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Impacts of diverse chemical inputs on soybean disease dynamics and crop performance

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Abstract

Late-season diseases (LSDs) are among the most important biotic constraints on soybean yield, often requiring effective chemical management strategies to mitigate their impact on crop health and yield. In this context, this study was developed to evaluate the effectiveness of carboxamide-based fungicide programs in controlling LSDs in soybean. The experiment was carried out in Pinhalzinho, São Paulo, Brazil, using a randomized complete block design (RCBD) with five treatments and four replicates. Treatments consisted of four fungicide management programs including carboxamides and one untreated control (checkplots without application). Fungicide applications began 27 days after sowing (DAS) and were repeated at 15-days intervals following disease detection. Evaluated variables included disease severity, area under the disease progress curve (AUDPC), number of pods per plant, number of seeds per pod, grain yield (kg ha^{-1}), and thousand-grain weight. Data were analyzed using analysis of variance (ANOVA) and means were compared by Tukey's test ($p \leq 0.05$). Carboxamide-based treatments reduced the progression of target spot and brown spot. However, no differences among treatments were observed for yield components, including number of pods, thousand-grain weight, and grain yield. Overall, carboxamide-based fungicide programs effectively reduced disease severity but did not influence soybean yield.

Keywords: *Glycine max* (L.). Leaf diseases. Carboxamides. Integrated disease management.

Introduction

Soybean (*Glycine max* (L.)) is a cornerstone crop in global agriculture, not only due to its high yield potential but also because of its critical role in food security and the economies of numerous countries. In Brazil, soybean ranks among the leading export commodities, contributing substantially to national agricultural revenues (BERTAGNOLLI *et al.*, 2022). It is the world's primary oilseed crop, despite containing a higher proportion of protein (approximately 40 %) than lipids (around 19 %). Its elevated protein content makes it a key raw material for animal feed production, as well as a wide range of food products for human consumption. Simultaneously, its lipid profile renders it highly suitable for vegetable oil extraction and biodiesel production (HIRAKURI, LAZZAROTTO, 2014).

However, soybean cultivation is increasingly challenged by foliar diseases that may significantly compromise both yield and grain quality. Among the most damaging diseases are Asian soybean rust (*Phakopsora pachyrhizi*) and frogeye leaf spot (*Cercospora sojina*), which affect the crop at various developmental stages and can lead to yield losses of up to 80 % if not effectively managed (BARRO *et al.*, 2023; HOSSAIN *et al.*, 2024).

Successful soybean production hinges on a multitude of factors, among which foliar disease management is paramount. A critical step in effective disease control is a comprehensive understanding of the pathosystem, including pathogen survival strategies, dispersal mechanisms, inoculum sources, and epidemiological behavior-whether biotrophic, hemibiotrophic, or necrotrophic.

This knowledge is essential for making informed decisions regarding both chemical and biological control strategies (MEYER *et al.*, 2022).

Effective disease management requires integrated strategies that encompass a range of agronomic practices. Key approaches include the deployment of resistant cultivars, seed treatment, crop rotation, and the strategic application of fungicides with diverse modes of action. The judicious selection and rotation of active ingredients are crucial to minimizing the risk of pathogen resistance and ensuring long-term efficacy across growing seasons. Hence, the adoption of integrated pest management (IPM) practices, in conjunction with technological innovations such as fungicides and genetically resistant varieties, is vital to sustaining the economic viability of soybean farming (FERREYRA-SUAREZ *et al.*, 2024).

Environmental conditions, particularly temperature and humidity, further influence disease severity and the effectiveness of control measures. Continuous monitoring of weather conditions, supported by predictive modeling tools, can guide optimal fungicide application timing, thereby maximize control efficacy while minimize unnecessary costs for producers (SANTOS *et al.*, 2024).

In this context, the use of multifaceted strategies to control fungal diseases is essential for the sustainable production of soybeans. This study was developed to evaluate the effectiveness of various chemical management approaches in controlling foliar diseases in soybean, focusing on their impact on crop health and grain yield.

Material and methods

The experiment was carried out in the municipality of Pinhalzinho, São Paulo, Brazil (22°46'46" S, 45°35'26" W), at an altitude of 1,784 meters. The region is characterized by an oceanic climate without a dry season, with mild summers and an average annual temperature of 22 °C (ALVARES *et al.*, 2014). Experimental data were collected during the 2024/2025 soybean growing season.

The experimental design followed a randomized complete block design (RCBD) with five treatments (Table 1) and four replicates. Each experimental unit consisted of six rows, each seven meters long, spaced 0.45 meters apart, resulting in a total plot area of 18.9 m^2. The useful area of each plot was defined as the four central rows. The treatments comprised four fungicide management programs and one untreated control (checkplots without application). Fungicide applications began 27 days after sowing (DAS) and were carried out at 15-day intervals, following key soybean phenological stages, namely V 5 (five-node vegetative stage) and R1 (beginning bloom), with subsequent applications at R1 + 14 d and R1 + 28 d (14 and 28 days after R1), depending on the treatment schedule.

Sowing was performed on October 7, 2024, using the cultivar 55I57RSF IPRO (Brasmax Zeus, GDM Seeds), with a final target population of 300,000 seeds ha^{-1} (equivalent to 15 seeds per meter). Manual harvesting took place on March 22th, 2025. Prior to sowing, maintenance fertilization was performed using 400 kg ha^{-1} of single superphosphate (SSP) and 150 kg ha^{-1} of potassium chloride (KCl).

Fungicide applications were carried out at 27, 35, 49, and 63 DAS using a CO_2-pressurized backpack sprayer, with a spray volume of 150 L ha^{-1} and a three-meter boom. The spraying system was equipped with six flat-fan nozzles spaced 0.45 meters apart, each delivering approximately 8.5 mL s^{-1}. Operating pressure was maintained at 3 bar (Table 2).

Phenotypic evaluations

The following agronomic traits were evaluated:

Table 1. Description of treatments, chemicals, doses, and application timing for soybean cultivation.

Treatments	Chemicals	Dose (g a.i. ha^{-1})	Application timing
1	Checkplots without application	-	-
2	Propiconazole + Difenoconazole	38 + 38	V5
	Benzovindiflupir + Prothioconazole + Chlorothalonil	34 + 68 + 1080	R1
	Benzovindiflupir + Prothioconazole + Chlorothalonil	34 + 68 + 1080	R1+14
	Difenoconazole + Ciproconazole + Chlorothalonil	75 + 45 + 1080	R1+28
3	Mefentrifluconazole + Pyraclostrobin + Fluxapyroxad	80 + 107 + 53	V5
	Fluxapyroxad + Prothioconazole + Mancozeb	50 + 70 + 1125	R1
	Fluxapyroxad + Prothioconazole + Mancozeb	50 + 70 + 1125	R1+14
	Fenpropimorph + Mancozeb	225 + 1125 + 50	R1+28
4	Trifloxystrobin + Tebuconazole	50 + 100 + 63	V5
	Bixafem + Prothioconazole + Trifloxystrobin + Mancozeb	63 + 88 + 75 + 1125	R1
	Impirfluxam + Prothioconazole + Mancozeb	42 + 84 + 1125	R1+14
	Trifloxystrobin + Ciproconazole + Chlorothalonil	75 + 32 + 1080	R1+28
5	Difenoconazole + Chlorothalonil	75 + 1080 + 30	V5
	Impirfluxam + Tebuconazole + Mancozeb	30 + 100 + 1200	R1
	Impirfluxam + Tebuconazole + Mancozeb	30 + 100 + 1200	R1+14
	Difenoconazole + Chlorothalonil	75 + 1080	R1+28

Source: authors (2025).

Table 2. Climatic conditions during the scheduled applications in the 24/25 crop season.

Applications	Date	Relative humidity (%)	Wind speed (km. h^{-1})	Temperature (°C)
1st	11/23/2024	62	0.00	29.60
2nd	12/01/2024	80	1.50	28.70
3rd	12/15/2024	70	1.70	30.70
4th	12/29/2024	75	0.50	29.90

Source: authors (2025).

i. **Disease Severity (SEV):** visual assessments of disease severity were performed weekly from 42 to 77 DAS using standardized diagrammatic scales specific to each soybean disease. The following diseases were evaluated: target spot (*Corynespora cassiicola*) (SOARES *et al.*, 2009), Cercospora leaf blight (*Cercospora kikuchii*) (MARTINS *et al.*, 2004), brown spot (*Septoria glycines*), and Asian soybean rust (*Phakopsora pachyrhizi*) (GODOY *et al.*, 2006).

ii. **Number of Pods per Plant (NP):** at the R6 growth stage, 10 plants were randomly selected from the central rows of each plot for evaluation.

iii. **Number of Seeds per Pod (NSP):** also, at R6, 10 randomly selected plants per plot were assessed.

iv. **Area Under the Disease Progress Curve (AUDPC):** disease progression was quantified using the method proposed by Shaner and Finney (1977), as shown in Equation 1:

$$AUDPC = \sum_{i=1}^{n} \left[\frac{Y_{(i+1)} + Y_i}{2} x \left(T_{(i+1)} - T_i \right) \right] \quad (1)$$

where:
AUDPC: area under the disease progress curve;
Y_i: disease severity at evaluation time i;
$Y_{(i+1)}$: disease severity at evaluation time $i+1$;
T_i: evaluation time for i, in terms of the number of days between each evaluation;
$T_{(i+1)}$: evaluation time for $i+1$.

v. **Control Efficacy (E):** the percentage mortality recorded in the treated and checkplots without application groups was used to determine fungicide efficacy following ABBOTT's formula (1925), as described in Equation 2:

$$E = \frac{(Mc - Mt)}{(Mc)} * 100 = \left(1 - \frac{Mt}{Mc} \right) * 100 \quad (2)$$

where:
E = control efficacy;
Mt = mortality observed in the fungicide treatment;
Mc = mortality observed in the untreated control.

vi. **Grain Yield (GY):** after manual harvest of the useful plot rows, grain weight was measured in kilograms, standardized to 13 % moisture, and converted to yield per hectare (kg ha^{-1}).

vii. **Thousand-Grain Weight (TGW):** a sample of 1,000 seeds from each plot was counted manually and weighed using a precision scale, in accordance with the Brazilian Rules for Seed Testing (BRASIL, 2009).

Statistical analysis

Phenotypic data were subjected to descriptive and exploratory analyses, along with assumption tests for normality (SHAPIRO, WILK, 1965), homogeneity of variances (BARTLETT, 1937), and independence of errors (DURBIN, WATSON, 1950). Subsequently, the data were analyzed using analysis of variance (ANOVA), and when significant, means were compared using Tukey's test at a 5 % significance level ($p \leq 0.05$). All statistical analyses were conducted using the R computing environment (R Development Core Team, 2024).

Results and discussion

During the trial, the presence of target spot (*C. cassiicola*), Septoria brown spot (*S. glycines*), and purple seed stain (*C. kikuchii*) was identified. Asian soybean rust (*P. pachyrhizi*) was not detected. Low incidence of target spot was registered throughout the study. Symptoms began to appear at 49 days after sowing (DAS), with low severity and no statistically significant differences among treatments (Table 3).

A more pronounced progression of the disease was observed from 63 DAS onwards, when treatment 1 had higher severity (2.77 %) compared to the others. At 70 DAS, the highest disease severity was recorded, with treatment 1 reaching the highest mean. On the same date, no differences were observed among treatments with chemical interventions. At 77 DAS, phytosanitary treatments significantly reduced severity compared to the untreated control ($p \leq 0.05$). Although numerical variations were observed among treatments (ranging from 1.08 % to 1.51 %), no statistical differences were detected among application protocols.

Control efficacy against target spot was assessed across five evaluation dates (Figure 1). In all assessments, control efficacy was associated to all fungicide-treated treatments (T2 to T5). Table 3 also provides the data used to calculate the AUDPC (area under the disease progress curve), a parameter that integrates disease severity over time into a single value. AUDPC reflects the dynamics of a disease epidemic by representing its progression over time and may help characterize pathogen host environment interactions and forecast future disease levels.

For target spot, the highest disease progression was recorded for treatment 1, with an AUDPC of 83.26 %, differing from the other treatments, which were effective in reducing the pathogen's progression. Studies such as those by Soares *et al*. (2009) emphasize that

Table 3. Mean severity (%) of target spot (*Corynespora cassiicola*) in the lower third of soybean plants, evaluated at six different dates after sowing (DAS) for the 24/25 crop season.

Treatments	DAS					
	42[2]	49	56	63	70	77
11	0	0.16 a[3]	0.63 a	2.77 a	5.47 a	3.75 a
2	0	0.11 a	0.15 a	1.00 b	2.13 b	1.08 b
3	0	0.10 a	0.31 a	1.59 b	2.40 b	1.51 b
4	0	0.12 a	0.25 a	1.32 b	2.24 b	1.28 b
5	0	0.08 a	0.31 a	1.55 b	2.53 b	1.49 b
C.V (%)	-	96.98	98.54	19.15	32.01	74.13

[1]Treatments: 1 = untreated control. 2 = propiconazole + difenoconazole (38 + 38 g a.i. ha^{-1}, V 5); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + ciproconazole + chlorothalonil (75 + 45 + 1080 g a.i. ha^{-1}, R1 + 28 d). 3 = mefentrifluconazole + pyraclostrobin + fluxapyroxad (80 + 107 + 53 g a.i. ha^{-1}, V 5); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1 + 14 d); fenpropimorph + mancozeb (225 + 1125 + 50 g a.i. ha^{-1}, R1 + 28 d). 4 = trifloxystrobin + tebuconazole (50 + 100 + 63 g a.i. ha^{-1}, V 5); bixafen + prothioconazole + trifloxystrobin + mancozeb (63 + 88 + 75 + 1125 g a.i. ha^{-1}, R1); impirfluxam + prothioconazole + mancozeb (42 + 84 + 1125 g a.i. ha^{-1}, R1 + 14 d); trifloxystrobin + ciproconazole + chlorothalonil (75 + 32 + 1080 g a.i. ha^{-1}, R1 + 28 d). 5 = difenoconazole + chlorothalonil (75 + 1080 + 30 g a.i. ha^{-1}, V 5); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + chlorothalonil (75 + 1080 g a.i. ha^{-1}, R1 + 28 d); V 5 = five-node vegetative stage; R1 = beginning bloom; R1 + 14 d and R1 + 28 d = 14 and 28 days after R1; [2]Days after sowing; [3]Means followed by the same letter are not significantly different at the 5 % probability level according to Tukey's test.

Source: authors (2025).

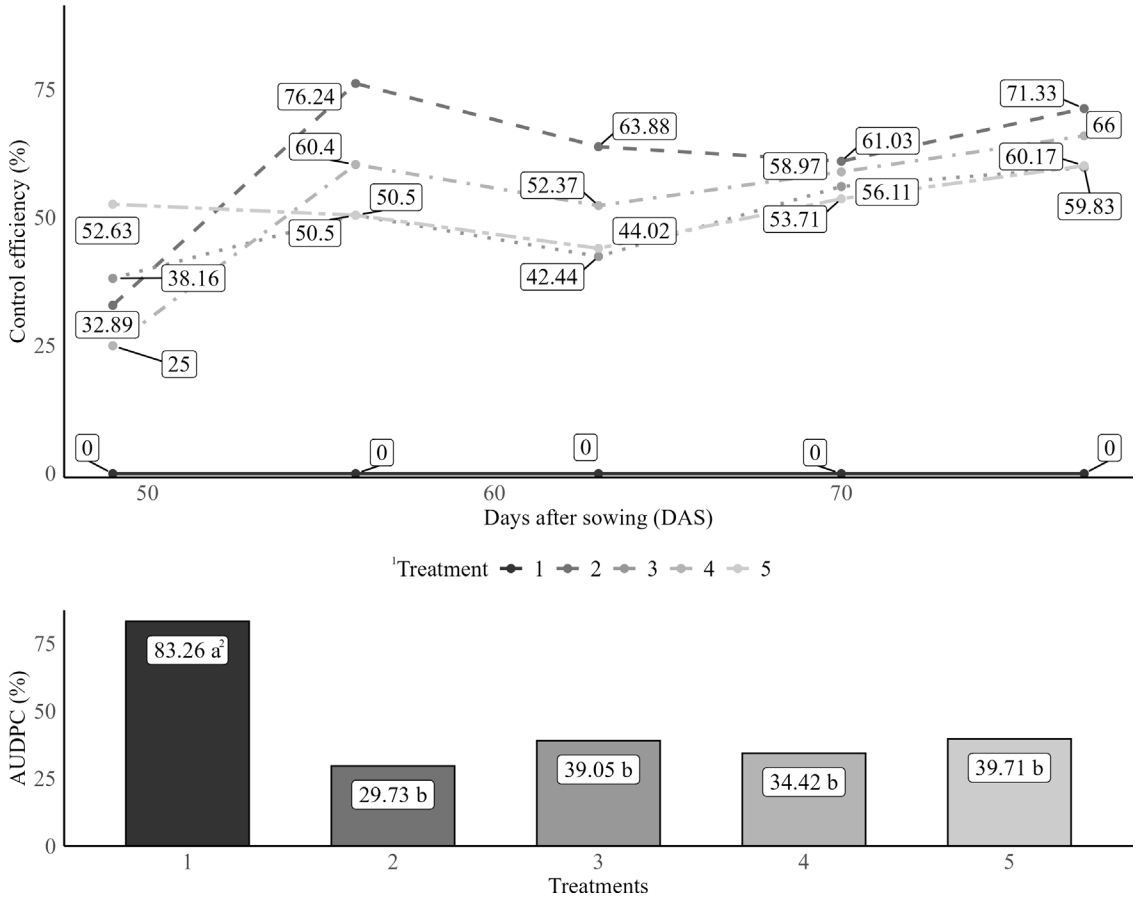
the occurrence of target spot is closely linked to prolonged leaf wetness periods, which were rare during the study due to drought stress.

The increased disease severity from 63 DAS onward indicates that even under unfavorable conditions, the pathogen may still establish during later stages of the crop cycle. The overall low severity observed reinforces the role of environmental factors in disease development, while also underscoring the importance of continuous monitoring, as the pathogen may become more problematic in wetter conditions (BASSO *et al.*, 2015; HARTMAN *et al.*, 2016).

Regarding brown spot (*S. glycines*), at 42 DAS treatments 3, 4, and 5 had significant differences compared to treatment 1 (Table 4). Treatment 2 showed intermediate behavior, not differing statistically from the untreated control (T1). At 49 DAS, the lowest severity was observed in treatment 2, which differed from remaining treatments. At 56 DAS, severity values ranged up 2.28 % in treatment 1, although no differences among treatments were detected. At 63 DAS, severity of 1.09 % was recorded in treatment 1, with no statistical difference from treatments 2, 4, and 5, which reached values of 0.64 %, 0.45 %, and 0.82 %, respectively. At the same date, treatment 3 stood out among the others, with lower means compared to T1. At 70 and 77 DAS, no differences among treatments were observed.

For brown spot, the greatest disease progression was recorded for treatment 1 (AUDPC of 47.81), whereas the other treatments with phytosanitary management showed lower values, with statistical differences compared to the control (T1) (Figure 2). Brown spot also had

Figure 1. Control efficacy (CE) calculated for target spot (*Corynespora cassiicola*) evaluated at five different dates after sowing (DAS) and area under the disease progress curve (AUDPC).



[1]Treatments: 1 = untreated control. 2 = propiconazole + difenoconazole (38 + 38 g a.i. ha^{-1}, V 5); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + ciproconazole + chlorothalonil (75 + 45 + 1080 g a.i. ha^{-1}, R1 + 28 d). 3 = mefentrifluconazole + pyraclostrobin + fluxapyroxad (80 + 107 + 53 g a.i. ha^{-1}, V 5); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1 + 14 d); fenpropimorph + mancozeb (225 + 1125 + 50 g a.i. ha^{-1}, R1 + 28 d). 4 = trifloxystrobin + tebuconazole (50 + 100 + 63 g a.i. ha^{-1}, V 5); bixafen + prothioconazole + trifloxystrobin + mancozeb (63 + 88 + 75 + 1125 g a.i. ha^{-1}, R1); impirfluxam + prothioconazole + mancozeb (42 + 84 + 1125 g a.i. ha^{-1}, R1 + 14 d); trifloxystrobin + ciproconazole + chlorothalonil (75 + 32 + 1080 g a.i. ha^{-1}, R1 + 28 d). 5 = difenoconazole + chlorothalonil (75 + 1080 + 30 g a.i. ha^{-1}, V 5); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + chlorothalonil (75 + 1080 g a.i. ha^{-1}, R1 + 28 d); V 5 = five-node vegetative stage; R1 = beginning bloom; R1 + 14 d and R1 + 28 d = 14 and 28 days after R1; [2]Means followed by the same letter are not significantly different at the 5 % probability level according to Tukey's test.

Source: authors (2025).

low severity throughout the study, likely due to the same adverse climatic conditions that limited target spot development. *S. glycines* is highly dependent on moisture and leaf wetness for dissemination and infection (HENNING *et al*., 2014; LIN, MEDEIROS, 2023). During the experiment, water deficit and high temperatures reduced disease incidence and severity.

Despite the low severity, the disease was observed in all assessments, indicating the pathogen's environmental presence, though

Table 4. Mean severity (%) of brown spot (*Septoria glycines*) in the lower third of soybean plants, evaluated at six different dates after sowing (DAS) for the 24/25 crop season.

Treatments	422	49	56	63	70	77
11	0.48 a[3]	0.98 a	2.28 a	1.09 a	1.81 a	0.75 a
2	0.18 ab	0.15 b	1.76 a	0.67 ab	0.58 a	0.29 a
3	0.10 b	0.28 a	0.97 a	0.24 b	1.00 a	0.11 a
4	0.09 b	0.33 a	0.91 a	0.45 ab	0.52 a	0.16 a
5	0.11 b	0.44 a	1.37 a	0.82 ab	0.83 a	0.28 a
C.V (%)	76.32	81.14	46.55	55.59	80.91	54.39

[1]Treatments: 1 = untreated control. 2 = propiconazole + difenoconazole (38 + 38 g a.i. ha^{-1}, V 5); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + ciproconazole + chlorothalonil (75 + 45 + 1080 g a.i. ha^{-1}, R1 + 28 d). 3 = mefentrifluconazole + pyraclostrobin + fluxapyroxad (80 + 107 + 53 g a.i. ha^{-1}, V 5); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1 + 14 d); fenpropimorph + mancozeb (225 + 1125 + 50 g a.i. ha^{-1}, R1 + 28 d). 4 = trifloxystrobin + tebuconazole (50 + 100 + 63 g a.i. ha^{-1}, V 5); bixafen + prothioconazole + trifloxystrobin + mancozeb (63 + 88 + 75 + 1125 g a.i. ha^{-1}, R1); impirfluxam + prothioconazole + mancozeb (42 + 84 + 1125 g a.i. ha^{-1}, R1 + 14 d); trifloxystrobin + ciproconazole + chlorothalonil (75 + 32 + 1080 g a.i. ha^{-1}, R1 + 28 d). 5 = difenoconazole + chlorothalonil (75 + 1080 + 30 g a.i. ha^{-1}, V 5); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + chlorothalonil (75 + 1080 g a.i. ha^{-1}, R1 + 28 d); V 5 = five-node vegetative stage; R1 = beginning bloom; R1 + 14 d and R1 + 28 d = 14 and 28 days after R1; ;[2]Days after sowing; [3]Means followed by the same letter are not significantly different at the 5 % probability level according to Tukey's test.

Source: authors (2025).

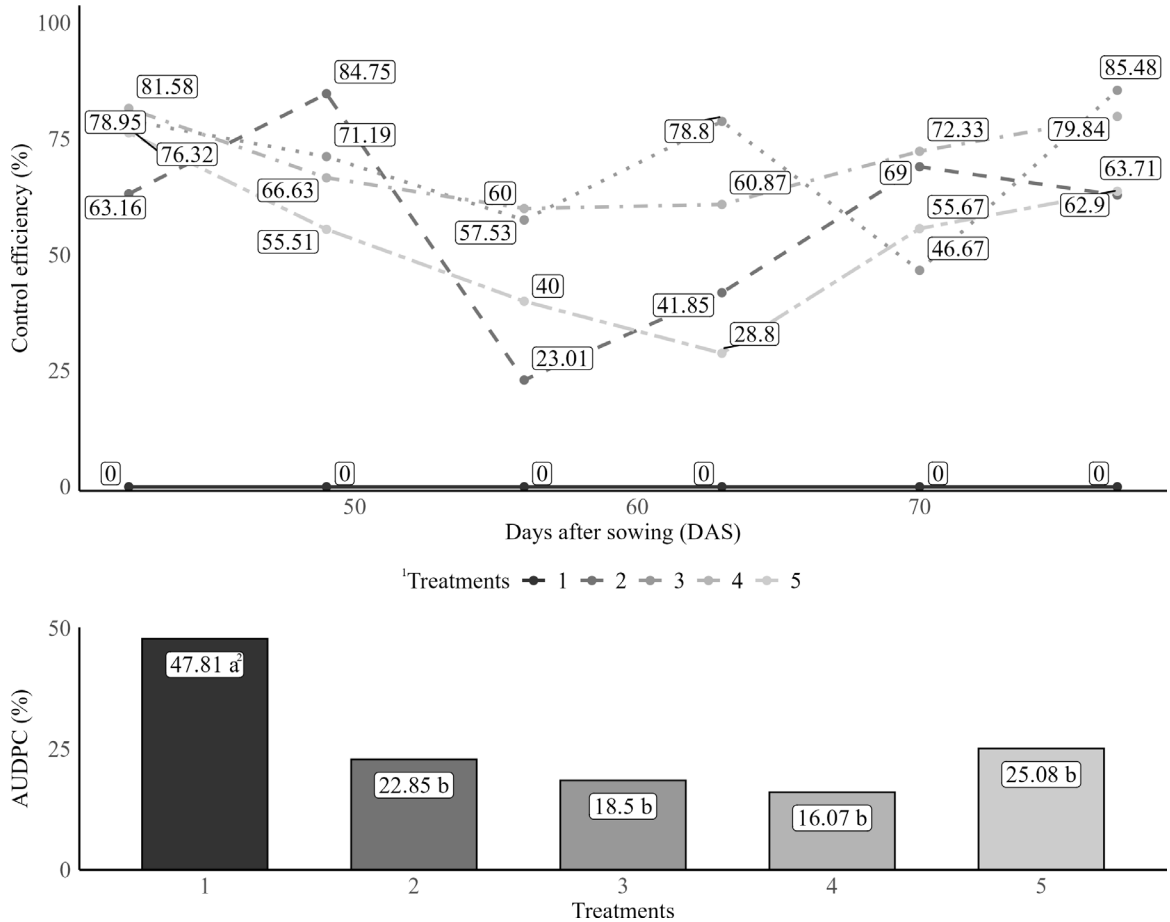
its progression was constrained by climatic conditions. As noted by Ito (2013), *S. glycines* may persist in the environment and be reintroduced in subsequent seasons. The presence of the pathogen, even at low severity, highlights the importance of management strategies to limit its spread, such as crop rotation and the removal of infected crop residues (SEIXAS *et al.*, 2020).

Incidence of purple seed stain (*C. kikuchii*) became evident at the end of the crop cycle, with assessments conducted at 100 DAS (Figure 3). The highest mean severity (5.13 %) was recorded in treatment 1, differing from the remaining treatments, which did not show significant variations among themselves. Purple seed stain tends to manifest in advanced stages of soybean development, especially under humid conditions and elevated temperatures (HARTMAN *et al.*, 2016). *C. kikuchii* can lead to premature defoliation and reduced photosynthetic capacity, compromising yield potential. This is a critical factor for soybean grain yield, as it limits the plant's ability to accumulate biomass (HARTMAN *et al.*, 2016). Therefore, early defoliation can significantly reduce yield, especially during critical phenological stages (GODOY *et al.*, 2006).

The low disease severity observed reinforces the importance of integrated management practices to reduce pathogen dissemination, along with the strategic use of fungicides during critical crop development stages—particularly when environmental conditions favor disease development (PRICE *et al.*, 2015; KASHIWA *et al.*, 2021).

Regarding the total number of pods and seeds per pod (Figure 4), no differences were observed for any of the evaluated variables. Although numerical variation was detected among treatments, these differences were not sufficient

Figure 2. Control efficacy (CE) calculated for brown spot (*Septoria glycines*) evaluated at six different dates after sowing (DAS) and area under the disease progress curve (AUDPC).



[1]Treatments: 1 = untreated control. 2 = propiconazole + difenoconazole (38 + 38 g a.i. ha^{-1}, V 5); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + ciproconazole + chlorothalonil (75 + 45 + 1080 g a.i. ha^{-1}, R1 + 28 d). 3 = mefentrifluconazole + pyraclostrobin + fluxapyroxad (80 + 107 + 53 g a.i. ha^{-1}, V 5); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1 + 14 d); fenpropimorph + mancozeb (225 + 1125 + 50 g a.i. ha^{-1}, R1 + 28 d). 4 = trifloxystrobin + tebuconazole (50 + 100 + 63 g a.i. ha^{-1}, V 5); bixafen + prothioconazole + trifloxystrobin + mancozeb (63 + 88 + 75 + 1125 g a.i. ha^{-1}, R1); impirfluxam + prothioconazole + mancozeb (42 + 84 + 1125 g a.i. ha^{-1}, R1 + 14 d); trifloxystrobin + ciproconazole + chlorothalonil (75 + 32 + 1080 g a.i. ha^{-1}, R1 + 28 d). 5 = difenoconazole + chlorothalonil (75 + 1080 + 30 g a.i. ha^{-1}, V 5); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + chlorothalonil (75 + 1080 g a.i. ha^{-1}, R1 + 28 d); V 5 = five-node vegetative stage; R1 = beginning bloom; R1 + 14 d and R1 + 28 d = 14 and 28 days after R1; [2]Means followed by the same letter are not significantly different at the 5 % probability level according to Tukey's test.

Source: authors (2025).

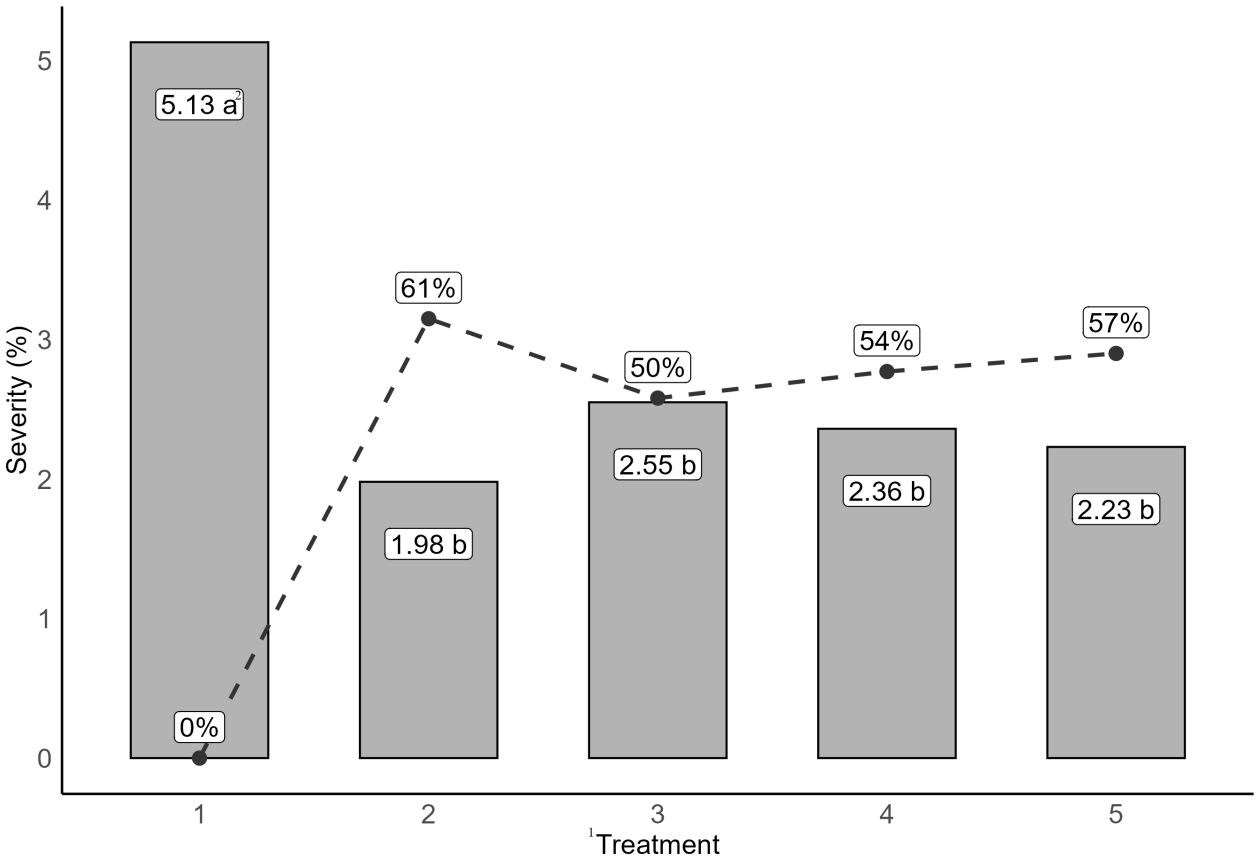
to distinguish them. Regarding the number of seeds per pod, no differences were observed, whereas treatment 3 reached the highest values for two-seed and four-seed pods. Furthermore, for three-seed pods and total pods, treatments maintained uniformity in yield components, indicating that the observed variations in disease levels were not sufficient to alter crop production.

For grain yield and 1000-grain weight (Figure 5), no differences were observed

among treatments. Grain yield ranged from 4,246.57 kg ha^{-1} in treatment 1 to 4,974.12 kg ha^{-1} in treatment 2, while 1000-grain weight varied from 176.25 g in T4 to 185.62 g in T3, with no significant differences among treatments.

Soybean yield was not influenced by foliar disease incidence (Figure 5). The low occurrence of foliar diseases, particularly target spot and purple seed stain, likely contributed to higher yields by minimizing premature defoliation and maintaining photosynthetic efficiency. Hartman

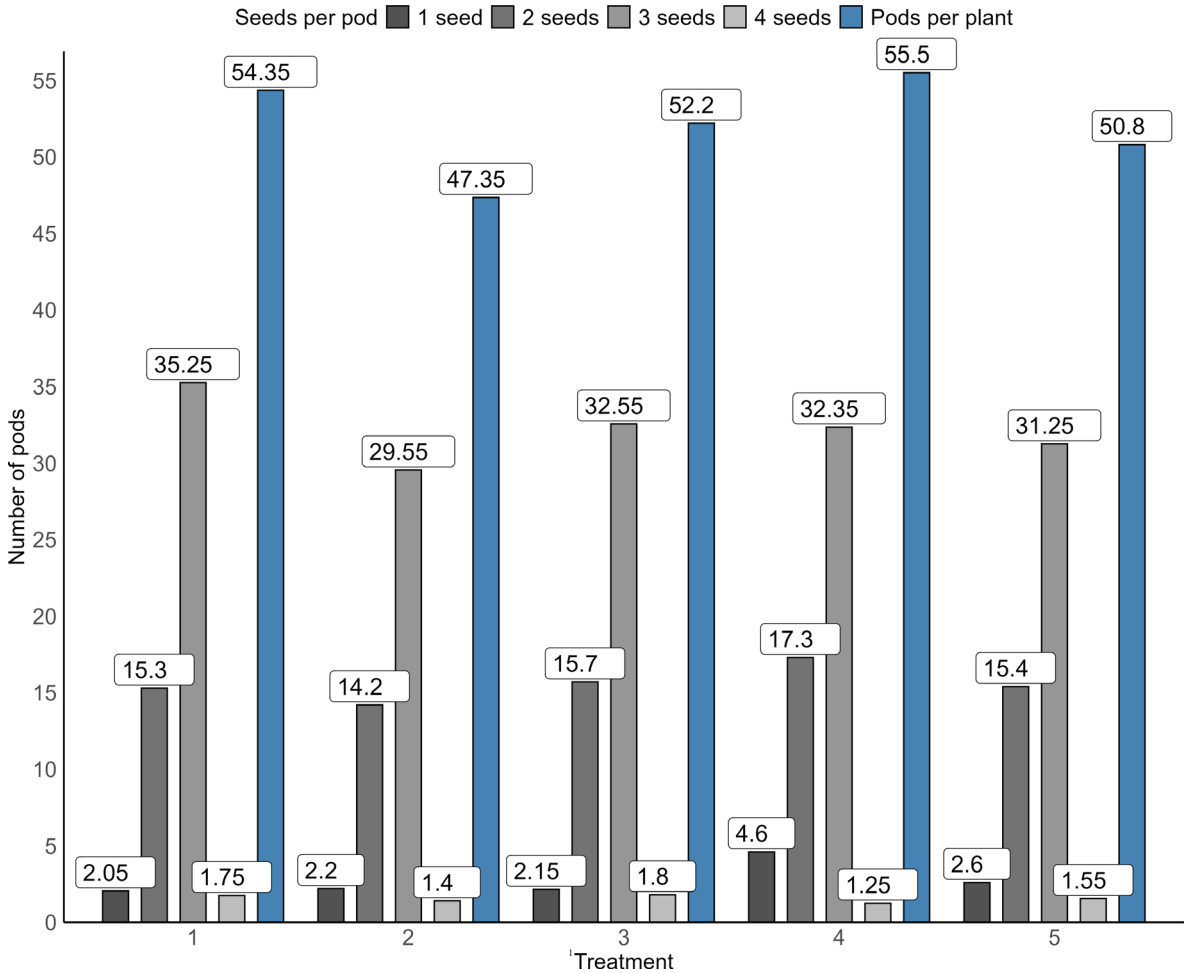
Figure 3. Mean severity (%) of leaf spot (*Cercospora kikuchii*) at 100 days after sowing (DAS) and percentage of control efficacy (%), for the soybean experiment in the 24/25 crop season.



[1]Treatments: 1 = untreated control. 2 = propiconazole + difenoconazole (38 + 38 g a.i. ha^{-1}, V 5); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + ciproconazole + chlorothalonil (75 + 45 + 1080 g a.i. ha^{-1}, R1 + 28 d). 3 = mefentrifluconazole + pyraclostrobin + fluxapyroxad (80 + 107 + 53 g a.i. ha^{-1}, V 5); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1 + 14 d); fenpropimorph + mancozeb (225 + 1125 + 50 g a.i. ha^{-1}, R1 + 28 d). 4 = trifloxystrobin + tebuconazole (50 + 100 + 63 g a.i. ha^{-1}, V 5); bixafen + prothioconazole + trifloxystrobin + mancozeb (63 + 88 + 75 + 1125 g a.i. ha^{-1}, R1); impirfluxam + prothioconazole + mancozeb (42 + 84 + 1125 g a.i. ha^{-1}, R1 + 14 d); trifloxystrobin + ciproconazole + chlorothalonil (75 + 32 + 1080 g a.i. ha^{-1}, R1 + 28 d). 5 = difenoconazole + chlorothalonil (75 + 1080 + 30 g a.i. ha^{-1}, V 5); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + chlorothalonil (75 + 1080 g a.i. ha^{-1}, R1 + 28 d); V 5 = five-node vegetative stage; R1 = beginning bloom; R1 + 14 d and R1 + 28 d = 14 and 28 days after R1;[2]Means followed by the same letter are not significantly different at the 5 % probability level according to Tukey's test.

Source: authors (2025).

Figure 4. Mean number of grains per pod and total number of pods evaluated at 85 days after sowing (DAS) for the soybean experiment in the 24/25 crop season.



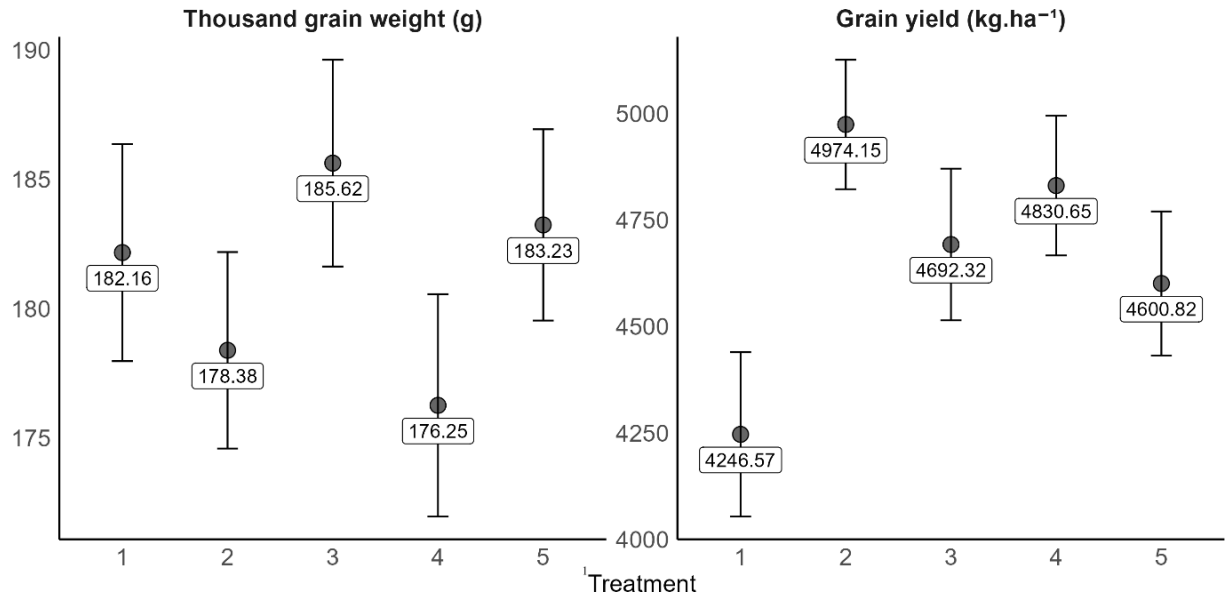
[1]Treatments: 1 = untreated control. 2 = propiconazole + difenoconazole (38 + 38 g a.i. ha^{-1}, V 5); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + ciproconazole + chlorothalonil (75 + 45 + 1080 g a.i. ha^{-1}, R1 + 28 d). 3 = mefentrifluconazole + pyraclostrobin + fluxapyroxad (80 + 107 + 53 g a.i. ha^{-1}, V 5); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1 + 14 d); fenpropimorph + mancozeb (225 + 1125 + 50 g a.i. ha^{-1}, R1 + 28 d). 4 = trifloxystrobin + tebuconazole (50 + 100 + 63 g a.i. ha^{-1}, V 5); bixafen + prothioconazole + trifloxystrobin + mancozeb (63 + 88 + 75 + 1125 g a.i. ha^{-1}, R1); impirfluxam + prothioconazole + mancozeb (42 + 84 + 1125 g a.i. ha^{-1}, R1 + 14 d); trifloxystrobin + ciproconazole + chlorothalonil (75 + 32 + 1080 g a.i. ha^{-1}, R1 + 28 d). 5 = difenoconazole + chlorothalonil (75 + 1080 + 30 g a.i. ha^{-1}, V 5); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + chlorothalonil (75 + 1080 g a.i. ha^{-1}, R1 + 28 d); V 5 = five-node vegetative stage; R1 = beginning bloom; R1 + 14 d and R1 + 28 d = 14 and 28 days after R1; [2]Means followed by the same letter are not significantly different at the 5 % probability level according to Tukey's test.

Source: authors (2025).

et al. (2016) emphasize that defoliation caused by foliar pathogens may significantly affect yield, especially during critical developmental stages.

No differences were observed among treatments for the 1000-grain weight, suggesting that although diseases may have affected yield

Figure 5. Soybean grain yield (kg ha^{-1}) and thousand grain weight (g) data.



[1]Treatments: 1 = untreated control. 2 = propiconazole + difenoconazole (38 + 38 g a.i. ha^{-1}, V 5); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1); benzovindiflupir + prothioconazole + chlorothalonil (34 + 68 + 1080 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + ciproconazole + chlorothalonil (75 + 45 + 1080 g a.i. ha^{-1}, R1 + 28 d). 3 = mefentrifluconazole + pyraclostrobin + fluxapyroxad (80 + 107 + 53 g a.i. ha^{-1}, V 5); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1); fluxapyroxad + prothioconazole + mancozeb (50 + 70 + 1125 g a.i. ha^{-1}, R1 + 14 d); fenpropimorph + mancozeb (225 + 1125 + 50 g a.i. ha^{-1}, R1 + 28 d). 4 = trifloxystrobin + tebuconazole (50 + 100 + 63 g a.i. ha^{-1}, V 5); bixafen + prothioconazole + trifloxystrobin + mancozeb (63 + 88 + 75 + 1125 g a.i. ha^{-1}, R1); impirfluxam + prothioconazole + mancozeb (42 + 84 + 1125 g a.i. ha^{-1}, R1 + 14 d); trifloxystrobin + ciproconazole + chlorothalonil (75 + 32 + 1080 g a.i. ha^{-1}, R1 + 28 d). 5 = difenoconazole + chlorothalonil (75 + 1080 + 30 g a.i. ha^{-1}, V 5); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1); impirfluxam + tebuconazole + mancozeb (30 + 100 + 1200 g a.i. ha^{-1}, R1 + 14 d); difenoconazole + chlorothalonil (75 + 1080 g a.i. ha^{-1}, R1 + 28 d); V 5 = five-node vegetative stage; R1 = beginning bloom; R1 + 14 d and R1 + 28 d = 14 and 28 days after R1; [2]Means followed by the same letter are not significantly different at the 5 % probability level according to Tukey's test.

Source: authors (2025).

components, grain size was not substantially influenced. According to Seixas *et al.* (2020), soybean grain yield results from the interaction among disease incidence, climatic conditions, and management practices. The low disease incidence observed in this study may have contributed to maintaining yield levels; however, adverse weather conditions likely also limited the crop's full productive potential.

Conclusion

The fungicide programs evaluated reduced the severity of soybean foliar diseases, including *Corynespora cassiicola*, *Septoria glycines*, and *Cercospora kikuchii*, during the crop cycle. Treatments including carboxamide-based fungicides, such as benzovindiflupyr, provided the highest levels of disease control, exceeding 60 % efficacy up to 56 days after sowing.

Despite the reduction in disease severity, no differences were observed among treatments for the number of pods, 1000-grain weight, or grain yield. Therefore, under the environmental and disease pressure conditions of this study, chemical disease management influenced foliar disease progression but did not affect yield components or final soybean productivity.

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