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Triazole + strobilurin controls cercosporiosis and coffee rust, and biostimulants + sucrose reduces phytotoxicity

Triazol + estrobilurina controla a cercosporiose e a ferrugem do café, e bioestimulantes + sacarose, reduz a fitotoxicidade

Triazol + estrobilurina controla la cercosporiosis y la roya del café, y bioestimulantes + sacarosa reducen la fitotoxicidad

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Abstract
Diseases such as cercospora, rust and problems with phytotoxicity are limitations in coffee production. The aim of this work was to reaffirm the efficiency of chemical control based on the chemical groups Triazol + Stribolurin on cercospora and coffee rust and its phytotoxic effect, as well as to verify whether biostimulants or 4% sucrose can minimize phytotoxicity. Two separate trials were carried out, the first of which included the following treatments: T1) Aproach® - 500 mL/ha, T2) Priori Xtra® - 750 mL/ha, T3) Sphere Max® - 400 mL/ha, T4) Opera® 1.5 L/ha, T5) Witness; the second trial included the following treatments: T1) Opera® 1.5 L/ha, T2) Opera® 1.5 L/ha + Fertiactyl® 0.5 L/ha, T3) Opera® 1.5 L + Stimulate® 1 L/ha, T4) Opera® 1.5 L/ha + Physio crop® 1. The first trial began in March 2022 on the Catuaí 62 Amarelo cultivar, with a hanging load of 20 bags/hectare, and the second in February 2023 on the Rubi MG 1185 cultivar, with no hanging load. The products based on triazole + strobilurin were efficient in controlling cercospora and rust, being similar to and superior to the control, the product based on picoxystrobin + cyproconazole, Aproach®, caused no reduction in plant growth, and the product based on pyraclostrobin + epoxiconazole, Opera®, caused the greatest reduction. The efficacy of the products Stimulate®, Fertiactyl® and sucrose 4% was also proven to mitigate the phytotoxic effects of the application of Opera®, improving the average number of leaves on the branches after treatment.
Keywords: Efficiency; Locking; Phytotoxicity; Phytotoxic.

Resumo
Doenças como cercospora, ferrugem e problemas com fitotoxicidade são limitações na produção cafeeira. O objetivo deste trabalho foi reafirmar a eficiência do controle químico baseado nos grupos químicos Triazol + Estribolurina sobre a cercospora e a ferrugem do cafeeiro e seu efeito fitotóxico, bem como verificar se bioestimulantes ou sacarose a 4% podem minimizar a fitotoxicidade. Foram realizados dois ensaios distintos, sendo que o primeiro incluiu os seguintes tratamentos: T1) Aproach® - 500 mL/ha, T2) Priori Xtra® - 750 mL/ha, T3) Sphere Max® - 400 mL/ha, T4) Opera® 1,5 L/ha, T5) Testemunha, no segundo ensaio foram realizados os tratamentos: T1) Opera® 1,5 L/ha, T2) Opera® 1,5 L/ha + Fertiactyl® 0,5 L/ha, T3) Opera® 1,5 L + Stimulate® 1 L/ha, T4) Opera® 1,5 L/ha + Physio

crop® 1. 5 L/ha, T5) Testemunha, conduzido em Bambuí-MG, o primeiro ensaio teve início em março de 2022 na cultivar Catuaí 62 Amarelo, com carga pendente de 20 sacos/hectare, e o segundo em fevereiro de 2023 na cultivar Rubi MG 1185, sem carga pendente. Os produtos à base de triazol + estrobilurina foram eficientes no controle da cercospora e da ferrugem, sendo semelhantes e superiores à testemunha, o produto à base de picoxistrobina + ciproconazol, Aproach®, não causou redução no crescimento das plantas, e o produto à base de piraclostrobina + epoxiconazol, Opera®, causou a maior redução. A eficácia dos produtos Stimulate®, Fertiactyl® e sacarose 4% também foi comprovada para atenuar os efeitos fitotóxicos da aplicação do Opera®, melhorando o número médio de folhas nos ramos após o tratamento.
Palavras-chave: Eficiência; Travamento; Fitotoxicidade; Fitotóxico.

Resumen
Enfermedades como la cercospora, la roya y problemas de fitotoxicidad son limitantes en la producción de café. El objetivo de este trabajo fue reafirmar la eficiencia del control químico basado en los grupos químicos Triazol + Stribolurin sobre cercospora y roya del café y su efecto fitotóxico, así como verificar si los bioestimulantes o la sacarosa al 4% pueden minimizar la fitotoxicidad. Se realizaron dos ensayos separados, el primero de los cuales incluyó los siguientes tratamientos: T1) Aproach® - 500 mL/ha, T2) Priori Xtra® - 750 mL/ha, T3) Sphere Max® - 400 mL/ha, T4) Opera® 1,5 L/ha, T5) Testigo; el segundo ensayo incluyó los siguientes tratamientos: T1) Opera® 1,5 L/ha, T2) Opera® 1,5 L/ha + Fertiactyl® 0,5 L/ha, T3) Opera® 1,5 L + Stimulate® 1 L/ha, T4) Opera® 1,5 L/ha + Physio crop® 1. El primer ensayo se inició en marzo de 2022 en el cultivar Catuaí 62 Amarelo, con una carga suspendida de 20 bolsas/hectárea, y el segundo en febrero de 2023 en el cultivar Rubi MG 1185, sin carga suspendida. Los productos a base de triazol + estrobilurina fueron eficaces en el control de cercospora y roya, siendo similares y superiores al testigo, el producto a base de picoxistrobina + ciproconazol, Aproach®, no causó reducción en el crecimiento de la planta, y el producto a base de piraclostrobina + epoxiconazol, Opera®, causó la mayor reducción. También se comprobó la eficacia de los productos Stimulate®, Fertiactyl® y sacarosa 4% para mitigar los efectos fitotóxicos de la aplicación de Opera®, mejorando el número medio de hojas en las ramas tras el tratamiento.
Palabras clave: Eficiencia; Cierre; Fitotoxicidad; Fitotóxico.

1. Introduction

Coffee is a plant native to the upper region of Ethiopia, which was introduced to Brazil around 1,727. It belongs to the Rubiaceae family and the Coffea genus, divided into two groups: C. arabica, which has the highest percentage of planted areas within the coffee community, and C. canephora, which has less area, but is expressive in warmer regions and at lower altitudes. Brazilian coffee production in the 2023/24 harvest reached 54.7 million bags of Arabica and Canephora coffee (Conab, 2024), which represents around 31% of the estimated world production for the 2023/24 harvest of 171.4 million bags (Ferreira, 2024). This high production value makes Brazil the world's largest producer, followed by Vietnam and Colombia.

In order to remain at the top of production, technology and efficient management are needed to deal with all the biotic and abiotic factors that can adversely affect the crop, highlighting as biotic factors the presence of diseases in the field, where cercosporiosis and coffee rust stand out for commonly generating losses in Brazil, in favorable conditions for the disease, these losses can reach 40% of production (Oliveira et al., 2021).

Cercosporiosis is caused by the fungus *Cercospora coffeicola*, and its damage ranges from loss of photosynthetic rate to loss of fruit quality. It is characterized by two types of pathogenic spots on coffee, brown eye spot (BES) and black spot (BS), both of which are necrotic spots, Both are subcircular to irregular necrotic spots, varying in color and width of the rings, but maintaining a lighter color in the center, surrounded by a brownish ring and a yellowish halo at the end, and these variations in their characteristics are caused by the same species (Vale et al., 2021).

Coffee leaf rust is caused by the fungus *Hemileia vastatrix*, and its damage is directly related to severe defoliation, which reduces photosynthetic rate and production. The lesions on the adaxial part of the leaf are rounded and yellowish at first, However, as the lesion progresses and the fungus sporulates, the central cellular tissue in the lesion may die and orange powdery pustules appear on the abaxial part of the leaf (Alhudaib & Ismail, 2024). This species has high genetic variability, with a total of 16 races identified in Brazil, where race II is the most common (Zambolim & Caixeta, 2019).

Lately, the use of resistant cultivars has increased, but a large part of the planted areas are still with susceptible cultivars, such as Mundo Novo and Catuaí, which makes chemical management the fundamental pillar for controlling cercosporiosis and coffee rust (Oliveira et al., 2021).

For chemical management in Brazil, according to Agrofit, 2024, of all the products registered for cercosporiosis or coffee rust, around 60% of them have the triazole chemical group in their formulation, either pure or in a mixture with another chemical group, with the mixture of triazole + strobilurin chemical groups being recurrent, which highlights the great importance of these chemical groups in controlling the main coffee diseases. The efficiency of mixtures of triazoles and stribolurins has already been well reported, but they have been called into question, given that resistance to triazoles already exists in other crops, which makes it important to carry out a survey of control efficiency over the years, to check that producers' management is being well positioned.

The triazole chemical group is also directly related to the stress condition during its assimilation, and when applied in high dosages tends to cause a toxic effect even in adult plants, mainly linked to the anti-gibberellin action developed by it, leaving the leaves stiff, small and dark green, with great fruiting, but the fruits become smaller and ripening is delayed (Matiello et al., 2015). According to Li et al. (2022), the more hydrophobic the triazole, the more likely it is to concentrate in tissues with a higher lipid content, which means that this group has a great capacity to concentrate and cause a phytotoxic effect when the plant has a low amount of water circulating, either because of the time of day when temperatures are higher, or because of more far-reaching climatic effects such as El Niño and La Niña, which have recurred in Brazil in recent years.

Thus, the aim of this study was to reaffirm the efficiency of chemical control based on the chemical groups Triazol + Stribolurin on cercosporiosis and coffee rust and its phytotoxic effect, as well as to check whether biostimulants or 4% sucrose can minimize phytotoxicity.

2. Metodologia

An experimental study was carried out, of a qualitative nature for the characteristics of the young leaves, and quantitative for the rest of the evaluations, internode length in centimeters (cm), area under the disease progress curve and average number of leaves on the branches after treatment (Pereira et al., 2018) using simple descriptive statistics with absolute frequency values (Shitsuka et al., 2014).

2.1 Place and date

This work was carried out in the municipality of Bambuí, located in the central-western region of Minas Gerais, in two separate trials.

The first trial was conducted on the Catuaí 62 Amarelo cultivar, aged 10 years, arranged at a spacing of 3.5 x 0.7 m, which had a hanging load of 20 bags/hectare, carried out on the Vista Longa farm, which began on March 20, 2022 and ended on April 20, 2022.

The second trial was carried out after harvesting, on the cultivar Rubi MG 1185, arranged at a spacing of 3.5 x 0.7 m. It did not have a pending load as it was 2 years old, carried out in the coffee-growing sector of the IFMG Bambuí campus, which began on February 8, 2023 and ended on April 29, 2023.

2.2 Experimental design of the first trial

The first trial used a DBC (Randomized Block Design) with 4 blocks and 12 plants per block, with one plant at each end being discarded in the evaluations. In the trial, four commercial products were applied plus the control, making up the following treatments (Table 1):

Table 1 - Commercial products tested for the control of cercosporiosis and coffee rust, trade name, active ingredient and dosage.

TREATMENT	COMMERCIAL PRODUCT	ACTIVE INGREDIENT	DOSE/HECTARE (400 L of fungicide solution/ha)
T1	Aproach®	picoxistrobin + ciproconazole	500 mL/ha
T2	Priori Xtra®	azoxistrobin + ciproconazole	750 mL/ha
T3	Sphere Max®	trifloxistrobin + ciproconazole	400 mL/ha
T4	Opera®	piraclostrobin + epoxiconazole	1,5 L/ha
Testemunha	Water		

*Vegetable oil was added to the spray at a dosage of 0.5% of the spray volume in all treatments. Source: Authors.

At the beginning, sampling was carried out to determine the ideal time to apply the chemical control, as well as assessing the initial level of infestation of the cercospora and rust diseases. To assess cercospora, 8 leaves per plant were sampled, assessing a total of 25 plants (Matiello et al., 2015), determining an infestation level of 15%. For rust, sampling was carried out in the middle third of the plant, assessing the 3rd and 4th pairs of leaves on both sides of the same plant, sampling 25 plants in total (Matiello et al., 2015), determining an infestation level of 12.5%. These evaluations were repeated 15 and 30 days after application to determine the level of cercospora and rust in the coffee tree, and these evaluations were carried out on April 3, 2022 and April 17, 2022. During the assessment on April 17, 2022, the length of the internodes was also measured, by measuring the length of the 2nd and 3rd internode in the middle third of the plant. The evaluations carried out served as a basis for calculating the area under the disease progress curve, obtaining the average and submitting it to analysis of variance (ANOVA), and when significant, submitted to the Scott Knot test at 5%, using the R software.

2.3 Experimental design of the second trial

The second trial was also conducted in a randomized block design with 4 blocks and 10 plants per block, with only the central 8 plants being evaluated. In the trial, the treatments were distributed with the product Opera® as the agent causing the phytotoxicity, because in the first trial, it proved to be the product with the greatest potential for toxicity, as will be discussed below. Different applications were tested to reduce the effect of phytotoxicity, including 4% sucrose, water (Control 0), Opera® (Control) and biostimulants (Table 2):

Table 2 - Treatments used to test the biostimulants + 4% sucrose to mitigate the phytotoxicity caused by Opera®.

TREATMENT	COMMERCIAL PRODUCT	ACTIVE INGREDIENT	DOSE/HECTARE (400 L of fungicide solution/ha)
T1	Opera®	piraclostrobin e epoxiconazole	1,5 L/ha
T2	Opera® + Fertiactyl®	piraclostrobin e epoxiconazole + (Seaweed extract)	1,5 L/ha + 0,5 L/ha
T3	Opera® + Stimulate®	piraclostrobin e epoxiconazole + (Synthetic phytohormones)	1,5 L/ha + 1,0 L/ha
T4	Opera® + Physio crop®	piraclostrobin e epoxiconazole + (Organomineral)	1,5 L/ha + 1,5 L/ha
T5	Opera® + Açucar	piraclostrobin e epoxiconazole + (Sucrose 4%)	1,5 L/ha + 4%
Testemunha	Water		

Source: Authors.

The second trial counted the average number of leaves on the plagiotropic branches 50 days after the application of each treatment. Firstly, the leaves were marked with plastic ties before application, so that the counts made afterwards only counted the new leaves that appeared after application, and only the fully opened leaves were counted. All the data obtained was subjected to Analysis of Variance (ANAVA) and significant data was subjected to the Scott Knot test at 5% significance using the R software.

2.4 Product application

The chemical products were applied using a STHIL costal atomizer with a maximum capacity of 15 liters of mixture. The volume of application was regulated up to the point where the plants ran off. The pH of the mixture was measured and a value of approximately 5.5 was obtained. Spraying was carried out in the morning, with a temperature close to 26°C and relative humidity close to 62%.

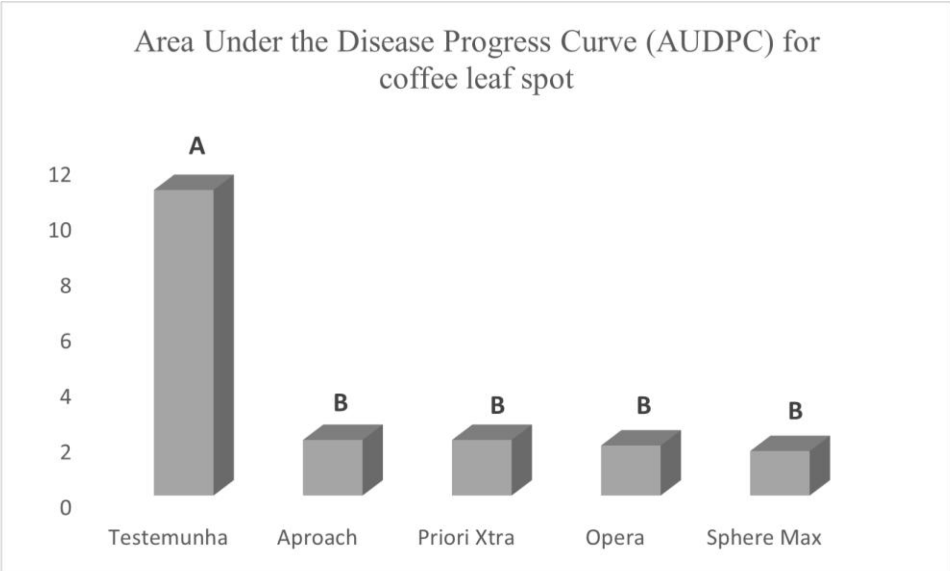
3. Results

3.1 First trial

3.1.1 Identification of cercosporiosis control efficiency

The products used did not differ significantly from each other in controlling coffee leaf cercosporiosis, but they did differ from the control product in reducing the incidence of this disease, as can be seen from the area under the progress curve (Figure 1).

Figure 1 - Area under the curve of cercosporiosis incidence in coffee trees treated with fungicides and the control.



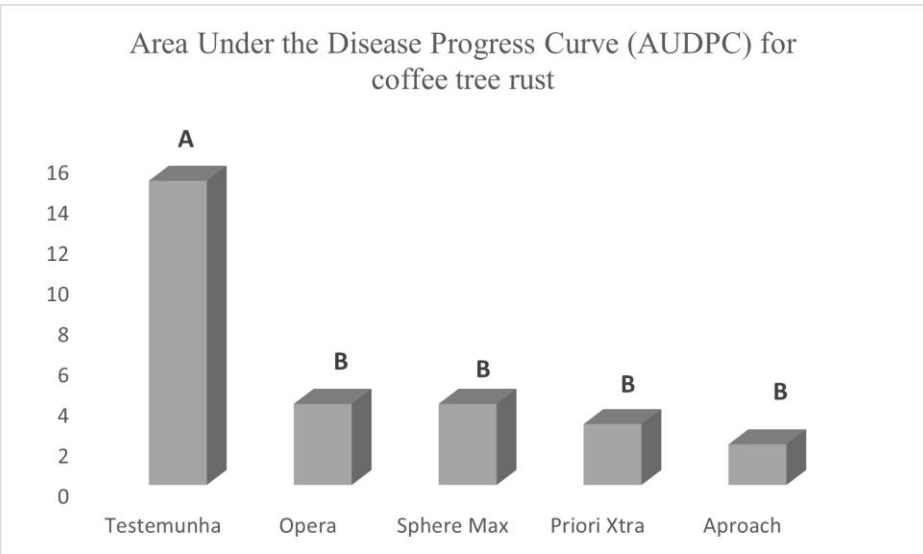
* Bars with different letters mean a statistical difference using the Skott Knott test at 5% significance. Source: Authors.

As can be seen in Figure 1, the four triazole + strobirulin-based products applied showed no difference between them, while in the control treatment, which received no fungicide, the level of cercosporiosis was much higher. The results obtained show that the commercial products, applied at the recommended dosages, are equally effective at controlling cercosporiosis, and this gives producers the security they need when deciding which product to use.

3.1.2 Identifying the efficiency of coffee rust control

The products used did not differ in their ability to control coffee leaf rust, but they did differ from the control product in reducing the incidence of this disease, as can be seen in the area under progress (Figure 2).

Figure 2 - Area under the curve of the progress of coffee leaf rust incidence submitted to treatments with fungicides and the control.



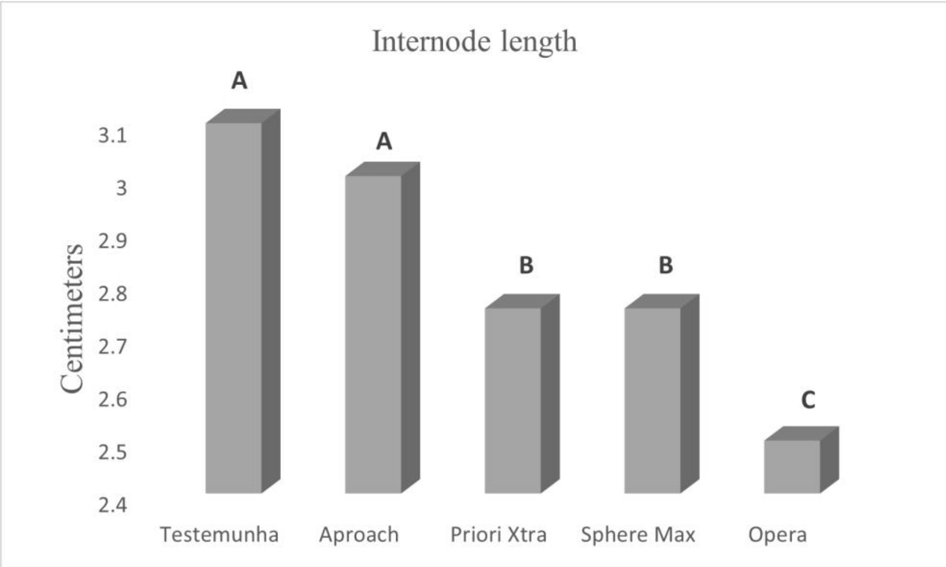
* Bars with different letters mean a statistical difference using the Skott Knott test at 5% significance. Source: Authors.

As can be seen in Figure 2, the four products based on triazole + strobirulin that were applied showed no difference between them, while in the control treatment, which received no fungicide, the level of rust was much higher. The results obtained show that the commercial products, applied at the recommended dosages, are equally effective at controlling rust, and this gives producers the security they need when deciding which product to use.

3.1.3 Identification of internode stagnation

There were significant differences between the treatments applied in terms of the size of the internode of the 2nd and 3rd pairs of leaves (Figure 3).

Figure 3 - Average length of the 2nd to 3rd internode of two plagiotropic branches located in the middle third of the plant 30 days after the treatments.



* Bars with different letters mean a statistical difference using the Skott Knott test at 5% significance. Source: Authors.

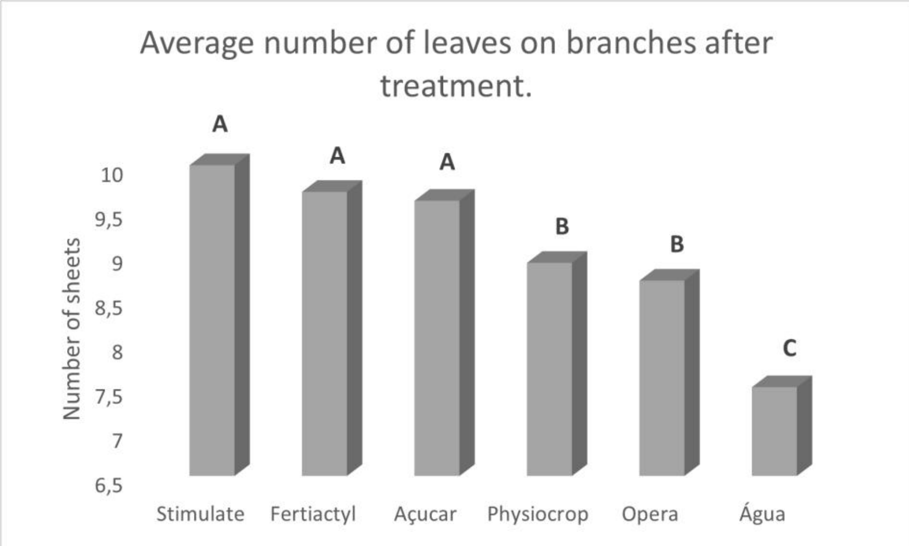
The treatments with the shortest internode lengths are those that use the molecules pyraclostrobin (Strobilurin) + epoxiconazole (Triazole) as their active ingredient. Bearing in mind that in the cercospora (Figure 3) and rust (Figure 4) control factors, both treatments showed the same efficiency, and that in the internode length factor there was a difference between the treatments, this characteristic can be used as information in the product choice factor for the producer.

3.2 Second trial

3.2.1 Identification of ways to mitigate the internode stagnation effect

There was a significant difference in the number of leaves on the branches after the products were applied (Figure 4).

Figure 4 - Number of leaves on the branches counted after applying the products.



* Bars with different letters mean a statistical difference using the Skott Knott test at 5% significance. Source: Authors.

As can be seen in Figure 4, the treatments based on Stimulate®, Fertiactyl® and sugar (T3, T2 and T5 respectively) were able to mitigate the effects of phytotoxicity, improving the average number of leaves on the branch after treatment, while the treatment based on Physiocrop® (treatment 4) behaved in the same way as the treatment that only used Opera® (treatment 1). Another result observed was in the control plant, which had only water applied, which had the lowest average number of leaves on the branch after treatment, given that no fungal application was carried out, which favors the development of the disease, and therefore defoliation. The effect of phytotoxicity on the plants is visible after the application of Opera®, as can be seen in Figure 5.

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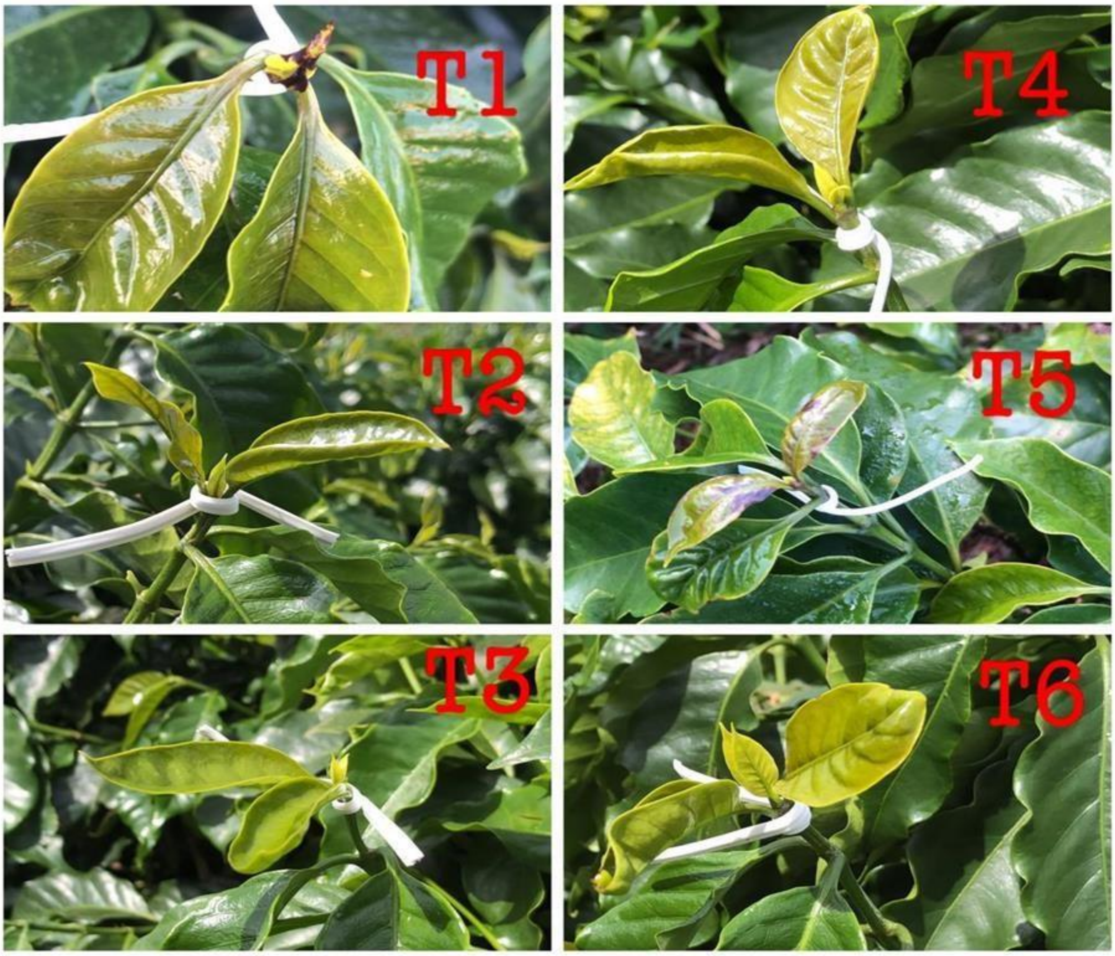
Figure 5 - Characteristics of the young leaves where the products were applied.



Source: Authors.

As can be seen in figure 5, treatment 1, which used only the application of Opera®, which represents the active ingredient epoxiconazole, suffered the most from phytotoxicity at the first moment, while the other treatments which combined various products + Opera®, as well as the control which used only water, suffered less when compared visually at the first moments.

4. Discussion

All the chemical fungicides based on Triazole + Stribolurin used in this work proved to be efficient in controlling cercosporiosis and coffee rust, being statistically equal to each other and different from the control agent.

This same result was obtained in 2016 by Matos et. al., who confirmed the efficiency of triazoles associated with strobilurins in field work, at the Nossa Senhora do Carmo farm in Romaria – MG, where different active ingredients were tested associated or separately, belonging to the same chemical groups as in the present work, with the triazoles and strobilurins acting on coffee rust, however in this work a significant difference was shown between the treatments, but all of them obtained an area below the disease progress curve (AACPD), smaller than the control, confirming its efficiency.

Another work that obtained similar results was carried out by Honorato Jr et. al., (2015), where he tested different combinations of fungicides based on triazole and strobilurins, carrying out part in the greenhouse and part in the field, combining foliar and soil application, where he proved that both applications achieved efficient control, keeping the rust level below the control, but with a significant difference between them.

Finally, Patricio and Braghini (2011) carried out a study with coffee seedlings, evaluating different active ingredients from the triazole + pyraclostrobin (strobilurin) chemical group for the incidence and severity of cercospora. The result was a significant difference between the treatments with the products compared to the control, all of which had efficient control, guaranteeing less disease than the control.

This study showed that the internode length was blocked, with the product Opera® standing out with the lowest internode growth, followed by Priori Xtra® and Sphere Max®, and finally Aproach®, which behaved like the control, concluding that this reduction in growth is explained by the action of the triazole, which inhibits the biosynthesis of the gibberellin hormone, as observed by Ribeiro et al. (2019). Therefore, the burning observed in figure 5 (T 1) may be caused by the triazole, which once again confirms the anti-gibberellin action and the hindrance to plant development caused by triazole-based applications, especially the active ingredient Epoxiconazole.

The author Child et al. (1993) also stated that fungicides from the triazole chemical group have the ability to inhibit the biosynthesis of gibberellin (GAs), which slows down the development of the plant, and as the dosage of triazole applied to the plant increases, so does the degree of plant locking, which is most critical when there is plant intoxication due to faulty application or lack of water, where excessive accumulation of the product occurs and leads to severe stagnation in the region.

This study confirms that Stimulate®, Fertiactyl® and 4% sucrose (sugar) minimized the stress caused by the application of triazole-based fungicides, which resulted in a higher number of leaves on the plagiotropic branches than the treatments using only water, Opera® and Opera® + Physio crop®. This effect can be explained by the action of the first three treatments to mitigate the effect of the inhibition of gibberellic acid biosynthesis caused by the triazole.

The application of Fertiactyl® is a source of nutrients such as nitrogen, phosphorus and potassium, which are linked to the production and regulation of phytohormones such as auxin and gibberellic acid (Taiz & Zeiger, 2013). The exogenous application of Stimulate® provides kinetin (Cytokinin), gibberellic acid (Gibberellin) and 4-indol-3ylbutyric acid (Auxin) in a synthetic form, suppressing the plant's deficiency directly. Finally, the application of sucrose benefits various factors within the plant, such as the production of sugars, vitamins and proteins (Tan et al., 2021), and also, according to Gautam et al., (2020), the exogenous application of sucrose increases the expression of genes involving phytohormones, including gibberellic acid.

It is also justifiable that the control behaved like Opera®, because the rust caused intense defoliation in the coffee tree, which caused the coffee tree to lose the leaves that were going to be counted, generating a similar result to the one with the application of Opera®, but for different reasons, since the anti-gibberellin action caused by epoxiconazole inhibited the growth of new leaves.

5. Conclusion

The analysis showed that fungicides based on triazole + strobirulin were efficient in controlling cercosporiosis and coffee rust and there was no difference between them in terms of control level.

It was also shown that the fungicide based on picoxystrobin (Strobilurin) + cyproconazole (Triazole), Aproach®, did not cause any reduction in plant growth, and the product based on pyraclostrobin (Strobilurin) + epoxiconazole (Triazole), Opera®, caused the most reduction.

The efficiency of the products Stimulate®, Fertiactyl® and sucrose 4% was also proven to mitigate the phytotoxic effects of the application of Opera®, improving the average number of leaves on the branches after treatment, and these treatments are a possible strategy for improving the producer's management.

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