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ORIGINAL ARTICLE

# Copper penetrant-mobile complex as a potential fungicide enhancer for Asian soybean rust

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ABSTRACT

Lima, J.V.O.; Cunha, J.P.A.R.; Silva Júnior, M.B. **Copper penetrant-mobile complex as a potential fungicide enhancer for Asian soybean rust. *Summa Phytopathologica*,** v.52, p.1-7, 2026.

Asian soybean rust remains one of the major diseases affecting soybean crops in Brazil. The reduced efficacy of some fungicides has led to the search for a better control of this disease. One strategy is to optimize the movement of fungicides to the lower parts of the canopy, which are more challenging to be reached by spraying. The objective of the present study was to evaluate the performance of three commercial fungicides, either alone or in combination with the copper penetrant-mobile complex. This product can enhance the fungicides by improving the translocation of active ingredients. Disease severity (upper and lower canopy) and soybean yield were evaluated in two consecutive seasons (2021/2022 and 2022/2023) after four applications of treatments. The copper penetrant-mobile complex combined with the fungicides prothioconazole + trifloxystrobin + bixafen and tebuconazole + picoxystrobin + mancozeb reduced (but not alone) the disease severity (upper and lower canopy), improving the disease management and increasing the soybean yield for two seasons, besides highlighting a strong correlation between these two variables analyzed.

**Keywords:** pesticide technology application; *Phakopsora pachyrhizi*; phytopathology; systemicity.

RESUMO

Lima, J.V.O.; Cunha, J.P.A.R.; Silva Júnior, M.B. **Complexo penetrante-móvel de cobre como potencializador de fungicidas para ferrugem asiática da soja. *Summa Phytopathologica*,** v.52, p.1-7, 2026.

A ferrugem asiática da soja continua sendo uma das principais doenças que afetam a cultura da soja no Brasil. A reduzida eficácia de alguns fungicidas tem levado à busca por melhor controle desta doença. Uma dessas estratégias é otimizar a movimentação dos fungicidas para as partes inferiores das plantas de soja, dossel vegetativo este com maior dificuldade de cobertura pelas pulverizações fitossanitárias. Os objetivos deste estudo foram avaliar o desempenho de três fungicidas comerciais, isoladamente e em combinação com o complexo penetrante-móvel de cobre. Este produto pode potencializar os fungicidas, melhorando a translocação dos princípios ativos. Este estudo avaliou a severidade da doença (dossel superior e inferior) e a produtividade da soja em duas safras consecutivas (2021/2022 e 2022/2023) após quatro aplicações dos tratamentos. O complexo químico sistêmico de cobre combinado com os fungicidas protioconazole + trifloxistrobina + bixafeno e tebuconazol + picoxistrobina + mancozebe reduziu (porém não isoladamente) a severidade da doença (dossel superior e inferior), melhorando o manejo da doença e aumentando a produtividade da soja por duas safras, com forte correlação entre estas duas variáveis analisadas.

**Palavras-chave:** tecnologia de aplicação de agroquímicos; *Phakopsora pachyrhizi*; fitopatologia; sistemicidade.

More than two decades after its first outbreak (22), Asian soybean rust (ASR; *Phakopsora pachyrhizi*) still remains one of the major diseases affecting soybean crops in Brazil. It has been a constant concern for the production chain, potentially causing yield losses of up to 90% (8). The challenges posed by ASR in Brazil are numerous; thus, a combination of regulatory and genetic strategies, as well as proper crop management, is necessary (7).

Fungicide applications by rotating chemical groups remain the best alternative (12). However, the lower efficacy of some active ingredients has led to the search for new disease control measures. Starting from the 2007/2008 crop season, some triazoles had their efficacy reduced (9).

The reduction in application volumes by soybean growers represents a challenging scenario (13). One of the issues in soybean application technology is to ensure that the sprayed droplets penetrate the upper leaf mass of the plants. Fungicides must overcome these barriers to achieve good coverage (4), ideally reaching all leaf areas of the plants, including the lower canopy (18). New strategies need to be sought to improve deposition of sprays on the lower part of the crop (19).

Choosing active ingredients that have better translocation to the lower parts of soybean plants and improved redistribution constitutes an alternative. Selecting products with better redistribution in plants can optimize phytosanitary management (21). Thus, the present study examined the copper penetrant-mobile complex (CuPMC) by testing the commercial product Fulland®, registered with MAPA as a copper foliar fertilizer. According to the manufacturer and patent holder of this formulation, its production involves the molecular fusion of various active ingredients and additives, providing high systemic activity and enabling its upward and downward movement through the plants, something still not well understood.

The objectives of the present study were to evaluate the performance of CuPMC in managing Asian soybean rust and to determine whether this product interacts positively with three fungicide formulations widely used in the market.

## MATERIALS AND METHODS

Two trials were conducted during the 2021/2022 and 2022/2023 growing seasons, at "Fazenda Novo Horizonte", located in Araxá, Minas Gerais State (MG), Brazil, at 19°33'6.70" S, 46°52'37.56" W and average altitude of 998 m. The local climate is classified as Cwa; average annual precipitation is 1.185 mm and the average annual temperature is 20.7°C. The three commercial fungicides evaluated were applied either alone or in combination with the CuPMC to field-grown plants. The used soybean cultivar was Brasmax Desafio RR 8473RSF (maturity group 7.4, medium cycle of 118 days, and plant density of 360,000 plants $ha^{-1}$).

Both sowing procedures were late so that the plants would be green during periods of *Phakopsora pachyrhizi* inoculum pressure, allowing the disease progression analysis in the field. In the 2021/2022 season, the soybean was planted in early January 2022. In the 2022/2023 season, seeding occurred in the second half of December 2022.

The trials were established in a randomized block design with a double factorial arrangement (2 x 4) and four replicates. The plots consisted of 4 planting rows of 5.0 m long each (10.0 m²), and the useful area comprised the 4 central meters of the 2 middle rows (4 m²). The first factor was the addition or absence of CuPMC. The second factor was three commercial fungicide products: 1) Blindado® (tebuconazole + picoxystrobin + mancozeb); 2) Fox Xpro® (prothioconazole + trifloxystrobin + bixafen); 3) Orkestra® (fluxapyroxad + pyraclostrobin), and 4) control with no fungicides. All adjuvants were added to the tank-mix at the levels recommended by the manufacturers, following the practices adopted at the field (Table 1).

The tested CuPMC was the commercial product Fulland®, a foliar fertilizer containing 3.5% copper and 1.33 g $mL^{-1}$ density. It was obtained through the molecular fusion of active ingredients and additives; this process remains a trade secret. Except for fungicide management, all other cultural practices followed the standard procedures for a commercial cultivation area.

All experimental plots received 4 applications of the same products during the phenological stages $V_N$, $R_1$, $R_3$, and $R_5$ (Table 1), at 15-day intervals. The treatments were applied with a $CO_2$ pressurized sprayer, operating at 300 kPa, 3.15 km $h^{-1}$ working speed, 0.84 L $min^{-1}$ flow rate, and 100 L $ha^{-1}$ application rate. A 2-meter boom was equipped with 4 flat-fan nozzles, model BD 110.02 from Magnojet®, spaced 50 cm apart.

Only the plants in the 2 central rows of each plot (10 linear meters with 160 plants) were considered useful for evaluation. The 2 parallel rows adjacent to these central rows were used as borders. The following variables were evaluated: 1) ASR severity on the lower part of the

**Table 1**. Treatments studied in the experiment.

| CuPMC | Rate L $ha^{-1}$ | Fungicide | Rate L $ha^{-1}$ | Application Stages |
|---|---|---|---|---|
| Fungicides alone | - | Control (no fungicides) | - | - |
| | | tebuconazole + picoxystrobin + mancozeb | 2.250 | $V_N$; $R_1$; $R_3$; $R_5$ |
| | | prothioconazole + trifloxystrobin + bixafen | 0.500 | $V_N$; $R_1$; $R_3$; $R_5$ |
| | | fluxapyroxad + pyraclostrobin | 0.350 | $V_N$; $R_1$; $R_3$; $R_5$ |
| CuPMC + fungicides | 0.500 | Control (CuPMC alone) | - | $V_N$; $R_1$; $R_3$; $R_5$ |
| | | tebuconazole + picoxystrobin + mancozeb | 2.250 | $V_N$; $R_1$; $R_3$; $R_5$ |
| | | prothioconazole + trifloxystrobin + bixafen | 0.500 | $V_N$; $R_1$; $R_3$; $R_5$ |
| | | fluxapyroxad + pyraclostrobin | 0.350 | $V_N$; $R_1$; $R_3$; $R_5$ |

**Key:** CuPMC: copper penetrant-mobile complex (P.C. Fulland®); tebuconazole + picoxystrobin + mancozeb (P.C. Blindado®) associated with 0.500 L $ha^{-1}$ adjuvant soy methyl ester (P.C. Rumba®); prothioconazole + trifloxystrobin + bixafen (P.C. Fox Xpro®) associated with 0.375 L $ha^{-1}$ adjuvant soy methyl ester (P.C. Aureo®); fluxapyroxad + pyraclostrobin (P.C. Orkestra®) associated with 0.500 L $ha^{-1}$ adjuvant non-ionic mineral oil (P.C. Assist®).

plants; 2) ASR severity on the higher part of the plants; 3) final ASR severity (average of higher and lower part of the plants), and 4) yield.

Severity was calculated from the AUDPC (lower canopy, higher canopy, and final severity – based on the lower and higher average); 8 plants per plot in the central part of the 2 middle rows were evaluated. Visual severity ratings for rust were assigned to 2 trifoliates from the upper part and 2 trifoliates from the lower part of the plants, totaling 6 leaflets assessed in each part of the plants. Six severity assessments were conducted, using the diagrammatic scale referenced by Godoy et al. (10). All AUDPC were calculated from the ASR severity data for the treatments, according to Shaner & Finney (16). Based on severities, control was determined according to Abbott's method (1).

At stage $R_7$ (physiological maturity), desiccation was performed for earlier harvest, using the herbicide Diquat at 2.0 L $ha^{-1}$. Three days after desiccation, all remaining plants from the useful plot area were manually harvested using a threshing grain harvester. Before threshing, the number of plants per plot was determined, and the yield was calculated by converting the harvested plants to a density of 360,000 plants $ha^{-1}$.

The following data checks were performed: normality, according to Kolmogorov-Smirnov test ($p \geq 0.05$); homoscedasticity of variances, according to Levene's test ($p \geq 0.05$), and block additivity, according to Tukey's test ($p \geq 0.05$). For assumptions that were not met, the original data were transformed to $\sqrt{((x)+1)}$. Data were processed using the software R Core Team (14) and ANOVA. Tukey's test ($p \leq 0.05$) was used for comparison of treatment means.

Pearson's correlation coefficient (also using R Core Team) was calculated between total ASR severity (average of lower and upper canopy) and soybean productivity as Kg $ha^{-1}$. Values between -1.0 (representing perfect negative correlation between the two variables) and 1.0 (representing perfect positive correlation between the two variables) were accepted.

## RESULTS AND DISCUSSION

Considering ASR severity in the lower part of the plants, the treatments tebuconazole + picoxystrobin + mancozeb, prothioconazole + trifloxystrobin + bixafen and fluxapyroxad + pyraclostrobin associated with CuPMC resulted in lower values in the 2021/2022 season, and no significant interaction was found between CuPMC and the fungicides. In the 2022/2023 season, such an interaction was significant, and the treatments tebuconazole + picoxystrobin + mancozeb and prothioconazole + trifloxystrobin + bixafen led to the lowest severity values. These results are relevant since the difficulty

**Table 2.** Means of SEV (I) (severity of ASR in the lower part of the plants), SEV (S) (severity of ASR in the upper part of the plants), and SEV (M) (total severities of ASR based on the average for upper and lower parts of the plants) for the treatments (2021/2022 and 2022/2023 seasons, analyzed separately).

| Season | CuPMC | Fungicides | SEV (I) | | SEV (S) | | SEV (M) | |
|---|---|---|---|---|---|---|---|---|
| 2021/2022 | Fungicides alone | Control (no fungicides) | 78.5% | aA | 78.5% | aA | 78.5% | aA |
| | | tebuconazole + picoxystrobin + mancozeb | 42.7% | aB | 3.4% | aB | 23.1% | aC |
| | | prothioconazole + trifloxystrobin + bixafen | 78.5% | aA | 1.6% | aB | 40.0% | aBC |
| | | fluxapyroxad + pyraclostrobin | 78.5% | aA | 6.1% | aB | 42.3% | aB |
| | CuPMC + fungicides | Control (CuPMC alone) | 78.5% | aA | 67.3% | aA | 72.9% | bA |
| | | tebuconazole + picoxystrobin + mancozeb | 12.3% | bB | 1.7% | bB | 7.0% | bB |
| | | prothioconazole + trifloxystrobin + bixafen | 12.3% | bB | 1.3% | bB | 6.8% | bB |
| | | fluxapyroxad + pyraclostrobin | 43.2% | bB | 4.2% | bB | 23.7% | bB |
| 2022/2023 | Fungicides alone | Control (no fungicides) | 78.5% | aA | 78.5% | aA | 78.5% | aA |
| | | tebuconazole + picoxystrobin + mancozeb | 25.7% | aC | 2.4% | bD | 14.0% | aC |
| | | prothioconazole + trifloxystrobin + bixafen | 27.5% | aC | 4.8% | bC | 16.1% | aC |
| | | fluxapyroxad + pyraclostrobin | 43.5% | aB | 8.7% | bB | 26.1% | aB |
| | CuPMC + fungicides | Control (CuPMC alone) | 78.5% | bA | 78.5% | aA | 78.5% | bA |
| | | tebuconazole + picoxystrobin + mancozeb | 20.6% | bC | 0.8% | bD | 10.7% | bC |
| | | prothioconazole + trifloxystrobin + bixafen | 19.3% | bC | 19.3% | bC | 10.1% | bC |
| | | fluxapyroxad + pyraclostrobin | 31.7% | bB | 5.0% | bB | 18.4% | bB |

| | SEV (I) | | SEV (S) | | SEV (M) | |
|---|---|---|---|---|---|---|
| Season | 2021/2022 | 2022/2023 | 2021/2022 | 2022/2023 | 2021/2022 | 2022/2023 |
| D | 0.587(≥0.01) | 0.185(≥0.01) | 0.0298(≥0.01) | 0.354(≥0.01) | 0.0263(≥0.01) | 0.0223(≥0.01) |
| F | 0.010(≥0.01) | 0.048(≥0.01) | 0.010(≥0.01) | 0.037(≥0.01) | 0.010(≥0.01) | 0.010(≥0.01) |
| F (P) [1] | 0.523(≥0.01) | 0.038(≥0.01) | 0.369(≥0.01) | 0.078(≥0.01) | 0.275(≥0.01) | 0.275(≥0.01) |
| F (P) [2] | 0.107(<0.05) [NS] | 0.022(<0.05) | 0.202(<0.05) [NS] | 0.642(<0.05) [NS] | 0.048(<0.05) | 0.014(<0.05) |
| CV (%) | 19.58% | 21.84% | 24.29% | 17.16% | 5.18% | 11.08% |

Means followed by different letters, lowercase (adoption of CuPMC) and uppercase (fungicides), on the line differ from each other according to Tukey's test, at 5% probability. **D**: Kolmogorov-Smirnov test (probability) for normality of residuals; **F**: Levene's test (probability) for homoscedasticity of variances; **F (P) [1]**: Tukey's test (probability) for additivity of blocks; **F (P) [2]**: Snedecor's test (probability) for interaction between the two factors; **CV (%):** coefficient of variation. [NS]: not significant. All data were transformed to $\sqrt{(x+1)}$.

in controlling diseases in the lower part of soybean plants is latent due to the high leaf mass and plant density of this crop.

As regards ASR severity in the upper part of the plants, in both seasons the interaction between CuPMC and the fungicides was not significant. Analyzing the effects separately, in the 2021/2022 season, again the treatments tebuconazole + picoxystrobin + mancozeb, prothioconazole + trifloxystrobin + bixafen and fluxapyroxad + pyraclostrobin were statistically equal. In the 2022/2023 season, tebuconazole + picoxystrobin + mancozeb associated with CuPMC resulted in the lowest severity values.

Analyzing the total severity (average of lower and upper canopies), in both seasons the interaction between CuPMC and the fungicides was significant. In the 2021/2022 season, the treatments tebuconazole + picoxystrobin + mancozeb, prothioconazole + trifloxystrobin + bixafen and fluxapyroxad + pyraclostrobin associated with CuPMC presented the lowest severity values. In the 2022/2023 season, the treatments tebuconazole + picoxystrobin + mancozeb and prothioconazole + trifloxystrobin + bixafen stood out. In both seasons, all treatments adopting CuPMC differed statistically from treatments without this combination.

Regarding productivity data (Table 3), in the 2021/2022 season, the interaction between CuPMC and fungicides was significant. Tebuconazole + picoxystrobin + mancozeb associated with CuPMC differed from the other treatments, showing 4.379 Kg $ha^{-1}$ productivity and 94.7% ASR control (total severity by averages of the lower and upper parts of the plants), while the control without any application reduced productivity by 45.6%.

In the 2022/2023 season (in which interaction between CuPMC and fungicides was not significant), analyzing the treatments separately, tebuconazole + picoxystrobin + mancozeb (5.371 Kg $ha^{-1}$) and prothioconazole + trifloxystrobin + bixafen (5.142 Kg $ha^{-1}$) resulted in the highest yields when associated with CuPMC. In this same season, these same fungicides led to 4.950 Kg $ha^{-1}$ (tebuconazole + picoxystrobin + mancozeb) and 4.907 Kg $ha^{-1}$ (prothioconazole + trifloxystrobin + bixafen), without the adoption of CuPMC. The recorded losses were 421 Kg $ha^{-1}$ (tebuconazole + picoxystrobin + mancozeb) and 234 Kg $ha^{-1}$ (prothioconazole + trifloxystrobin + bixafen).

The commercial product costs of 500 mL $ha^{-1}$ is in the range of US$ 8.00 per application, totaling US$ 32.00 for the four applications. Taking as a reference the average Brazilian price of a soybean bag in the last five years, the complete treatment costs between 60 and 90 kilograms (1.0 to 1.5 bags of 60 kilograms of soybeans $ha^{-1}$). Based on the results of the present study, the return on investment with the use of CuPMC is achievable.

The correlation between the total ASR severity (average of lower and upper parts of the plants) and productivity (Table 4) was also relevant. According to Pearson's correlation coefficient, treatments adopting CuPMC obtained -0.98 (2021/2022 season), representing an almost perfect negative correlation between these two variables (lower total disease severity increased soybean productivity). For the 2022/2023 season, both coefficients for treatments with and without CuPMC were similar (-0.97). Therefore, it is reinforced that the lower

**Table 3**. Averages of PROD (productivity as Kg $ha^{-1}$), %RP (productivity reduction, compared to the best treatment), %C (I) (ASR control in the lower part of the plants), %C (S) (ASR control in the upper part of the plants), and %C (M) (average ASR control between the upper and lower parts of the plants) for the treatments (2021/2022 and 2022/2023 seasons, analyzed separately).

| Season | CuPMC | Fungicides | **PROD** | **%RP** | **%C (I)** | **%C (S)** | **%C (M)** |
|---|---|---|---|---|---|---|---|
| 2021/2022 | Fungicides alone | Control (no fungicides) | 3008 cA | 45.6% | 0.0% | 0.0% | 0.0% |
| | | tebuconazole + picoxystrobin + mancozeb | 4131 bC | 6.0% | 84.0% | 96.8% | 90.4% |
| | | prothioconazole + trifloxystrobin + bixafen | 3533 bB | 23.9% | 72.3% | 97.8% | 85.1% |
| | | fluxapyroxad + pyraclostrobin | 3226 cB | 35.7% | 56.9% | 91.5% | 74.2% |
| | CuPMC + fungicides | Control (CuPMC alone) | 3103 cA | 41.1% | 9.3% | 26.5% | 17.9% |
| | | tebuconazole + picoxystrobin + mancozeb | 4379 aA | 0.0% | 91.6% | 97.9% | 94.7% |
| | | prothioconazole + trifloxystrobin + bixafen | 4101 bA | 6.8% | 92.3% | 98.2% | 95.2% |
| | | fluxapyroxad + pyraclostrobin | 3996 bA | 9.6% | 74.4% | 95.0% | 84.7% |
| 2022/2023 | Fungicides alone | Control (no fungicides) | 2254 cB | 138.3% | 0.0% | 0.0% | 0.0% |
| | | tebuconazole + picoxystrobin + mancozeb | 4950 bC | 8.5% | 78.6% | 97.4% | 88.0% |
| | | prothioconazole + trifloxystrobin + bixafen | 4907 bC | 9.5% | 76.1% | 94.3% | 85.2% |
| | | fluxapyroxad + pyraclostrobin | 3794 bB | 41.6% | 63.9% | 82.5% | 73.2% |
| | CuPMC + fungicides | Control (CuPMC alone) | 2539 cA | 111.5% | 6.7% | 10.1% | 8.4% |
| | | tebuconazole + picoxystrobin + mancozeb | 5371 aA | 0.0% | 89.9% | 98.7% | 94.3% |
| | | prothioconazole + trifloxystrobin + bixafen | 5142 aA | 4.5% | 89.8% | 98.2% | 94.0% |
| | | fluxapyroxad + pyraclostrobin | 4325 bA | 24.2% | 79.8% | 91.4% | 85.6% |

| **Test** | **2021/2022 Season** | **2022/2023 Season** |
|---|---|---|
| D | 0.089(≥0.01) | 0.0850.01) |
| F | 0.475(≥0.01) | 0.031(≥0.01) |
| F(P) [1] | 0.041(≥0.01) | 0.834(0.01) |
| F(P) [2] | 0.000(0.05) | 0.632(0.05) [NS] |
| CV(%) | 3.61% | 5.95% |

Means followed by different letters, lowercase (adoption of CuPMC) and uppercase (fungicides), on the line differ from each other according to Tukey's test, at 5% probability. **D**: Kolmogorov-Smirnov test (probability) for normality of residuals; **F**: Levene's test (probability) for homoscedasticity of variances; **F (P) [1]**: Tukey's test (probability) for additivity of blocks; **F (P) [2]**: Snedecor's test (probability) for interaction between the two factors; **CV (%):** coefficient of variation. [NS]: not significant. %C (I) and %C (S): calculated by the Abbott's Method. All data were transformed to √(x +1).

**Table 4**. Averages of PROD (productivity as Kg ha $^{-1}$), SEV (M) (total ASR severity based on the average for upper and lower parts of the plants), and Pearson correlation coefficient between the averages of PROD and SEV (M) for the treatments (2021/2022 and 2022/2023 seasons, analyzed separately).

| Harvest | CuPMC | Fungicides | PROD | SEV (M) | Pearson |
|---|---|---|---|---|---|
| 2021/2022 | Fungicides alone | Control (no fungicides) | 3008 cA | 78.5% aA | -0.87 |
| | | tebuconazole + picoxystrobin + mancozeb | 4131 aB | 23.1% aB | |
| | | prothioconazole + trifloxystrobin + bixafen | 3533 bB | 40.0% aBC | |
| | | fluxapyroxad + pyraclostrobin | 3226 cB | 42.3% aC | |
| | CuPMC + fungicides | Control (CuPMC alone) | 3103 cA | 72.9% bA | -0.98 |
| | | tebuconazole + picoxystrobin + mancozeb | 4379 aA | 7.0% bB | |
| | | prothioconazole + trifloxystrobin + bixafen | 4101 bA | 6.8% bB | |
| | | fluxapyroxad + pyraclostrobin | 3996 bA | 23.7% bB | |
| 2022/2023 | Fungicides alone | Control (no fungicides) | 2254 cB | 78.5% aA | -0.97 |
| | | tebuconazole + picoxystrobin + mancozeb | 4950 aB | 14.0% aC | |
| | | prothioconazole + trifloxystrobin + bixafen | 4907 aB | 16.1% aC | |
| | | fluxapyroxad + pyraclostrobin | 3794 bB | 26.1% aB | |
| | CuPMC + fungicides | Control (CuPMC alone) | 2539 cA | 78.5% bA | -0.97 |
| | | tebuconazole + picoxystrobin + mancozeb | 5371 aA | 10.7% bC | |
| | | prothioconazole + trifloxystrobin + bixafen | 5142 aA | 10.1% bC | |
| | | fluxapyroxad + pyraclostrobin | 4325 bA | 18.4% bB | |

Averages followed by different letters, lowercase (adoption of CuPMC) and uppercase (fungicides), in the row differ from each other according to Tukey's test, at 5% probability. **Pearson**: Pearson correlation coefficient between the average productivity as Kg ha $^{-1}$ and the average ASR severity (upper and lower parts of the plants). All data were transformed to $\sqrt{(x+1)}$.

disease severity the higher the soybean productivity; consequently, the adoption of fungicides in the management of ASR is of utmost importance.

Different studies have reported the efficiency of carboxamides in controlling ASR; however, Klosowski et al. (12) pointed out that the emergence of *Phakopsora pachyrhizi* populations that are less sensitive to strobilurins, triazoles and carboxamides is a major concern in Brazil. Barro et al. (2) reported a decline in performance for two fungicide mixtures with IQe + ISDH (azoxystrobin + benzovindiflupyr and picoxystrobin + benzovindiflupyr).

Reis, Carregal and Zanata (15) cited the excessive use of only double mixtures in recent decades (azoxystrobin + cyproconazole, and pyraclostrobin + epoxiconazole), exposing these active ingredients, which may have determined the reduction in their fungitoxicity to ASR. Juliatti et al. (11) reported better efficiency in combining DMI, QoI and SDHI fungicides with multisite fungicides for ASR management. The adopted CuPMC enhanced the performance of tebuconazole + picoxystrobin + mancozeb, confirming the synergistic effect of mancozeb associated with triazoles and strobilurins.

Some tests with new generation chemical compounds are necessary to find alternatives to the emergence of resistant *Phakopsora pachyrhizi* populations (19). The results found in the present study highlighted the addition of CuPMC to fungicides, even though the current literature has practically no information on its use.

The FRAC Code List (6) reports the major cupric fungicides available on the market: copper oxychloride, copper hydroxide, copper sulfate and cuprous oxide. In the present study, it is not possible to say whether CuPMC has any fungicidal properties. In the past, CuPMC was presented as a copper ethylphosphonate and/or copper phosphite.

Considering copper fungicides, it is important to differentiate between nutritional copper and fungicidal copper, which depends on the concentration and rate per area. Different studies have cited that metallic copper is not biologically active, since only $Cu^{+}$ (= cuprous) and $Cu^{2+}$ (= cupric) ions must be mobilized in the original salt to achieve this property.

Copper phosphonates and other copper chemical complexes contain some organic radicals in their composition (20). Such products can facilitate the management of plant diseases for supplying bioactive copper, which can activate defense mechanisms (pathogenesis-related proteins − PRs, phytoalexins and phenolic compounds) that inhibit or delay the action of pathogens (17). Furthermore, unlike occasional copper sources, some copper phosphonates and copper chemical complexes can translocate via the xylem and phloem and can be used in the management of pathogens (3).

These data add that the performance of cupric fungicide is determined by the bioactive copper level available to the plants, since this form penetrates and inactivates the fungi. This cupric form also activates enzymes and physiological processes, such as resistance induction by plants (17). According to the manufacturer of the CuPMC adopted in the present study, Fulland® only has bioactive copper in its formulation, without metallic copper.

Since CuPMC is a still little explored compound, its potential and benefits to crops, as well as its capability of promoting disease control, cannot be accurately stated based on various field observations and limited published research papers.

A study by Silva Júnior et al. (17) indicated that CuPMC promoted a reduction in the severity of anthracnose (*Colletotrichum truncatum*) in soybean pods and seeds, increasing the activity of catalase (CAT) and peroxidase (POX). De Lima et al. (5) explained that the addition of CuPMC favored the translocation of five fungicide active ingredients from sprayed to non-sprayed parts in soybean plants.

The results obtained in the present study showed that the addition of CuPMC to the tested fungicides optimized their performance and minimized the exposure and selection of ASR populations that are not sensitive to the active ingredients.

## CONCLUSIONS

CuPMC associated with the fungicides prothioconazole + trifloxystrobin + bixafen and tebuconazole + picoxystrobin + mancozeb reduces the severity (lower canopy, higher canopy and average of both) for two consecutive seasons.

Soybean productivity was also higher with these same fungicides associated with CuPMC, compared to the fungicide treatments without CuPMC.

When used alone, CuPMC achieved the same results as the fungicide-free control. This reinforces the need for combined use (fungicides + CuPMC).

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**Declaração de disponibilidade de dados**
Os dados de pesquisa estão disponíveis no corpo do artigo.

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