore trap (a spore trap was installed 15 days after crop emergence in a location with good wind circulation, avoiding proximity to roads to minimize dust accumulation on the blades). The trap was positioned approximately 40cm above the crop canopy. Blades were changed weekly, and from the closing of the interrows (when plant leaflets began touching), changes were performed twice a week, with a maximum of four applications; Climate vulnerability

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Table 1. Number of fungicide applications on different phenological stages of soybean BMX Zeus IPRO

*Tabela 1. Número de aplicações de fungicidas em diferentes estádios fenológicos do cultivar de soja BMX Zeus IPRO*

| Treatment[1] | Crop season 2022/23 | | Crop season 2023/24 | |
|---|---|---|---|---|
| | Nº of applications | Stage[1] | Nº of applications | Stage[1] |
| Control | *** | *** | *** | *** |
| Preventive | 4 | R1/R3/R5/R6 | 4 | R1/R3/R5/R6 |
| Spore monitoring | 0 | *** | 1 | R6 |
| Agroconnect[2] | 4 | R1/R3/R5/R6 | 3 | R3/R5/R6 |
| Curative | 2 | R4/R6 | 3 | R3/R5/R6 |

(1) Phenological stage according to Ritchie *et al.* (1982). (2) Climate Vulnerability System (Agroconnect platform).

*(1) Estágio fenológico segundo Ritchie* et al. *(1982). (2) Sistema de Vulnerabilidade Climática (plataforma Agroconnect).*

system (Agroconnect platform): This strategy was employed using the climate vulnerability system on the Epagri/Ciram Agroconnect platform (available at http://www.ciram.sc.gov.br/agroconnect/). Applications began when the system presented a risk of infection equal to or greater than moderate from the R1 stage. Moderate risk consists of relative humidity ≥90%, temperatures between 18°C and 25°C for 6 to 11 hours (Ramos *et al.*, 2018), with a maximum of four applications; Curative applications began when the first symptoms/signs of rust were observed in the soybean plants. Starting at the R1 stage, 10 leaflets per plot were randomly collected twice a week from the basal, median, and apical parts of soybean plants and taken to the Epagri Plant Health Laboratory for analysis under a binocular stereoscopic microscope (Zeiss, Brazil). When symptoms/signs of Asian rust were detected, fungicide application was recommended, for which the R6 stage (physiological maturity) was the last stage for application.

Fungicides were applied biweekly, starting at the R1 stage, when required. The treatments applied are described in Table 2. Applications were made using a $CO_2$-pressurized backpack sprayer equipped with a two-cone nozzle bar, operated at a pressure of 3.5 bar (350KPa), with a spray volume of 200L $ha^{-1}$. The diagrammatic scale proposed by Godoy *et al.* (2006) was used to estimate disease severity. This assessment measured the percentage of leaf area covered by disease symptoms and was performed on the lower, middle, and upper thirds of 10 plants in the central row of each plot. Severity assessments were performed at 15-day intervals, starting after the appearance of the first symptoms and before the application of the tested fungicides. Defoliation was assessed at the R6 stage according to the method proposed by Hirano *et al.* (2010). To quantify productivity, the grains from the useful area of the plots were weighed and extrapolated to kg $ha^{-1}$ (with 13% moisture, wet basis). To determine the mass of 100 grains, eight subsamples of 100 grains per treatment were collected and weighed, adjusting for a moisture content of 13%.

The data were subjected to analysis of variance after verifying the assumptions. In case of a significant effect, the means were compared by Tukey's test. The mean values of the variables for each treatment were subjected to multivariate cluster and principal component analyses, presented in dendrograms and biplots. All analyses were performed with the R environment (R CORE TEAM, 2021).

In both harvests, there was a significant difference in grain yield between Agroconnect platform, preventive applications, and curative strategies compared to the control and spore-monitoring treatments. A higher thousand-seed weight (TSW) was also observed with these same treatments. The severity of Asian soybean rust did not show a significant difference in

Table 2. Treatments applied to manage Asian soybean rust of two crop cycles (2022/2023-2023/2024) in Chapecó, Brazil

*Tabela 2. Tratamentos aplicados para o manejo da ferrugem asiática da soja em duas safras (2022/2023- 2023/2024) em Chapecó, Brasil*

| Applications | Active ingredient (a.i) | Doses |
|---|---|---|
| 1ª | bixafen 125g $L^{-1}$ + prothioconazole 175 g $L^{-1}$ + trifloxystrobin 150g $L^{-1}$ + soybean oil methyl ester 720g $L^{-1}$ + mancozeb 750g $Kg^{-1}$ | 500mL $ha^{-1}$ + 500mL $ha^{-1}$ + 2kg $ha^{-1}$ |
| 2ª | benzovindiflupyr 75g $L^{-1}$ + prothioconazole 150g $L^{-1}$ + mancozeb 750g $Kg^{-1}$ | 500mL $ha^{-1}$ + 500mL $ha^{-1}$ |
| 3ª | bixafen 125g $L^{-1}$ + prothioconazole 175 g $L^{-1}$ + trifloxystrobin 150g $L^{-1}$ + soybean oil methyl ester 720g $L^{-1}$ + mancozeb 750g $Kg^{-1}$ | 500mL $ha^{-1}$ + 500mL $ha^{-1}$ + 2kg $ha^{-1}$ |
| 4ª | trifloxystrobin 375g $L^{-1}$ + cyproconazole 160g $L^{-1}$ + fenpropimorph 750g $L^{-1}$ + mancozeb 750g $Kg^{-1}$ | 200mL $ha^{-1}$ + 500mL $ha^{-1}$ + 2kg $ha^{-1}$ |

the 2023 harvest, but in 2024, lower disease severity was observed with the Agroconnect platform, spore-monitoring, curative, and especially preventive strategies.

The use of preventive strategies, spore-monitoring, and curative applications resulted in a lower percentage of plant defoliation compared to the Agroconnect platform and control in both harvests (Table 3). Cluster analysis indicated the formation of two groups in both harvests: one group formed by the spore-monitoring and control strategies, and the other consisting of the remaining treatments (Figures 1a and 1c). These groupings are explained in the biplot graphs (Figures 1b and 1d), in which the Agroconnect platform and curative strategies were closely related to the increase in grain yield and thousand-seed weight.

Based on the results obtained in both harvests, it can be concluded that the fungicide application, particularly preventive measures, reduced disease severity, decreased plant defoliation, and increased productivity compared to other strategies. This is because controlling Asian soybean rust during the presymptomatic stage typically results in higher plant protection, leading to increased yield responses (Beruski *et al.*, 2020). Furthermore, initial infection by *P. pachyrhizi* occurs in the lower and older leaves, accelerating their fall and reducing the duration of the healthy green leaf area. This process limits the plant ability to intercept and absorb solar radiation, which in turn negatively affects crop yield (Kumudini *et al.*, 2008). Moreover, during the reproductive phase, soybean plants were especially sensitive to leaf loss, which can significantly impact productivity (Reis *et al.*, 2018).

The scientific literature showed few scientifically supported and rationally based alternatives for timing the first fungicide application in soybean crops. The first application should be strategically timed, but unfortunately, this rule has often not been followed in the chemical control of soybean rust in Brazil, resulting in continuous and accelerated directional selection (Reis *et al*., 2018). On the other hand, current fungicides are highly efficient in controlling Asian soybean rust when applied preventively, but show reduced efficacy when applied curatively (Netto, 2020).

The results reinforce the importance of fungicide applications, especially preventive ones, as an effective and reliable strategy to protect soybean plants against Asian rust. This approach ensures higher stability in production and enhances producers' profitability.

Table 3. Yield components, disease severity, and leaf defoliation according to strategies used to control Asian soybean rust of two crop cycles (2022/2023- 2023/2024) in Chapecó, Brazil

*Tabela 3. Componentes de rendimento, severidade da doença e desfolha em função das estratégias utilizadas no controle da ferrugem asiática da soja de duas safras (2022/2023-2023/2024) em Chapecó, Brasil*

| Treatment[1] | Crop season | | | |
|---|---|---|---|---|
| | 2022/23 | 2023/24 | 2022/23 | 2023/24 |
| | Grain yield (kg ha$^{-1}$) | | TSW (g) | |
| Agroconnect[2] | 5,885 a | 4,062 a | 199.34 a | 195.41 b |
| Preventive | 5,874 a | 4,550 a | 201.32 a | 204.07 a |
| Curative | 5,724 a | 4,083 a | 197.09 a | 187.86 c |
| Control | 4,783 b | 3,330 b | 176.81 b | 154.26 d |
| Spore monitoring | 4,768 b | 3,236 b | 173.62 b | 156.74 d |
| CV (%) | 4.13 | 4.29 | 6.34 | 2.99 |
| | Severity (%) | | Defoliation (%) | |
| Control | 0.5[n/s] | 79 a | 47 a | 86 a |
| Agroconnect[2] | 0.5 | 45 b | 52 a | 83 a |
| Spore monitoring | 0.5 | 28 c | 21 b | 27 b |
| Curative' | 0.5 | 26 c | 22 b | 23 b |
| Preventive | 0.5 | 13.4 d | 19 b | 13 c |
| CV (%) | *** | 24.91 | 16.76 | 15.93 |

(1) Means followed by the same letters in the row and in the column do not differ in the Scott-Knott test with 5% of significance. TSW: thousand-seed weight. (2) Climate Vulnerability System (Plataforma Agroconnect). CV (%): Coefficient of variation. N/S: not significant.

*(1) Médias seguidas de letras iguais na linha e na coluna não diferem no teste de Scott-Knott com 5% de significância. TSW: peso de mil sementes. (2) Sistema de Vulnerabilidade Climática (Plataforma Agroconnect).CV (%): Coeficiente de variação. N/S: não significativo.*

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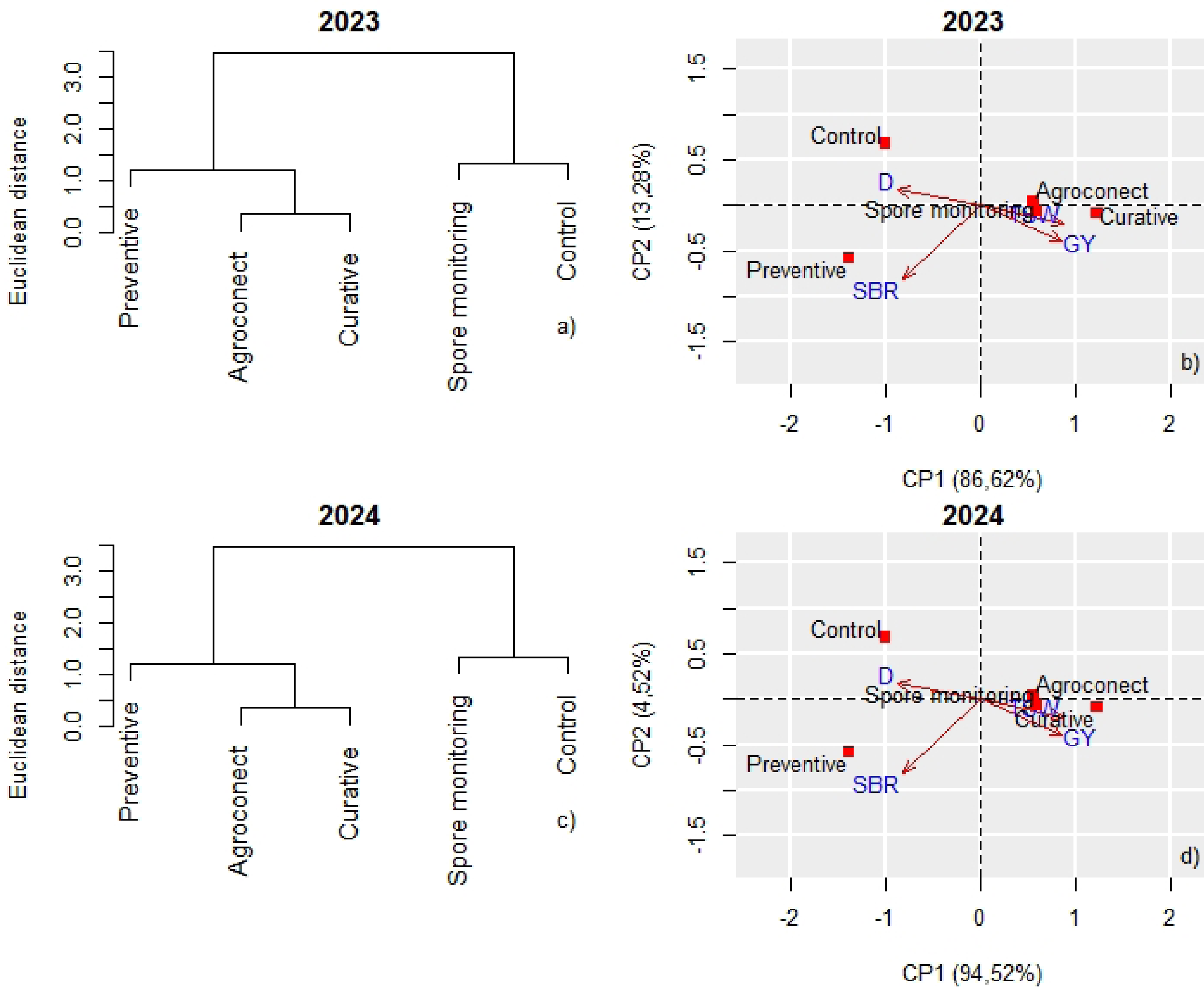


Figura 1. Dendrogramas (a e c) e gráficos Biplot (b e d) baseados nas médias das variáveis rendimento de grãos, peso de mil sementes, desfolha (%) e incidência de ferrugem asiática da soja (%) com base tratamentos avaliados nas safras 2023 e 2024 em Chapecó, Brasil.
*Figure 1. Dendrograms (a and c) and Biplot graphs (b and d) based on the averages of the variables: grain yield, thousand-seed weight, defoliation (%), and incidence of Asian soybean rust (%) based on treatments evaluated in two crop cycles (2022/2023- 2023/2024) of Chapecó, Brazil*

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