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In Vitro EVALUATION OF FERTILIZERS ON PLANT PATHOGENIC FUNGI

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ABSTRACT: Fertilizers induce indirect resistance in plants and can contribute to the management of phytopathogens. This research aimed to evaluate the efficiency of different fertilizers in inhibiting the growth of six plant pathogenic fungi: *Corynespora cassiicola*[1], *Colletotrichum lindemuthianum*[2], *Exserohilum turcicum*[3], *Fusarium oxysporum*[4], *Fusarium solani*[5] and *Sclerotinia sclerotiorum* using the 'in vitro' method. The experiment consisted of twelve treatments with five replicates, with each plot containing one Petri dish. Fertilizers with copper sulfate and sulfur (Tatic® from SATIS®) at doses of 2.5, 5, 10, and 20 ml/l; nickel sulfate and copper sulfate (022/17 sample from SATIS®) at doses of 5, 10, 15, and 20 ml/l; phosphorus, sulfur, and copper (Azurra Plus® from Biocross®) at 3 ml/l; fertilizer composed of phosphorous acid, hydrated manganese sulfate and hydrated zinc sulfate (Eurofit Max® from Timac Agro®) at 3 ml/l; product with copper amine (Copper Crop® from Althec Crop Science®) at 1 ml/l, and mock (without any product) were tested. Products were diluted in PDA growth medium, which was poured into petri dishes and a fungal mycelium disc was added to each dish. Fungal mycelium diameter, Mycelial Growth Velocity Index (MGVI), and Mycelial Growth Inhibition (MGI%) were measured at various time intervals. Fertilizers composed of copper sulfate and sulfur (Tatic®) and phosphorus, sulfur, and copper (Azurra Plus®) completely inhibited the growth of all tested fungi, while the other fertilizers had varying effects on different fungi. The promising results of specific fertilizers in controlling plant diseases have increased their use as alternative management strategies.

KEYWORDS: fungi inhibition, alternative management, pathogens, copper sulfate.

AVALIAÇÃO In Vitro DE FERTILIZANTES NO CONTROLE DE FUNGOS FITOPATOGÊNICOS

RESUMO: Os fertilizantes induzem resistência indireta em plantas e podem contribuir para o manejo de fitopatógenos. Esta pesquisa teve como objetivo avaliar a eficiência de diferentes fertilizantes na inibição do crescimento "in vitro" de seis fungos fitopatogênicos de plantas *Colletotrichum lindemuthianum*[1] *Corynespora cassiicola*[2], *Exserohilum turcicum*[3], *Fusarium oxysporum*[4], *Fusarium solani*[5] e *Sclerotinia sclerotiorum*[6]. O experimento consistiu em doze tratamentos com cinco repetições, com cada parcela contendo uma placa de Petri. Foram testados os seguintes fertilizantes nas seguintes composições: sulfato de cobre e enxofre (Tatic® da empresa SATIS®) nas doses de 2,5, 5, 10 e 20 ml/l, o fertilizante composto por cobre, sulfato de níquel e sulfato de cobre (codificado 022/17 da SATIS®) nas doses de 5, 10, 15 e 20 ml/l; o fertilizante à base de fósforo, enxofre e cobre (Azurra Plus® da Biocross®) na dose de 3 ml/l; o fertilizante à base de ácido fosfórico, manganês hidratado e sulfato de zinco hidratado (Eurofit Max® da Timac Agro®) na dose de 3 ml/l; um fertilizante composto por amina de cobre (Copper Crop® da Althec Crop Science®) na dose de 1 ml/l e por fim um controle (sem nenhum produto). Os fertilizantes foram diluídos no meio de crescimento BDA, e a mistura resultante foi vertida em placas de Petri estéreis. Após a solidificação do meio, discos de micélio fúngico foram adicionados a cada placa. Posteriormente foi avaliado o diâmetro do micélio fúngico, o Índice de Velocidade de Crescimento Micelial (MGVI) e a Inibição do Crescimento Micelial (MGI%) foram medidos em vários intervalos de tempo. Os fertilizantes a base de sulfato de cobre e enxofre (Tatic®) e fósforo, enxofre e cobre (Azurra Plus®) inibiram completamente o crescimento de todos os fungos testados, enquanto os outros fertilizantes tiveram efeitos variados nos diferentes fungos. Os resultados promisso-

res de fertilizantes específicos no controle de doenças de plantas aumentam seu uso como estratégias alternativas de manejo.

PALAVRAS CHAVE: inibição fúngica, manejo alternativo, patógenos, sulfato de cobre

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INTRODUCTION

The use of fertilizers as an additional method for controlling plant pathogens is increasing. A well-nourished plant can respond more quickly and efficiently to pathogen attacks. Nutrients not only contribute to the defense mechanisms of plants but can also have a direct toxic action against certain pathogens (Lemire, 2013).

Pests and plant pathogens cause varying degrees of damage to a variety of agricultural crops around the world. According to Savary et al. (2019), losses in rice crops (*Oryza sativa*) can reach 30%, while productivity losses in wheat (*Triticum aestivum*), corn (*Zea mays*), and soybean (*Glycine max* L. Merril) crops are around 20%.

The fungus *Corynespora cassiicola* (Berk & Curt.) Wei, which causes the disease commonly known as target spot, has been detected in over 300 hosts, including soybean, cotton (*Gossypium hirsutum*), eucalyptus (*Eucalyptus globulus*), cucumber (*Cucumis sativus*), and coffee (*Coffea arabica*) (Sumabat et al., 2018). The fungus *Colletotrichum lindemuthianum* (Sacc. et Magn.) Scrib. causes anthracnose, one of the main common bean (*Phaseolus vulgaris* L.) diseases, which can cause losses up to 100% (Queiroz et al., 2019).

The fungus *Sclerotinia sclerotiorum* (Lib.) de Bary, causes the disease known as white mold, which can parasitize more than 400 plant species of different genera, mainly in dicotyledons such as soybean and common bean (Hossain et al., 2023). Helminthosporium-leaf blight is a disease caused by *Exserohilum turcicum* (Pass.) Leonar & Suggs (syn. *Helminthosporium turcicum* (Pass.) and *Drechslera turcica* (Pass.) Subram & Jain) fungi and affects sorghum (*Sorghum bicolor*) and corn, causing significant losses worldwide (Muller et al., 2020). The genus Fusarium has wide geographical distribution and causes wilts, rots, seedling death, flower abortion, and storage rots, in addition to being one of the major producers of mycotoxins worldwide (El-Sayeda et al., 2022).

The use of fungicides dates from ancient civilizations, where various natural substances were used to mitigate plant diseases and avoid losses.

Copper sulfate has been used as a fungicide since the 19th century to treat wheat seeds against charcoal (*Ustilago tritici*). However, due to its high solubility in water and easy penetration into plant tissues, it can induce phytotoxicity reactions, making its use unsuitable for foliar applications. In 1882, the Bordeaux mixture was discovered, which had excess calcium hydroxide that neutralized copper sulfate. This neutralization is important for preventing phytotoxic effects on plants. This mixture reduced the incidence of downy mildew (*Plasmopara viticola*) in vineyards (Reis et al., 2021). In addition to its use as fungicide, micronutrient copper participates in several physiological processes in plants, such as photosynthesis, respiration, protein metabolism, as well as in nitrogen fixation and reduction (Tripathi et al., 2022). Optimal copper concentrations (Cu) act in chlorophyll, chloroplasts, and membrane formation. However, high concentrations can cause physiological imbalances in plants (Ahmad et al., 2015).

Although many copper-based products have fungicidal effect, they are often registered as fertilizers, and their effect against plant pathogenic fungi has not been evaluated. On the other hand, cupric fungicides are called multisite due to the different mechanisms of toxic action on the pathogen. Due to this multisite mode of action, pathogens have certain difficulty in developing resistance to these products. Copper-based fungicides are classified as inorganic and insoluble in water, considered as salts. Cu^{+} ions act on the fungus cells by preventing the enzymes from the respiration process and protein synthesis, reducing the activities of organelles and cell membrane, consequently affecting exchanges with these elements. During this process, pathogens release metabolites that react with copper compounds and become toxic, causing cell death (Garrido, 2017).

Another example of fungicidal nutrient is nickel (Ni), which has direct or indirect effect on microorganisms. Nickel salts have been effectively controlled fungal diseases since the 1930s. According to Lemire et al. (2013), the effect of nickel on disease control is mainly due to the metabolic changes induced in the host plant, reducing the disease severity. Einhardt et al. (2020) reported that nickel is related to the production of lignin and protection of the cell membrane, providing rigidity and impermeability to the cell wall.

Sulfur (S) was one of the first fungicides used by humans to control powdery mildew and is still in use today as fungicide due to its effectiveness and low toxicity (Devendar and Yang, 2019). In addition to their direct toxic effect on plant pathogens, some nutrients strengthen plant tissues, such as phosphorus (P), which can reduce the vegetative phase of plants, thereby reducing the period of greater susceptibility to fungi that act on young tissues (Jain et al., 2019).

Although foliar fertilizers do not necessarily provide direct control or prevention of phytopathogens, it is interesting to understand the effect of fertilizers on disease management for a more conscious use of these products. The Bordeaux mixture, for instance, is registered as a fertilizer, which is used in disease management due to its recognized fungicidal properties. Other fertilizers are also registered as fertilizer but may also exhibit fungicidal effects.

The aim of this study was to evaluate the 'in vitro' effect of foliar fertilizers on plant pathogenic fungi such as *C. cassiicola*, *C. lindemuthianum*, *F. oxysporum*, *F. solani*, *S. sclerotiorum*, and *E. turcicum*.

MATERIAL AND METHODS

The study was conducted at the Microbiology Laboratory of 'Faculdades Associadas de Uberaba' - FAZU, located in the municipality of Uberaba (MG), Brazil. The fungistatic effect of foliar fertilizers, namely 022/17 (composed of 2.5% copper, 0.5% nickel sulfate, and 1.4% sulfur) and Tatic® (14% copper sulfate and 6% sulfur) from SATIS®, Azurra Plus® (20% phosphorus -P_2O_{5-}, 2% sulfur, and 4.5% copper) from Biocross®, Eurofit Max® (40-50% phosphorous acid, 5-10% hydrated manganese, and 2-7% hydrated zinc sulfate) manufactured by Timac Agro®, and Copper Crop® (7.4% copper and 8.4% sulfur trioxide) from Althec Crop Science®, were evaluated. The doses tested were as follows: Azurra Plus® at 3 ml/l (manufacturer's recommended dose for foliar application), Copper Crop® at 1 ml/l (manufacturer's recommended dose for soybean foliar application), Eurofit Max® at 3 ml/l (manufacturer's recommended dose for foliar application), 022/17 at 5, 10, 15, and 20 ml/l, Tatic® at 2.5 (manufacturer's recommended dose for foliar application), and 5, 10, and 20 ml/l, and mock (negative control containing only Potato Dextrose Agar medium).

Fungal *C. lindemuthianum*, *C. cassiicola*, *F. oxysporum*, *F. solani*, *S. sclerotiorum*, and *E. turcicum* isolates, originating from pure cultures, were provided by the Department of Plant Pathology of the Federal University of Lavras (UFLA).

Fungi were plated on Potato Dextrose Agar (PDA) medium and kept at room temperature (25 to 30°C) and ambient light. After seven days of fungal growth, 6 mm diameter discs were removed from areas under active sporulation to conduct the experiment. The 6 mm discs containing mycelia were placed at the center of Petri dishes containing PDA culture medium in addition to fertilizers. Fertilizers were added to the PDA culture medium after autoclaving, when the medium had average temperature of 37°C. Then, the products added to the medium were homogenized and poured into Petri dishes. Five replicates were performed for each treatment (n=12), arranged in an entirely randomized design. Each experimental unit consisted of a Petri dish with diameter of 9 cm, containing PDA medium plus the evaluated products. Petri dishes with the respective treatments were conditioned at room temperature (25 to 30°C) and ambient light.

Individual evaluation of the fungal growth diameter was carried out using ruler graduated in millimeters, until the fungal mycelium control treatment covered the entire plate length. Evaluations were conducted at various time intervals after inoculation (DAI) for each fungus: 3, 5, 7, 10, 12, 14, and 18 DAI for *C. cassiicola*; 3, 5, 7, 10, and 12 DAI for *C. lindemuthianum*; 3, 5, 7, and 10 DAI for *F. oxysporum*; 3, 5, 7, 10, and 12 DAI for *F. solani*; 3 and 5 DAI for *S. sclerotiorum*; and 3, 5, 7, and 10 DAI for *E. turcicum*.

The Mycelial Growth Velocity Index (MGVI) was calculated as a function of the averages of mean diameters. This allowed the establishment of the fungal growth inhibition, as shown by the following formula:

$$MGVI = \frac{S(D - Dp)}{N}$$

Where:
MGVI = Mycelial Growth Velocity Index
D = current mean diameter;

Dp = previous mean diameter;
N = number of days after inoculation.

The growth inhibition rate was calculated when the mycelial growth in the control plates reached the edge of the petri dish. The inhibition rate was determined using the following formula:

$$GI\% = \frac{(H - h)}{H} X\,100$$

Where (H) represents the fungal mycelial growth diameter in the control plate, and (h) represents the fungal mycelial growth diameter in the plate treated with fertilizers.

Statistical analyses were conducted using the SASM-AGRI software (Canteri et al., 2001). Analysis of variance (ANOVA) was used to identify differences among treatment groups. Homogeneity of variances was tested, and means were compared using the DUNCAN test. Statistical significance was set at $P<0.05$.

RESULTS AND DISCUSSION

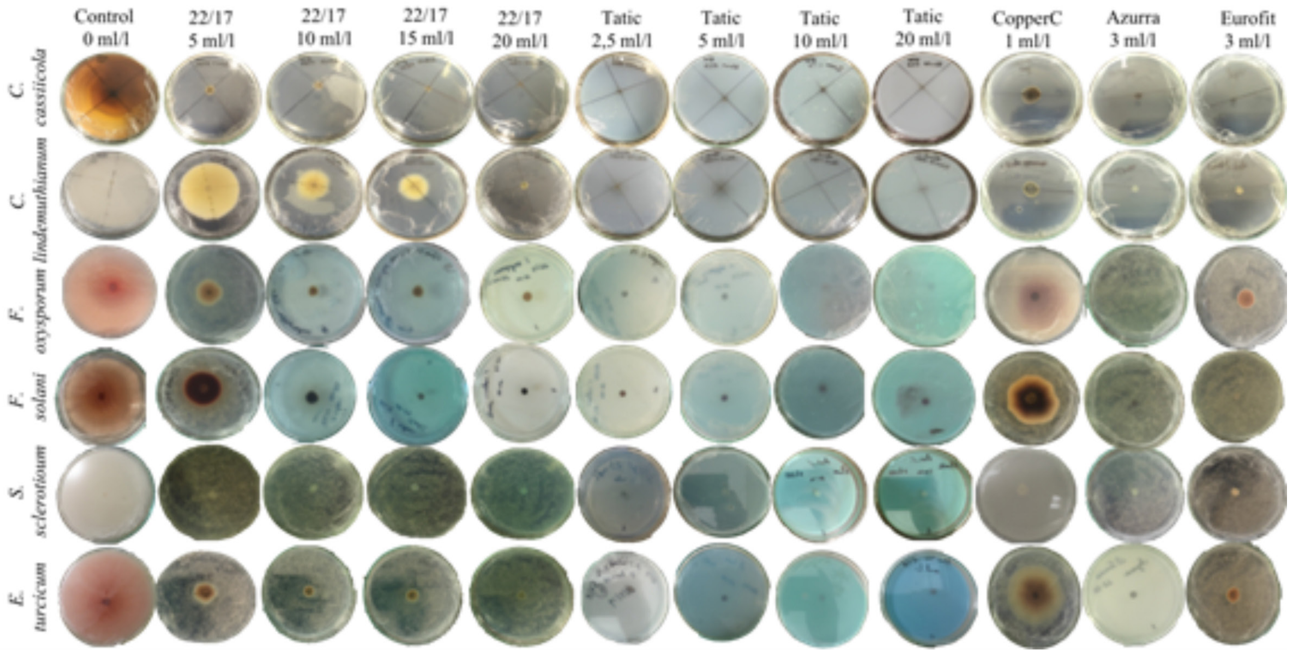
The tested fertilizers, including Tatic®, 22/17, Azurra®, Eurofit Max®, and Copper Crop®, significantly inhibited fungal mycelial growth on solid media ($p \leq 0.05$) at most doses compared to control (Table 1). Tatic® and Azurra Plus® completely inhibited mycelial growth of all six fungi under study (*C. cassiicola*, *C. lindemuthianum*, *E. turcicum, F. oxysporum*, *F. solani* and *S. sclerotiorum*) at all evaluated doses (Table 1 and Figure 1). Although copper-based products are often registered as fertilizers, they have also been widely used in agriculture for managing fungal and bacterial diseases. Moraes et al. (2009) used copper sulfate to control anthracnose in bean crops and observed reduction in disease severity. The authors reported that the copper sulfate doses used in their study via foliar application (highest dose of 78 mg L^{-1}) were too low to have a contact fungitoxic effect by copper. The reduction in the disease severity was attributed to the lower susceptibility of the host tissue related to the higher lignin content found in copper-treated plants.

Table 1. The mycelium growth diameter (in cm) was measured for *C. cassiicola* at 18 days after inoculation (DAI), *C. lindemuthianum* at 12 DAI, *F. oxysporum* at 10 DAI, *F. solani* at 12 DAI, *S. sclerotiorum* at 5 DAI, and *E. turcicum* at 10 days after inoculation of the fungi in PDA medium with different concentrations of fertilizers. The fertilizers evaluated were 22/17 (at 5, 10, 15, and 20 ml/l), Tatic® (at 2.5, 5, 10, and 20 ml/l), CopperCrop® (at 1 ml/l), Azurra® (at 3 ml/l), and Eurofit® (at 3 ml/l).

Fertilizers	Doses (ml/l)	*C. cassiicola*	*C. lindemuthianum*	*F. oxysporum*	*F. solani*	*S. sclerotiorum*	*E. turcicum*
Control	0	9 A	9 A	9 A	9 A	9 A	9 A
22/17	5	2,7 C	7,08 B	3,36 B	6,1 B	0,6 B	2,98 C
22/17	10	0,6 D	4,14 C	2,68 C	2,36 C	0,6 B	1,98 D
22/17	15	0,6 D	3,3 D	2,26 D	1,62 CD	0,6 B	1,54 F
22/17	20	0,6 D	1,04 E	1,42 E	1,56 CD	0,6 B	1,08 G
Tatic	2,5	0,6 D	0,6 E	0,6 F	0,6 D	0,6 B	0,6 H
Tatic	5	0,6 D	0,6 E	0,6 F	0,6 D	0,6 B	0,6 H
Tatic	10	0,6 D	0,6 E	0,6 F	0,6 D	0,6 B	0,6 H
Tatic	20	0,6 D	0,6 E	0,6 F	0,6 D	0,6 B	0,6 H
CopperC	1	3 B	7,04 B	9 A	6,46 B	9 A	7,72 B
Azurra	3	0,6 D	0,6 E	0,6 F	0,6 D	0,6 B	0,6 H
Eurofit	3	0,6 D	0,6 E	1,6 E	0,6 D	0,6 B	1,78 E

The reported values are the average of five replicates. Different letters following values in the column indicate significant differences according to the Duncan's test at 5% probability level.

Figure 1: Petri dishes displayed inhibition of the plant pathogenic fungi, including *C. cassiicola*, *C. lindemuthianum*, *F. oxysporum*, *F. solani*, *S. sclerotiorum*, and *E. turcicum*, when treated with 22/17 (at 5, 10, 15, and 20 ml/l), Tatic® (at 2.5, 5, 10, and 20 ml/l), CopperCrop® (at 1 ml/l), Azurra® (at 3 ml/l), and Eurofit® (at 3 ml/l) fertilizers at the last day of evaluation.



However, in the present study, Tatic® and Azurra Plus® were able to completely inhibit fungal growth even at the lowest doses (2.5 ml/l and 3 ml/l, respectively). This fact can be explained by the unspecific action of copper in various fungi and bacteria, in addition to the presence of cationic surfactants. The cations present in surfactants can bind to anions present in the phospholipid membrane of microorganisms by ionic interaction, facilitating the action of the mineral (Salah et al., 2021). Tatic® is a copper sulfate (14% concentration) solubilized in a cationic surfactant medium and sulfur (6% concentration), while Azurra Plus® contains 2.5% copper.

In contrast, fertilizer 22/17, which was manufactured from copper sulfate and nickel sulfate solubilized in amines and reacted with carboxylic acid, did not show the same fungicide effect as Tatic®. The mean values of colony diameters as a function of the fertilizer 22/17 dose for all fungi analyzed in this study are shown in Figures 2 to 7. Although no reduction in the fungi mycelial growth at lower doses was observed, as observed for Tatic® fertilizer, reduction in mycelial growth was observed with increasing doses. This lower effect on fungal growth may be due to its formulation, which contains only 2.5% copper.

Figure 2: Mean diameter of *C. cassicola* colonies (in cm) measured at 10 days after inoculation on PDA medium containing different 22/17 fertilizer doses (0, 5, 10, 15, and 20 ml/l).

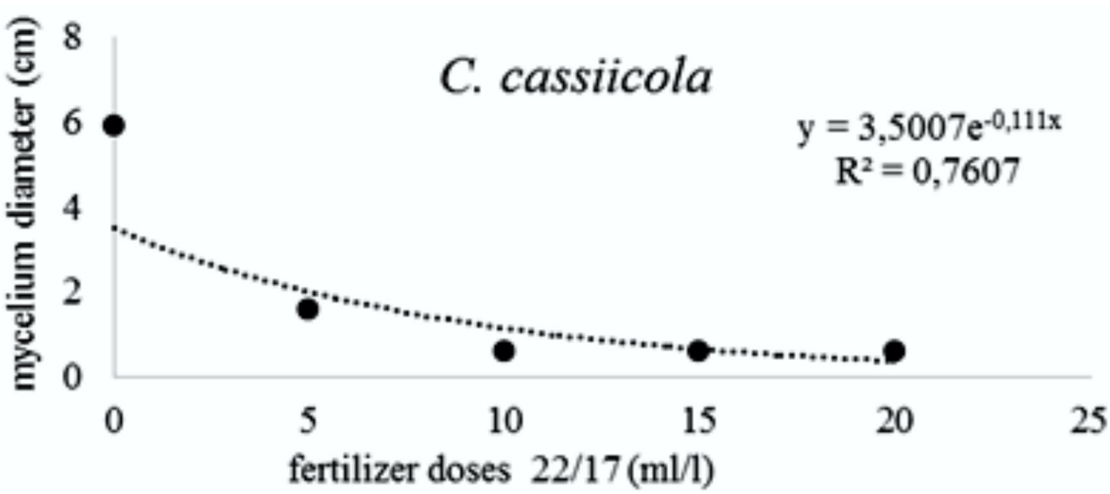


Figure 3: Mean diameter of (cm) *C. lindemuthianum* colonies as a function of fertilizer 22/17 doses (0, 5, 10, 15 and 20 ml/l) at 10 days after inoculation on the PDA medium with the fertilizer.

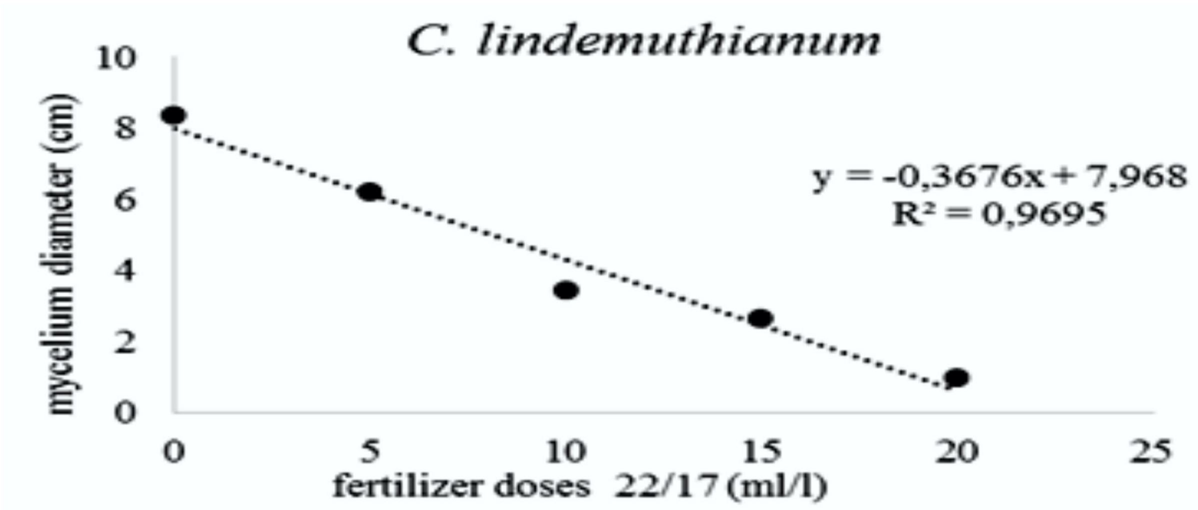


Figure 4: Mean diameter of *F. oxysporum* colonies (in cm) measured at 10 days after inoculation in PDA medium containing different 22/17 fertilizer doses (0, 5, 10, 15, and 20 ml/l).

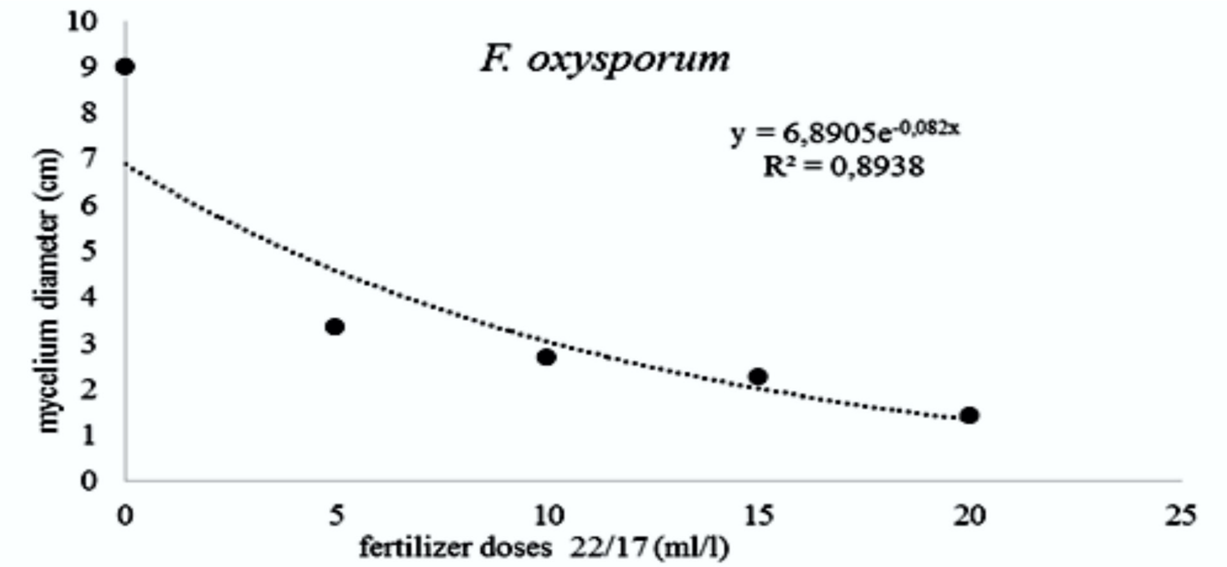


Figure 5: Mean diameter of *F. solani* colonies (cm) as a function of 22/17 fertilizer doses (0, 5, 10, 15 and 20 ml/l) at 10 days after inoculation in the PDA medium.

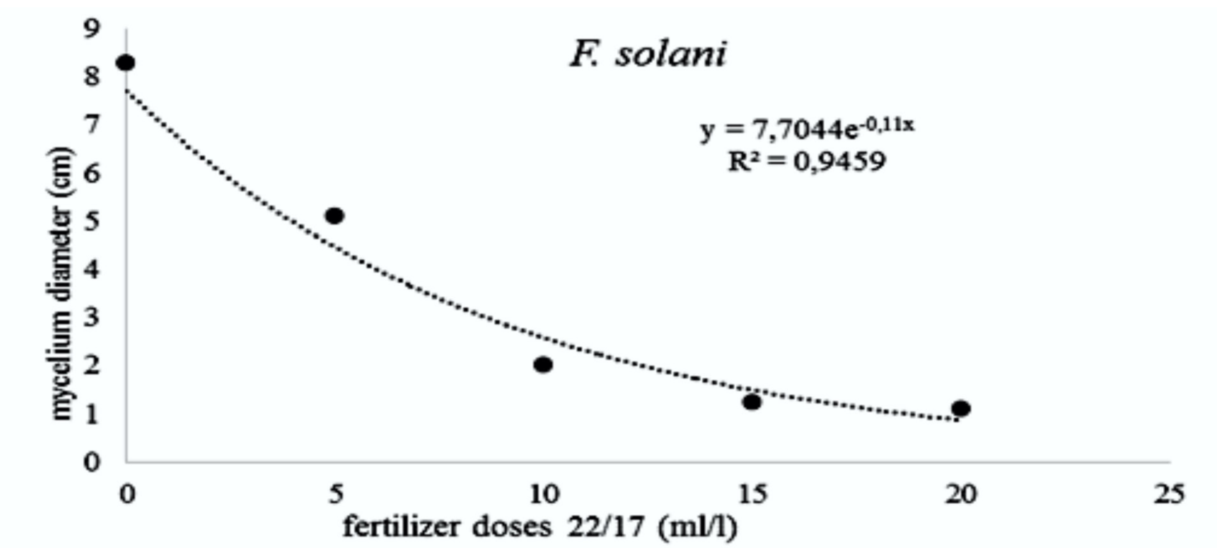


Figure 6: Mean diameter (cm) of *S. sclerotiorum* colonies as a function of 22/17 fertilizer doses (0, 5, 10, 15 and 20 ml/l) 5 days after inoculation in the PDA medium with the fertilizer.

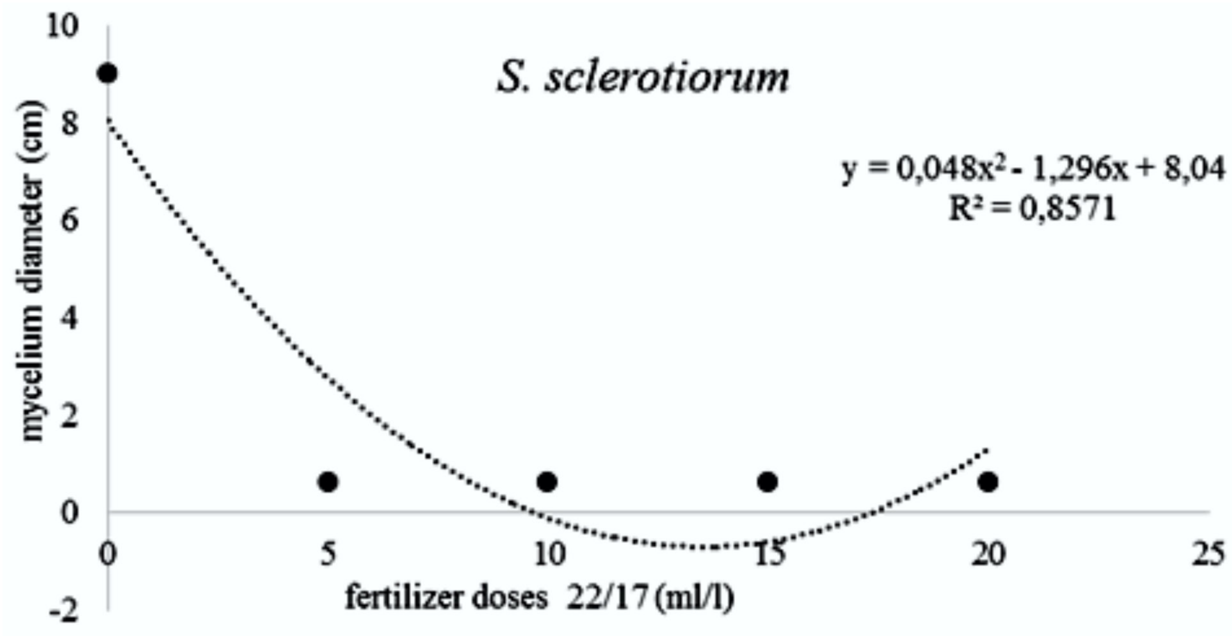
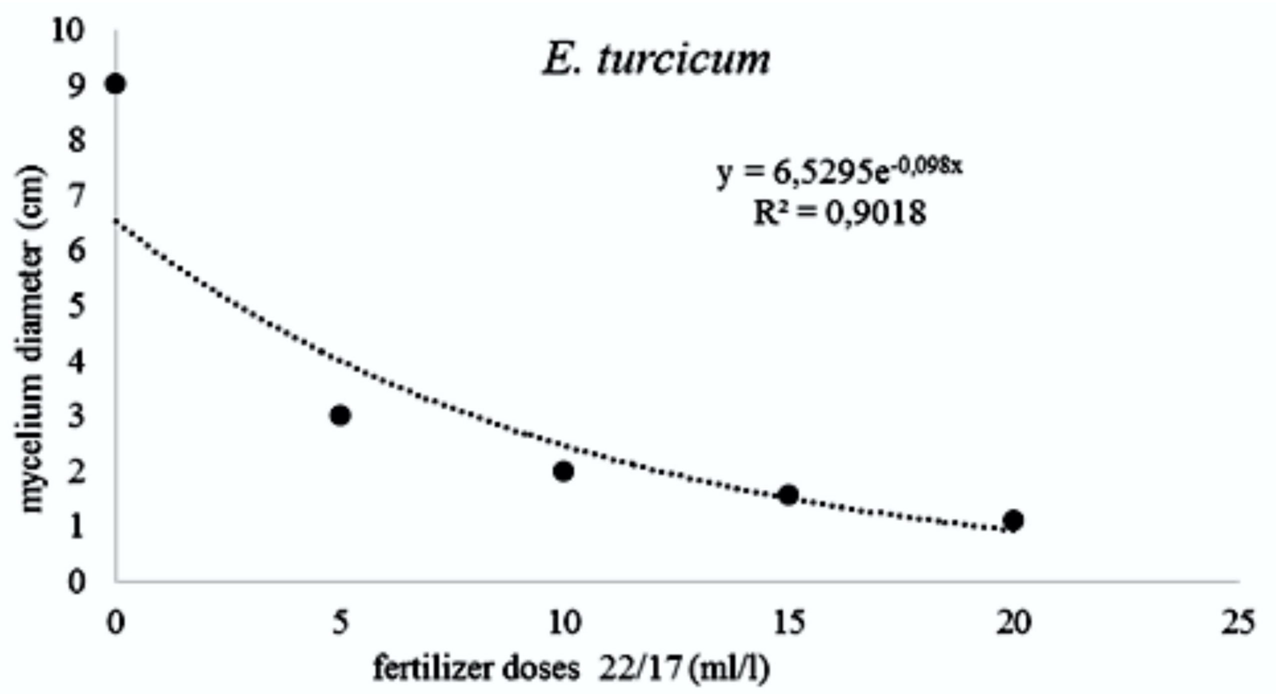


Figure 7: Mean diameter of *E. turcicum* colonies (in cm) as a function of 22/17 fertilizer doses (0, 5, 10, 15, and 20 ml/l) at 5 days after inoculation in PDA medium.



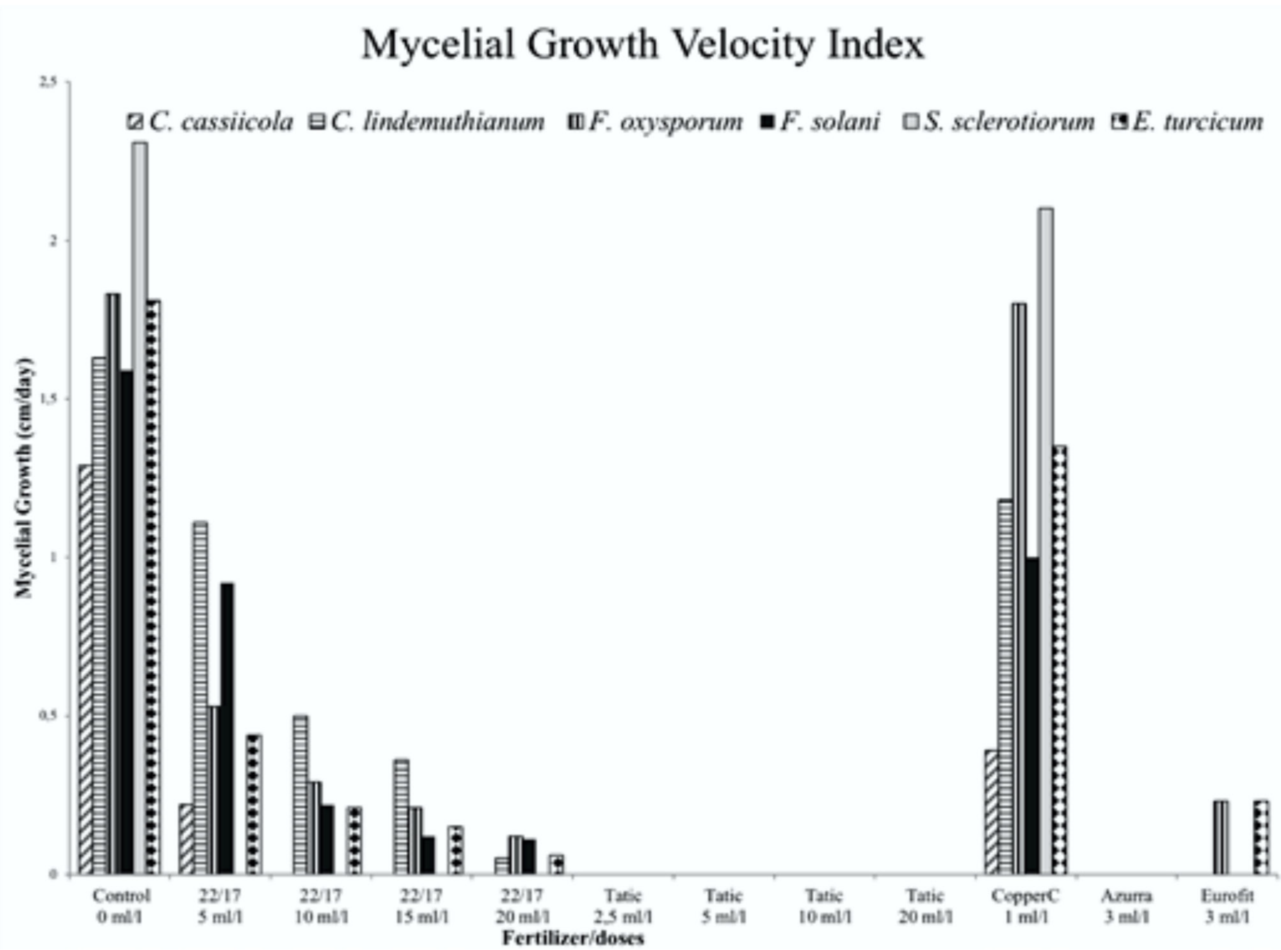
Copper Crop® promoted the highest *F. oxysporum* and *S. sclerotiorum* growth, and although statistically different from the negative control, it also showed abundant mycelial growth when in contact with this product. Additionally, Garrido (2016) and Garrido (2017) reported reduction in downy mildew (*Plasmopara viticola*) and leaf spot (*Phomopsis viticola*) severity in grapevines treated with Copper Crop®. Copper Crop® was also found to be effective in preventing rust (*Hemileia vastatrix*) and brown-eye spot (*Cercospora coffeicola*) in coffee plants, according to Silva and Dias (2018). The bioactive copper in Copper Crop®, although not reducing the mycelial growth of fungi at tested doses, is readily absorbed by the plant and participates in vital processes such as photosynthesis, respiration, protein metabolism, and cell wall formation, in addition to being involved in plant defense mechanisms.

On the other hand, Eurofit Max® fertilizer, marketed as a biostimulant, does not contain copper in its composition. However, it contains 40% to 50% phosphoric acid and 5% to 10% hydrated manganese and showed good performance in inhibiting mycelial growth of the evaluated fungi (Table 1 and Figure 1). Ferreira et al. (2022) also observed reduction in downy mildew incidence and severity in organic grapevines treated with Eurofit Max®, compared to control. Although phosphoric acid has direct and fast effect by stimulating the plant's natural defense mechanisms, it can also be toxic, inhibiting a particular process (oxidative phosphorylation) in the metabolism of microorganisms, especially in oomycete groups (Dann and McLeod, 2021).

Azzurra Plus® demonstrated excellent mycelial growth control of the evaluated fungi (Table 1, Figure 1). Despite its low copper concentration (4.5%), it also contains sulfur (2%) and phosphorus (20%). This study is the first to evaluate the efficiency of Azzurra Plus® as an 'in vitro' fungicide.

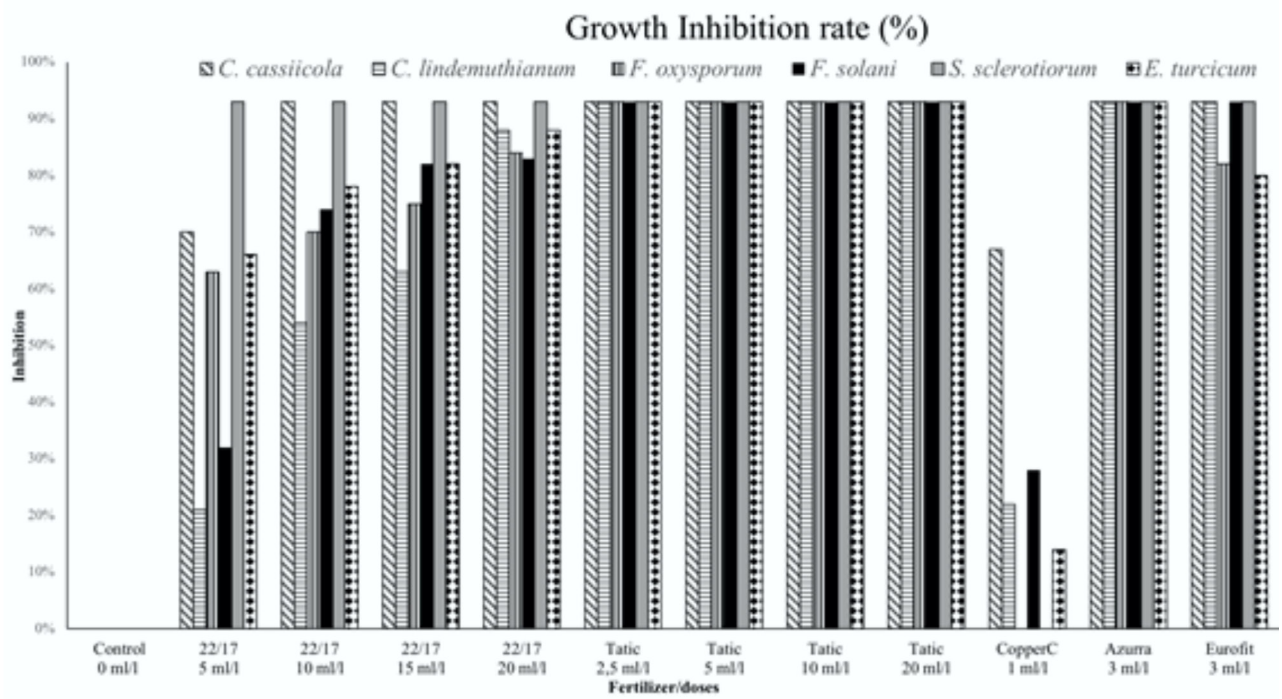
The Mycelial Growth Velocity Index (MGVI), obtained as a function of the average diameters observed, is inversely proportional to the inhibitory fungal growth action by a certain product. The highest MGVI values were observed for negative control and Copper Crop® (Figure 8). Furthermore, *F. oxysporum* in the treatment with Copper Crop® showed growth of 1.8 cm/day, which was statistically equal to control treatment with growth of 1.83 cm/day. The lowest MGVI results were observed for the *C. cassiicola*, *C. lindemuthianum*, *F. oxysporum*, *F. solani*, *S. sclerotiorum*, and *E. turcicum* fungi submitted to Tatic® and Azzurra Plus® fertilizers at all tested doses. These results show that it is possible to manage the use of these two fertilizers to aid in plant protection and disease control. However, the present study was conducted under controlled conditions, and there are a variety of other factors in the field that interfere with disease development.

Figure 8. Mycelium Growth Velocity Index (MGVI) in cm/day was measured for the *C. cassiicola*, *C. lindemuthianum*, *F. oxysporum*, *F. solani*, *E. turcicum*, and *S. sclerotiorum* fungi treated with varying doses of fertilizers including 22/17 (at doses of 5, 10, 15, and 20 ml/l), Tatic® (at doses of 2.5, 5, 10, and 20 ml/l), CopperCrop® (at dose of 1 ml/l), Azurra® (at dose of 3 ml/l), and Eurofit® (at dose of 3 ml/l).



The highest growth inhibition rate (GI%) was observed in *C. cassiicola*, *C. lindemuthianum*, *F. oxysporum*, *F. solani*, *S. sclerotiorum*, and *E. turcicum* fungi when treated with Tatic® (at all tested doses) and Azurra Plus® fertilizers, which demonstrated a 93% inhibition rate (Figure 9). Tsunoda and Nishimoto (1986) reported that for a new chemical formulation to be considered effective, its efficiency rate must be over 80%. Thus, if the results of the current study were replicated under field conditions, the use of these two products as fungicides would be justified.

Figure 9. Growth inhibition rate (%) of *C. cassiicola*, *C. lindemuthianum*, *F. oxysporum*, *F. solani*, *E. turcicum*, and *S. sclerotiorum* was determined after treatment with fertilizers at different doses: 22/17 (5, 10, 15, and 20 ml/l), Tatic® (2.5, 5, 10, and 20 ml/l), CopperCrop® (1 ml/l), Azurra® (3 ml/l), and Eurofit® (3 ml/l).



Moreover, as the fertilizer 022/17 dose increased, significant increase in GI% was observed. At dose of 10 ml/l, *C. cassiicola* and *S. sclerotiorum* showed 93% inhibition, *C. lindemuthianum* and *E. turcicum* demonstrated 88%, *F. oxysporum* had 84%, and *F. solani* showed 83% inhibition. Numerous studies have demonstrated the efficacy of nickel against plant pathogens. For example, nickel has been used to control blast disease (*Pyricularia oryzae*) in rice (Ramalingam et al., 2023) and powdery mildew (*Microsphaera diffusa*) in soybeans (Barcelos et al., 2018). Einhardt et al. (2020) also observed a 35% reduction in Asian rust in soybean crops when nickel was used. When in contact with nickel, plants exhibited less oxidative stress and higher amount of lignin.

Fertilizers have various functions, including providing nutrition and contributing to the defense mechanisms of plants. They can also offer fungistatic effects and act similarly to some fungicides with protective action (Tripathi et al., 2022). Among fertilizers under study, Tatic® (SATIS®) and Azurra Plus® (Biocross®) exhibited excellent antifungal potential and can be used to prevent economic losses caused by the tested fungi. While Eurofit Max®, Copper Crop®, and 022/17 (SATIS®) showed significant results for some fungi, *F. oxysporum* and *E. turcicum* were the least responsive to the effects of fertilizers.

The evaluated fertilizers demonstrated promising ‘in vitro’ fungistatic action results. However, it is important to note that these results were obtained under isolated and controlled conditions. In the field, several environmental factors, in addition to the pathogen and the host plant, can influence the development of diseases. Nutrients are crucial for good plant development and have high potential in controlling several diseases. Furthermore, these products act on the physiological processes of plants and are toxic to some fungi. Additionally, fertilizers have a different action site compared to systemic fungicides and can be used in combination with them to control fungal diseases, particularly for fungi that have developed resistance to site-specific fungicides.

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