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Short note
Nota breve

COMBINATION OF FUNGICIDES AND RESISTANCE INDUCER FOR THE MANAGEMENT OF ASIAN SOYBEAN RUST

COMBINACIÓN DE FUNGICIDAS E INDUCTOR DE RESISTENCIA PARA EL MANEJO DE LA ROYA ASIÁTICA DE LA SOJA

Marco Maidana-Ojeda
Universidad Nacional de Itapúa, Facultad de Ciencias Agropecuarias y Forestales. Encarnación, Paraguay.
Orcid: https://orcid.org/0000-0001-5488-6255
Sergio Vázquez
Universidad Nacional de Itapúa, Facultad de Ciencias Agropecuarias y Forestales Encarnación, Paraguay.
Orcid: https://orcid.org/0009-0004-5233-5416
Sergio Figueredo
Universidad Nacional de Itapúa, Facultad de Ciencias Agropecuarias y Forestales Encarnación, Paraguay.
Orcid: https://orcid.org/0009-0005-8018-8342
Guillermo A. Enciso-Maldonado
Universidad Católica Nuestra Señora de la Asunción, Unidad Pedagógica Hohenau Hohenau, Paraguay.
Orcid: https://orcid.org/0000-0002-9528-7627
***Autor corresponsal**: Guillermo A. Enciso-Maldonado: guillermo.enciso@uc.edu.py*

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ABSTRACT
Between September 2018 and February 2019, an experiment was conducted in Pirapó, Paraguay, to assess the effectiveness of site-specific fungicides (Prothioconazole 17.5% + Trifloxystrobin 15%) and multisite fungicides (Mancozeb 80%), along with a resistance inducer (copper, manganese, zinc, boron, and amino acids), at different phenological stages of soybean to control rust and improve yield. A randomized complete block design was used with 13 treatments and four replications. The treatments varied in the combination and timing of product application. The severity of rust, control efficacy, defoliation, number of pods per plant, 100-grain weight, and yield were evaluated. The site-specific fungicides reduced the severity of rust at all phenological stages, whether applied alone or in combination with other products. No additional benefits were found by mixing multisite fungicides with resistance inducers. Treatments with only Mancozeb or inducer showed greater defoliation. Treatments T6 and T10 presented the highest number of pods per plant, though without statistically significant differences compared to other effective treatments. There were no differences in 100-grain weight, and the highest yields were observed in treatments T5 and T7.
Keywords: Glycine max L. Merril; Phakopsora pachyrhizi; mancozeb; chemical control.

RESUMEN
Entre septiembre/2018 y febrero/2019 se realizó un experimento en Pirapó, Paraguay, para evaluar la efectividad de fungicidas sitio-específicos (Protioconazol 17,5% + Trifloxistrobin 15%) y multisitios (Mancozeb 80%), junto con un inductor de resistencia (cobre, manganeso, zinc, boro y aminoácidos), en diferentes estadios fenológicos de la soja para controlar la roya y mejorar el rendimiento. Se utilizó un diseño experimental en bloques completos al azar con 13 tratamientos y cuatro repeticiones. Los

tratamientos variaron en la combinación y el momento de aplicación de los productos. Se evaluó la severidad de la roya, eficacia de control, defoliación, número de vainas/planta, peso de 100 granos y rendimiento. Los fungicidas sitio-específicos redujeron la severidad de la roya en todos los estadios fenológicos, aplicados solos o en combinación con otros productos. No se encontraron beneficios adicionales al mezclar fungicidas multisitios con inductores de resistencia. Los tratamientos solo con Mancozeb o inductor mostraron mayor defoliación. Los tratamientos T6 y T10 presentaron el mayor número de vainas/planta, aunque sin diferencias estadísticas significativas respecto a otros tratamientos eficaces. No hubo diferencias en el peso de los 100 granos, y los rendimientos más altos se observaron en los tratamientos T5 y T7.
Palabras clave: Glycine max L. Merril; Phakopsora pachyrhizi; mancozeb; control químico.

SHORT NOTE

Asian soybean rust (ASR), caused by the fungus *Phakopsora pachyrhizi*, is one of the most destructive diseases affecting soybean crops in subtropical and tropical regions of Asia, Africa, Oceania, and the Americas[1]. This disease is noted for the complexity of its plant-pathogen interaction, complicating initial phases of diagnosis, quantification, and loss estimation[2]. It is characterized by high virulence and rapid epidemiological progression, leading to accelerated chlorosis, senescence, and defoliation, which can result in severe damage. Since its initial detection in Paraguay, the disease has spread to Bolivia, much of Brazil, and regions in Argentina, such as Formosa and Chaco. In Brazil, during the 2002 and 2003 campaigns, losses were estimated at approximately 4.011 million tons of soybeans[3,4].
The predominant management of this disease is using fungicides, applying them to the foliage as soon as the first symptoms are detected[5,6]. The effectiveness of fungicide control critically depends on accurate diagnosis, the type and dose of fungicide, disease severity, timely application, and proper distribution and deposition of the product on the target[7].

To combat this disease, fungicides such as sterol synthesis inhibitors (DMI), quinone inhibitors (QoI), and succinate dehydrogenase inhibitors (SDHI) have been used. However, repeated use of these compounds has led to the development of resistant populations, necessitating new strategies to mitigate resistance[4,8]. According to Mendoza-Duarte et al.[9], one strategy to prevent resistance includes combining a multisite fungicide such as chlorothalonil, mancozeb, or copper oxychloride with site-specific fungicides like triazoles, strobilurins, and carboxamides. However, this approach increases production costs, underscoring the importance of deciding the most appropriate time to include, for example, mancozeb in combinations with site-specific fungicides[4].

This study aims to evaluate the efficacy of a site-specific fungicide combined with a multisite fungicide and a resistance inducer for managing soybean rust and its impact on yield.

The experiment was conducted in the district of Pirapó, Itapúa, Paraguay (26° 51' 57" S and 55° 37' 55" W) at an altitude of 218 meters above sea level, on a soil classified as Rhodic Kandiudox with fine clay texture[10]. The study period spanned from September 2018 to February 2019.

The experimental design was a randomized complete block with 13 treatments and four replications. Each experimental unit consisted of eight rows, each six meters long. Rows were spaced 0.45 meters apart, with 12 seeds planted per linear meter. A one-meter space was left between each block. The useful area consisted of the four central rows, each five meters long, totaling 9 m². The soybean cultivar used was NA 5909 RG.

Treatments involved the application of a combination of fungicide Prothioconazole 17.5% + Trifloxystrobin 15% at a dose of 400 mL/ha, Mancozeb 80% at 1 kg/ha, and a resistance inducer based on copper, manganese, zinc, boron, and amino acids (0.2 L/ha) at different stages of crop development (Table 1).

Treatment application was performed using a motorized backpack sprayer at a constant pressure of 4 bar, with conical nozzles and a flow rate of 150 L/ha of water. Application conditions were temperatures of 25-30° C, relative humidity above 80%, and wind speed less than 10 km/h.

Treatments	Description
T1	Control
T2	Mancozeb at R1, R3 and R5 stages
T3	Resistance inducer at R1, R3 and R5 stages
T4	Fungicide at R1, R3 and R5 stages
T5	Fungicide + Mancozeb at R1, R3 and R5 stages
T6	Fungicide + Resistance inducer at R1, R3 and R5 stages
T7	Fungicida + Mancozeb + Resistance inducer at R1, R3 and R5 stages
T8	Mancozeb + Resistance inducer at R1, R3 and R5 stages
T9	Resistance inducer at R1stage, and Fungicide at R3 and R5 stages
T10	Fungicide + Resistance inducer at R1 stage, Fungicida + Mancozeb at R3 and R5 stages
T11	Fungicide + Resistance inducer at R3 stage and Fungicide at R5 stage
T12	Fungicide + Mancozeb at R3 and R5 stages
T13	Fungicide at R3 and R5 stages

***Table 1**. Treatments applied at different phenological stages for the management of soybean rust in Pirapó, Itapúa, Paraguay.*

The management of the experimental plot began with desiccation using 2 kg/ha of glyphosate (88.8%) applied 14 days before planting. Sowing occurred on September 21, 2018, using a direct seeding planter that also facilitated single-grain dosing and application of 07-20-10 fertilizer at a dose of 140 kg/ha. Seed treatment included a mix of Fipronil 18% + Imidacloprid 36at 200 mL/100 kg of seeds and Fludioxonil 2.5% + Metalaxyl-M 2% + Tiabendazol 15% at 150 mL/100 kg of seeds, along with a legume bio-stimulant, containing 0.5% cobalt, and 3% molybdenum (100 mL/100 kg of seeds).

Ten days after plant emergence (DDE), clethodim 24% at 1 L/ha was applied to control *Digitaria insularis* grass. At 32 DDE, glyphosate 67.9% potassium salt at 1.5 L/ha was used to manage broadleaf weeds. Fungicide applications according to designated treatments were made at stages R1 (November 16), R3 (December 6), and R5 (December 26). For the control of the soybean looper (*Chrysodeixis includens*), lambda-cyhalothrin 16% + tiametoxan 22% at 0.25 l/ha was applied at 10 DDE, and emamectin benzoate 11.4% + lufenuron 40% at 100 mL/ha at 32 and 69 DDE. At 49 DDE, to manage brown stink bug (*Euschistus heros*), imidacloprid 30% + alpha-cypermethrin 10% at 0.1 L/ha was used, and at 89 DDE, thiamethoxam 75% at 100 g/ha + bifenthrin 20% at 100 mL/ha was applied. Harvesting and threshing were manually performed on February 11, 2020, 135 days after emergence.

Severity was assessed 15 days after the application of the last fungicide treatment. For this, 10 leaves from each third of the plant (lower, middle, and upper) were selected from each experimental unit to verify the presence of symptoms and confirm sporulation using a 60x magnifying glass. Observations were compared against the diagrammatic scale of Godoy et al.(11). The percentage reduction in severity for fungicide treatments compared to the control was calculated using the following formula: Control Efficacy (%) = 100 - [100 x (Severity in treatment / Severity in control)](12).

Defoliation was assessed by visual observation 20 days after the last fungicide application, using the scale of Hirano et al.(13).

At harvest, 10 plants from each experimental unit were selected to quantify the number of pods by counting the total per plant. To determine 100-grain weight, 100 units of grains were collected and weighed using a precision scale with 0.001 g sensitivity. Finally, yield in kg/ha was calculated manually by cutting and threshing the grains. These were weighed on a precision scale capable of up to 30 kg. The moisture content of the grains was adjusted to 14%, and the yield was expressed in kg/ha using the formula: Yield = (field weight / harvested area in m2) x 10,000 x (100 - grain moisture) / 87).

The data were organized using Excel spreadsheets and analyzed through an analysis of variance (ANOVA) using the InfoStat software(14), to determine whether there were significant differences between the treatments. For the data on severity, efficacy, and defoliation, an arcsine transformation was applied. Where significant differences were identified, a comparison of means was conducted using Tukey's test at the 5% level.

The F-test analysis reveals significant differences between treatments regarding disease severity, highlighting the impact of various treatments on disease control. Treatment T4 demonstrated superior efficacy, reducing severity to just 0.8%, a result that aligns with its high control efficacy (92.8%). This finding is consistent with studies that emphasize the effectiveness of site-specific fungicides in managing soybean rust by reducing disease severity and improving plant health (8,10). Similarly, treatments T5, T7, and T10 also recorded low severity levels (ranging from 1.8% to 2.3%) and achieved efficacy rates above 80%. This suggests that these treatments are particularly effective in controlling soybean rust, likely due to their active ingredients and timing of application, which aligns with findings in the literature that stress the importance of optimized fungicide programs[15]. In contrast, the control treatment (T1) showed the highest severity at 14.7%. The moderate efficacy observed in other treatments (ranging from 39.8% to 69.0%) indicates variability in treatment effectiveness, which could be due to differences in timing and frequency of application[16].

Defoliation is a critical variable as it directly affects the photosynthetic capacity of the soybean plants[17,18]. Treatments T7 and T9 demonstrated the lowest defoliation rates (around 12%), indicating their effectiveness in preserving foliage under disease pressure. This result is consistent with the findings that suggest certain fungicide treatments can significantly reduce defoliation, thereby maintaining plant vigor and yield potential[19]. In contrast, the control treatment (T1), which experienced the highest severity, also exhibited the highest defoliation (27.5%), underscoring the relationship between disease severity and leaf loss.

Treatments	Severity (%)	Control efficacy (%)	Defoliation (%)
T1	14.7 e	0.0 a	27.5 c
T2	8.8 cde	39.8 abc	22.0 abc
T3	10.3 de	28.5 abc	19.3 abc
T4	0.8 a	92.8 d	13.8 ab
T5	2.2 ab	84.0 cd	13.8 ab
T6	4.9 bcd	65.5 cd	13.3 ab
T7	2.3 abc	82.5 cd	12.0 a
T8	8.0 cde	55.5 bcd	12.8 ab
T9	4.4 bcd	69.0 cd	11.8 a
T10	1.8 ab	88.3 cd	14.8 ab
T11	5.2 abcd	63.5 cd	15.0 ab
T12	6.0 bcde	59.8 cd	19.5 abc
T13	6.4 bcde	54.8 bcd	23.8 bc
Media	**5.8**	**59.5**	**16.8**
FC	**9.6****	**8.9****	**4.9****
CV (%)	**28.7**	**32.0**	**14.3**

Table 2. *Treatment efficacy on soybean rust: severity, control efficacy, and defoliation percentages.*

Regarding the variables related to soybean productivity, the analysis of variance indicates that there are significant differences between treatments for the number of pods per plant and yield, while no effect is observed on the 100-grain weight (Table 3). The number of pods per plant is an important yield component. The analysis revealed significant differences among treatments, with T5, T7, and T10 producing the highest number of pods, suggesting these treatments may enhance reproductive success in soybeans. These results align with studies indicating that certain fungicides, when applied at critical growth stages, can improve the reproductive output of soybean plants by reducing disease pressure[20]. The lower number of pods in other treatments may reflect suboptimal control of disease or stress factors that impact flowering and pod set[21,22].

The uniformity in 100-grain weight across treatments suggests that fungicidal treatments did not significantly impact grain size. The non-significant F-test result (FC 1.10) corroborates this, indicating that the treatments did not alter the final grain weight, which could be attributed to the inherent genetic potential of the soybean variety used rather than the external treatments[(23)]. This result aligns with existing literature where grain weight remains unaffected by disease management strategies unless severe defoliation occurs during grain filling[(21,22,24)].

Yield showed significant differences among treatments, with T7, T5, and T10 achieving the highest yields. This suggests that these treatments are most effective in enhancing soybean productivity, likely due to their superior disease control and maintenance of plant health. This results are consistent with studies that highlight the yield benefits of effective rust management using integrated fungicide programs[(4,9,10,15,20,24)]. The moderate coefficient of variation (CV 8.99%) for yield reflects the expected variability in agricultural field trials, yet it also suggests that the treatments were generally effective under the given conditions[(25,26)].

Tratamientos	Pods per plant	100-grain weight (g)	Yield (Kg/ha)
T1	34,5 a	13,6	2613 a
T2	36,3 a	13,8	2972 a
T3	37,6 ab	14,0	2755 a
T4	39,4 abc	13,9	3164 abc
T5	43,8 bc	13,6	3859 cd
T6	34,9 a	14,1	3181 abc
T7	45,3 a	14,1	3984 d
T8	36,7 a	14,0	3062 ab
T9	35,5 a	13,5	3214 abc
T10	45,0 c	14,0	3609 bcd
T11	34,8 a	13,8	3098 ab
T12	40,2 abc	13,9	3324 abcd
T13	35,7 a	13,8	3047 ab
Media	38,4	13,8	3222
FC	2,74**	1,10ns	7,45**
CV (%)	12,43	2,69	8,99

Table 3. *Treatment effects on pod per plant, 100-grain weight, and yield.*

The integrated management strategy employing a combination of site-specific and multisite fungicides with resistance inducers represents a promising approach to managing asian soybean rust in soybean crops. It ensures effective disease control, preserves plant health, and enhances yield, which is crucial for maintaining the viability of soybean production in regions prone to asian soybean rust. Further research should focus on refining application timings and exploring the economic implications of these integrated approaches to optimize their practical application in field settings.

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