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Production of nine potato cultivars treated with pyraclostrobin and submitted to different fertilization levels

Produção de nove cultivares de batata tratadas com piraclostrobina e submetidas a diferentes níveis de adubação

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ABSTRACT

Treatments with pyraclostrobin, a fungicide from the strobilurin chemical group, have induced physiological effects in several plants, which may influence their productivity. In this study, two experiments were carried out to study the effect of a commercial product containing pyraclostrobin + metiram on productivity and virus dissemination in potato cultivars. The first experiment was carried out in Maria da Fé-MG, applying different combinations of the product via furrow at planting and via foliar application, in post-emergence, using the cultivar Cupido and two fertilizer levels: 2,500 kg/ha and 3,500 kg/ha of NPK in the formulation 4:14:8. In the second experiment, eight French potato cultivars were tested in São Gonçalo do Sapucaí-MG, with applications of the fungicide via furrow and via foliar application. An interaction between the fertilizers and cultivars with the types of fungicide treatments used was observed. There was a significant increase of 13.6% in the production of the treated potato cv. Cupido, when the fungicide was applied in the furrow and the NPK level was 2,500 kg/ha. The production of all eight cultivars tested was higher in the treated plots, and the greatest productivity gain was 28% in cv. Eole. In both experiments, pyraclostrobin did not affect the spread of the virus in the field. This study showed that pyraclostrobin has the potential to increase potato productivity and reduce fertilizer use. However, the best treatment and the best fertilizer level should be determined for each cultivar, since the cultivars used responded differently to the same treatments.

Index terms: Fungicide; strobilurin; viruses; fertilization; physiological effect.

RESUMO

Tratamentos com piraclostrobina, fungicida do grupo químico das estrobilurinas, têm induzido efeito fisiológico em diversas plantas, podendo influenciar na sua produtividade. Neste trabalho, foram realizados dois experimentos, objetivando estudar o efeito de um produto comercial contendo Piraclostrobina + metiram na produtividade e disseminação de vírus em cultivares de batata. O primeiro experimento foi realizado em Maria da Fé-MG, aplicando diferentes combinações do produto via sulco no plantio e via foliar, em pós-emergência, utilizando a cultivar Cupido e dois níveis de adubação: 2,500 kg/ha e 3,500 kg/ha de NPK na formulação 4:14:8. No segundo experimento, foram testadas oito cultivares de batata francesa em São Gonçalo do Sapucaí-MG, com aplicações do fungicida via sulco e via foliar. Foi constatada interação entre os fertilizantes e cultivares com os tipos de tratamentos fungicidas usados. Houve um aumento significativo de 13,6% na produção da batata tratada cv. Cupido, quando a aplicação do fungicida foi feita no sulco e o nível de NPK foi de 2.500 kg/ha. A produção de todas as oito cultivares testadas foi maior nas parcelas tratadas, e o maior ganho de produtividade foi de 28% na cv. Eole. Nos dois experimentos a piraclostrobina não afetou a disseminação do vírus no campo. Neste trabalho verificou-se que a piraclostrobina tem potencial para aumentar a produtividade da batata e reduzir o uso de fertilizantes. Entretanto, o melhor tratamento e o melhor nível de adubação devem ser determinados para cada cultivar, visto que as cultivares empregadas responderam de modo distinto aos mesmos tratamentos.

Termos para indexação: Fungicida; estrobilurina; vírus; adubação; efeito fisiológico.

Introduction

Pyraclostrobin plays a direct role in regulating hormonal balance and enhancing carbon and nitrogen assimilation in plants, particularly under stressful conditions. Additionally, its application has been shown to significantly improve plant defense responses. (Dal Cortivo et al., 2017; Liang et al., 2018; Sulewska et al., 2019; An et al., 2023; Zhang et al., 2024). They have reported that nitrogen assimilation by plants treated with pyraclostrobin is greater than that of untreated plants, culminating in a significant increase in biomass, yield and nitrogen content. Based on these studies, it is believed that the several fungicides available on the market belonging to the chemical group of strobilurins, in addition to having the expected antifungal activities, also raise the quality and yield of

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the crop (Tsialtas et al., 2018; Mesara et al., 2022; Guimarães et al., 2017; Fang et al., 2024, Venancio et al., 2024).

Hermes et al. (2002) evaluated the effect of a fungicide of the F500 family (pyraclostrobin) on plants infected with viruses and bacteria, infiltrating the fungicide in tobacco plants (*Nicotiana tabacum* cv. Xanthi nc), previously treated and infected with TMV. They observed a very high induction and faster expression of the PR1 TMV gene, with consequent accumulation of the respective protein, in pretreated plants than in control plants. This protein is responsible for local necrotic lesions (HR) developed in response to viral infection, and the acceleration of this defense response in treated hosts demonstrated the ability of this fungicide to induce resistance to Tobacco mosaic virus (TMV). Another evidence of this fact was the reduction of about 50% in the size of the necrotic lesion observed in the leaves of treated plants.

Similar results were observed for the bacterium *Pseudomonas syringae* pv. tabaci in tobacco plants of the same cultivar. Therefore, it is believed that fungicides containing any kind of strobilurin, in addition to their antifungal action, also act to protect plants by increasing their defense response, which is usually induced later by the elicitor pathogen itself (Udayashankar et al., 2012; Itako et al., 2015; Tsialtas et al., 2018; Skandalis et al., 2016; Guimarães et al., 2017). It is believed that fungicides whose active principle is pyraclostrobin, as well as other substances in this chemical group, can inhibit the electron transport chain and increase the level of reactive oxygen species (ROS) within the mitochondria. This would induce an increase in the expression of unknown nuclear defense genes, resulting in the inhibition of viral movement and replication (Xie et al., 2001).

The fungicide known as CabrioTop®, which has pyraclostrobin and metiram as active principles, has been extensively studied for its ability to cause increased vigor in potato plants, even when infected by viruses. This fact points to the possibility that this chemical group may act in the development and even in the spread of viral diseases in crops, through the activation of genes responsible for reducing or paralyzing the replication and movement of viral particles. It would be a very good and attractive alternative management, since this fungicide is able to control very efficiently one of the main diseases of this crop, late blight caused by *Phytophtora infestans* (Fagan, 2010). Thus, the use of the product to control late blight could provide an extra benefit, also acting in reducing losses caused by viral diseases.

In this work, the behavior of eight French and one Brazilian potato cultivars (cv. Cupido) was investigated in relation to virus dissemination in the field, considering its initial and final incidence in the tubers, and the production of plants when subjected to two levels of fertilization and treatment with pyraclostrobin.

Material and Methods

Experiment setup with Cupido cultivar

The experiment was carried out at the EPAMIG Experimental Station, in the municipality of Maria da Fé in Minas Gerais, located at 1,280 meters of altitude, 22º18'29"south latitude and 45º22'32" west longitude.

The experimental model used with Cupido cultivar was a randomized block design (DBC), with each plot consisting of 2.4 m^2, using 20 tubers and 8 replications, with a spacing of 0.8 m between rows and 0.30 m between plants. Two levels of fertilization were used with NPK (4% N - 14% P_2O_5 - 8% K_2O): the first being below the one usually used, 2,500 kg/ha, and the second, following what has been used by the farmer, 3,500 kg/ha. At each level of fertilization, the following treatments were applied with the fungicide pyraclostrobin + metiram: (i) application of the fungicide only in the planting furrow, at a dosage of 2,000 g/ha; (ii) spraying the fungicide only about ten days after seedling emergence, at a dosage of 1,800 g/ha; (iii) combination of the two previous treatments, that is, application in the furrow and spraying ten days after seedling emergence; and (iv) control, without the fungicide pyraclostrobin + methiran. The spraying of this fungicide in the treated plots, after emergence, was carried out in a more directed way, using a manual costal sprayer with an empty conical spray nozzle, flow rate of 500 L/ha and low pumping pressure, thus avoiding drift between the neighboring plots.

For phytosanitary control, two chemical products recommended for potato cultivation were used, namely, the fungicide with active principle pencycuron (Monceren PM) to combat *Rhizoctonia solani*, and the fungicide based on metalaxyl + mancozeb (Ridomil Gold) to combat *Phytophtora infestans*. The frequency of applications varied according to the incidence and severity of disease in the field and the manufacturer's recommendations.

Experiment setup with eight potato cultivars treated with pyraclostrobin

The experiment was carried out in the municipality of São Gonçalo do Sapucaí - Minas Gerais, from June to September season, aiming to investigate the effect of pyraclostrobin present in the fungicide used on the production of plants of eight French potato cultivars: Bailla, Eole and Florice, intended for cooking; Canelle, Emeraude, Opaline and Soléia, intended for both frying and cooking, and Gredine, which produces small tubers, suitable for the production of pre-cooked tubers, vacuum-packed. The potato tubers used in this experiment was firstly analyzed by DAS-ELISA (double sandwich antibody – enzyme-linked immunosorbent assay) using polyclonal antisera against potato virus y (PVY), potato leafroll virus (PLRV), potato virus x (PVX) and potato virus s (PVS), following the manufacturer's instructions.

The sprouted seed tubers, from the cold chamber, were planted using a randomized block experimental design (DBC), with each plot consisting of 3.6m^2, using 15 tubers and 6 replications. The plots were subjected to two treatments: (i) application of the fungicide pyraclostrobin + metiram, at a dose of 4,500 g/ha in the planting furrow, followed by spraying with the same product at a concentration of 1,800 g/ha, about 10 days after plant emergence and (ii) control, without application of the fungicide. The doses of the fungicide applied were chosen according to the manufacturer's recommendations and based on experiments that have been carried out in the field. Sprays with pyraclostrobin + metiram followed the same methodology as in the first experiment, avoiding drift between plants.

The phytosanitary control in this case was carried out using the fungicide whose active principle is pencycuron (Monceren PM) to combat *Rhizoctonia solani* and the insecticide based on deltamethrin (Decis) to combat *Diabrotica speciosa* (kitty). The number of applications and doses varied according to the incidence and severity of disease in the field and the manufacturer's recommendations.

Assessment of virus spread and potato cultivars yield

To determine the initial and final virus incidence in both experiments, the potato tubers of Cupido cv. used in the first experiment and the tubers of the eight cultivars used in the second experiment were first analyzed by DAS-ELISA (Clark & Adams, 1977) using polyclonal antisera against PVY, PLRV, PVX and PVS before planting and after harvest, following the manufacturer's instructions.

The potato yield evaluation was carried out by separating the tubers by size, with the aid of two sieves capable of separating them according to the size of their meshes: large (> 45mm in diameter), medium (>28mm<45mm) and small (≤28mm). These were then weighed, and the data obtained were subjected to analysis of variance. Mean values were analyzed using the Scott-Knott test at a 5% probability level, using the SISVAR® computer program.

Results and Discussion

Effect of pyraclostrobin on the virus spread and on the yield of Cupido cultivar at two levels of fertilization

Figure 1 shows the layout of the experiment carried out with the Cupido potato cultivar, at different stages of the plant's life cycle. The analysis of the tubers used as seeds, in the first experiment, showed an initial incidence of 1% for PVY, and absence of PLRV, PVX and PVS. After harvesting the experiment, the mean of the final incidence of PVY was 5% and that of PLRV, which was absent in the seeds, was 2%, in all experimental plots, with no difference between the treatments used. Therefore, treatments with the fungicide pyraclostrobin + metiram seem not to have influenced the dissemination of these viruses in the field. The final incidence showed that the spread of PVY and the transmission of PLRV, from outside to inside the field, were relatively small, indicating that there was a good control with the phytosanitary treatments carried out. Usually, the incidence of PVY in Brazilian potato fields tend to be higher (Kreuze et al., 2020). Daniels et al. (2002) reported an incidence of 17% of PVY and 3% of PLRV in tubers pf F1 generation after the first field multiplication of G0 potato seeds.

Analyzing the yield of plants subjected to the same treatment, at the two levels of fertilization, it was observed that when the fertilization level was 2,500 kg/ha the treatment in the furrow allows 13.6% of yield gain (ton/ha) and when the plants was treated in furrow and after emergence the gain was 5.8% (Table 1). When the fertilization was 3,500 kg/ha, only the plants treated after emergence and treated in furrow plus after emergence, showed a gain of 8.1% and 6.0%, respectively, comparing to the control plants.

Comparing the two fertilization levels, only the plants that received a treatment with pyraclostrobin + metiram after emergence had higher yields, increasing from 12.36 ton/ha to 15.33 ton/ha (24.03%). Plants with the highest level of fertilization, which received treatment only in furrow or furrow + emergence had a production equal to or inferior than that with lower fertilization level.

Statistical analyzes showed that there was a significant interaction ($p<0.005$) between the treatment with fungicide and the level of fertilization in each area. The verification of this interaction was important, since it indicated that treatments with the fungicide pyraclostrobin + metiram cannot be generalized to different levels of fertilization. Furthermore, it showed that the treatment of plants in the field with lower amount of fertilization led to a greater gain in production and was similar to the plot with the best performance at the highest level of fertilization, with treatment only after emergence. Therefore, the producer could save on fertilizer and invest in treatment with this product, which, as an additional effect, provides good control of important fungal diseases such as late blight.

Tyasmoro et al. (2019) also reached similar conclusion when tested the effect of rates of nitrogen, from 30 kg/ha to 120 kg/ha, combined with foliar spray of pyraclostrobin in maize plants. They observed that the application of pyraclostrobin on maize increased significantly the efficiency of N fertilization as N is the most needed mineral for plant growth and production in cropping systems (Souri & Hatamian, 2019; Aghaye Noroozlo et al., 2019). Carucci et al. (2020) also tested the interaction among several level of nitrogen doses and strobilurin in two wheat cultivars. Based in their results, they hypothesized that in Mediterranean condition, would be possible to reduce the nitrogen application rate from 130 kg/ha to 90 kg/ha with the combination with strobilurin. It could represent a useful agronomic strategy.

Figure 1: Experiment carried out in Maria da Fé, MG, with the potato cultivar cupido and two levels of fertilization. A: experiment at 15 days after plant emergence; B: experiment at 30 days after emergence; C: experiment at 50 days after emergence; plant infected with PVY.

Table 1: Production of potato plants of Cupido cultivar subjected to different treatments with CabrioTop®, at two levels of fertilization in Maria da Fé, MG.

Fertilization Treatament/CabrioTop®	Average Production per Tuber Size (T/ha)					Total Yield T/ha	% Gain
	Large	% of total	Medium	% of total	Small		
2.500 kg/ha							
Furrow	7.3 A*c**	51.6	6.6 Bb	46.2	0.3 Bc	14.2 Bc	13.6
Post-emergence	6.9 Ab	55.4	5.4 Aa	43.4	0.1 Aa	12.4 Aa	
Post-emergence + furrow	7.9 Ad	60.2	5.1 Aa	38.4	0.2 Ab	13.2 Bb	5.8
Control	5.6 Ba	44.7	6.8 Bb	54.3	0.1 Aa	12.5 Aa	
3.500 kg/ha							
Furrow	7.9 Ab	58.3	5.5 Aa	40.8	0.1 Aa	13.6 Aa	
Post-emergence	9.8 Cc	63.7	5.4 Aa	35.0	0.2 Bb	15.3 Bc	8.1
Post-emergence + furrow	7.1 Aa	52.4	6.2 Bb	46.1	0.2 Ab	14.2 Bc	6.0
Control	7.9 Ab	55.6	6.1 Ab	43.2	0.2 Ab	13.4 Aa	

*Averages followed by the same capital letter, in the column, do not differ from each other using the Scott Knott Test at the 5% probability level, when comparing the eight treatments, at the two fertilizer levels. **Averages followed by the same lowercase letter, in the column, do not differ from each other using the Scott Knott Test at the 5% probability level, when comparing the four treatments within each fertilizer level. (CV%=3.82).

The interaction between nitrogen levels and pyraclostrobin has been studied for several plant species. Groff et al. (2020) investigated the physiological effect of pyraclostrobin on wheat plants grown in soil with content of nitrogen ranging from 30 kg/ha to 101 kg/ha. They observed that plants with or without being sprayed with the fungicide increased their chlorophyll content with the increasing of nitrogen doses. However, the crescent doses of nitrogen induced a linear increase in the fresh mass of the plants only when they were sprayed with pyraclostrobin. In the same way, Shetley et al. (2015) evaluated the grain yields of three maize

cultivars in three locations in Missouri state, when sprayed and non-sprayed with pyraclostrobin and combined with 13 fertilizers. They observed that the application of 30-0-0-0 (%N-%P_2O_5-%K_2O-%S) was the only foliar fertilizer that increased grain yields by 10% at two locations compared to the non-treated control.

Sometimes the effect of fungicides from the chemical group of strobilurins depends on the availability of the nitrogen in the soil. Ishikawa et al. (2012) employed several spray programs of fungicides containing strobilurins combined with different nitrogen doses aiming to study the response of wheat cv. Hereward in terms of grain yield and N content, in Newport – UK. They observed that the accumulation of dry matter and N content increased with the increase of rates of N application. They pointed out that the benefit of applying fungicides could only be exploited with nitrogen fertilization.

Divergent results can also be found in the literature. Schumacher et al. (2017) did not detect any beneficial or deleterious effects of the pyraclostrobin application at different times and applications combinations in two hybrids of maize grown in the summer season in Jataí – Go-Brazil. Martinazzo et al. (2016) investigated the chlorophyll content and the activity of the enzyme nitrate reductase in tomato plants submitted to complete nutrient solution and nutrient solution ½ ionic strength of the nitrogen. The application of pyraclostrobin reduced the chlorophyll synthesis in plants in complete nutrient solution but increased the chlorophyll content 28 days after application of the pyraclostrobin to plants in the solution with lower nitrogen concentration.

In this work, comparing the different treatments within each level of fertilization, it was observed that, at the lowest level, only two of the treatments led to significant gains in relation to the control plots: the treatment only in the furrow (13.6%) and the combination of treatments in the furrow and post-emergence (5.8%) (Table 1). At the highest level of fertilization, the only treatment that led to an increase of 8.1% compared to the control was spraying the plants about 10 days after emergence.

Cupid is a potato cultivar that has ideal frying characteristics, so the production of larger tubers is more desirable. Considering this, all treatments with pyraclostrobin + metiram, at the lowest level of fertilization were better compared to the control, and the one that induced a greater production of large tubers was obtained in the combined treatment, in the furrow and post-emergence, not coinciding with the one with the highest total production, with treatment only in the furrow. Already at the fertilization level higher, the best treatment was post-emergence, which coincided with the highest total production (Table 1).

Even knowing that pyraclostrobin can induce a physiological effect on plants, resulting in an increase in protein content, plant mass and plant yield, the interaction mechanism between strobilurins, the plant and the environment still needs further studies. The application of the fungicide in the planting furrow, when the level of fertilization is higher, seems not to have favored the initial development of the potato cultivar Cupido. It becomes necessary to carry out other experiments, using different levels of fertilization, with other cultivars and dosages of pyraclostrobin + metiram, for a definitive conclusion.

Evaluation of virus spread and yield of eight potato cultivars subjected to treatment with pyraclostrobin

The plot of the experiment with the eight potato cultivars at different stages of their life cycle can be seen in Figure 2. In this experiment the virus dissemination in potato plants of different cultivars also did not show any difference between treated and untreated plots. The initial virus indices ranged from zero (cvs. Bailla, Emeraude, Eole, Florice and Soleia) to 7.8% of PVY (cv. Opaline), while the other viruses were absent. In determining the final virus index, PLRV was not detected only in cultivars Gredine, Opaline and Soleia. In the other cultivars, the average PLRV index ranged from 1.2 to 4%, while that of PVY was between 5.3% and 15.5%.

The cultivars with the lowest incidence of PVY were Soleia (5.3%), Bailla and Florice (both around 10%) and those with the highest infection rate were Eole (14.3%), Gredine (15.4%) and Canelle (15.6%). These results clearly showed that pyraclostrobin did not interfere with virus acquisition and transmission, showing that there was no interference in the vector feeding process in the treated potato plant.

Different cultivars often show a variation in resistance to virus spread in the field. Studying the degeneration of four potato cultivars, Daniels et al. (2002) observed that in the first generation the incidences of PVY and PLRV were, respectively: cv. Baronesa 7.5% and 0.3%, cv. Catucha 22% and 19%, cv. Elvira 42% and 0%. In the second generation the virus incidences were: cv. Baronesa 67% and 6%, cv. Catucha 68% and 49%, and cv. Elvira 94% and 2%. Similar variation was observed with the eight potato cultivars under the conditions of this experiment.

The difference between the average production of plants treated and not treated with the fungicide pyraclostrobin + metiram varied for each cultivar, showing that there was a significant interaction between the cultivar and the treatment ($p<0.005$) (Table 2). When analyzing the proportion of large tubers produced by each of the cultivars, the highest proportion of large tubers was observed in cv. Florice. In six of them the treated plots produced a greater number of tubers than the untreated ones. Only in the Canelle and Soleia cultivars the untreated ones showed equal and greater production than the treated ones, respectively.

The smallest proportion of large tubers was observed in cv Gredine, but this was to be expected, because it was developed to produce a larger quantity of medium tubers, to be pre-cooked and vacuum packed. It is noted that the treated plots of cultivar Gredine produced a greater number of medium tubers than the untreated ones, which represents a gain, especially when considering that the untreated plots produced more large tubers than the untreated ones.

Figure 2: Experiment carried out with eight potato cultivars in São Gonçalo do Spucaí, MG. A: potato field 10 days after plants emergence; B: potato field 50 days after plants emergence (1: cv. Eole treated with pyraclostrobin; 2: non-treated cv. Florice); C: plant infected with PLRV; D: experiment harvesting).

Table 2: Effect of fungicides on the yield of eight potato cultivars in São Gonçalo do Sapucaí, MG.

Cultivar	Treatment with CabrioTop®	Average Production by Tuber Size (T/ha)					Yield (T/ha)	Gain (%)
		Large	% of total	Medium	% of total	Small		
Bailla	Treated	7.0 b*	31.8	13.3 b	60.5	1.7 b	22.0 **F b	12.7
	Non-treated	5.4 a	27.6	11.9 a	61.0	2.2 a	19.5 G a	
Canelle	Treated	9.0 a	45.0	9.9 b	49.5	1.1 b	20.0 D b	9.4
	Non-treated	9.4 a	51.7	8.4 a	45.9	0.5 a	18.3 D a	
Emeraude	Treated	7.7 b	49.3	7.2 a	46.2	0.7 a	15.6 B b	9.2
	Non-treated	6.3 a	43.8	7.2 a	50.3	0.8 a	14.3 B a	
Eole	Treated	13.5 b	69.6	4.9 a	25.3	1.0 a	19.4 G b	22.5
	Non-treated	10.2 a	64.6	4.7 a	29.7	0.9 a	15.8 C a	
Florice	Treated	10.2 b	73.9	3.1 a	22.4	0.5 a	13.8 A b	9.0
	Non-treated	9.1 a	72.2	3.0 a	23.8	0.5 a	12.6 A a	
Gredine	Treated	4.8 b	28.2	9.4 b	55.2	2.8 b	17.0 C b	13.4
	Non-treated	3.9 a	26.2	8.7 a	58.4	2.3 a	14.9 B a	
Opaline	Treated	15.2 b	66.4	7.1 b	31.0	0.6 b	22.9 F b	16.6
	Non-treated	11.2 a	56.8	7.7 a	39.1	0.8 a	19.7 D a	
Soleia	Treated	15.5 a	54.8	11.9 b	42.0	0.9 b	28.3 H b	19.6
	Non-treated	16.3 b	69.1	6.7 a	28.4	0.6 a	23.6 F a	

*Averages followed by the same lowercase letter, in the column, do not differ from each other, according to the Scott Knott Test at the 5% probability level, within the same cultivar. **Averages followed by capital letters in the column do not differ from each other, according to the Scott Knott 5% probability test, when the 16 treatments were purchased. CV (%) = 4.73.

Despite having noticed a greater overall proportion of medium tubers in the Bailla cultivar, this does not mean a loss, as this is also intended for frying. This was because this cultivar has a tuber with a diameter of around 45 mm, allowing it to pass through the meshes of the sieve used in the classification. However, it has an elongated tuber, which guarantees its use as a frozen pre-fried or for sale in natura for frying.

Evaluating the total production, the cultivar Eole presented the greatest production gain, with an increase of 22.5%, followed by Soléia, whose treated plants produced 19.6% more than the control ones (Table 2). The smallest increment was observed in Emeraude and Canelle cultivars, with differences around 9% between treated and control plants. In the other cultivars there was more than 12% increase in the production of plants submitted to treatment with the fungicide. In the previous experiment, it was noticed that the same treatments with this product varied with the level of fertilization, when the same potato cultivar was used. In this experiment, it was observed that when the level of fertilization was fixed for different cultivars, their reaction to treatment with this product was also different. However, anyway there is a gain in production in plants treated with fungicide (pyraclostrobin + metiram). Cultivar Eole, which had one of the highest final rates of PVY incidence, had the greatest increase in production, that is, more than 20%. This could indicate that pyraclostrobin caused a physiological effect that prevented losses caused by a higher incidence of PVY. However, additional experiments should be carried out to better investigate this issue.

Other authors already found the interaction between the treatment with pyraclostrobin and plant cultivars. Carucci et al. (2020) carried out an experiment in rainfed Mediterranean conditions to investigate the influence of strobilurin combined with different nitrogen doses (from 60 kg/ha to 120 kg/ha) on two durum wheat cultivars (Sfinge and Saragolla). They reported that the effect of strobilurina was different for the two wheat cultivars under different N fertilization applied, indicating that the genetic response of each one was unlike. Therefore, they comment that the positive effect of strobilurin on nitrogen uptake and remobilization efficiency ultimately depends on the cultivars, what means that the interaction between strobilurin treatment and cultivar seems to be very important. Venancio et al. (2024) evaluated the forage yield, morphology and nutritional value of three winter cereal: wheat, white oats and black oats in presence and absence or pyraclostrobin. They registered positive changes in the morphology and chemical characteristics of the plants, but white oats expressed a greater balance between productivity and chemical characteristics for quality forage production compared to wheat and black oats.

Considering that the combination of pyraclostrobin + metiram is used to control fungal diseases, its usage will always be beneficial for the potato crop, which is highly susceptible to fungi such as *Phytophtora infestans*. However, for its rational use aiming at the plant yield, there is a need to carry out more studies to determine the best treatment, capable of allowing the maximum expression of the genetic potential of each potato cultivar.

Conclusions

All potato cultivars treated with pyraclostrobin + metiram showed higher productivity. Furthermore, the application of pyraclostrobin + metiram did not impact the dissemination of PVY and PLRV in the field. There was interaction between potato cultivars and pyraclostrobin treatment at the same fertilizer level, and between pyraclostrobin treatments and different fertilizer levels. The Cupido potato cultivar treated with pyraclostrobin + metiram showed higher productivity when a lower NPK level (2,500 kg/ha) was used.

Author Contribution

Conceptual idea: Galvino-Costa, S.B.F.; Figueira, A.R.; Methodology design: Galvino-Costa, S.B.F.; Figueira, A.R.; Data collection: Galvino-Costa, S.B.F.; Figueira, A.R.; Rabelo Filho, F.A.C.; Pádua, J.G.; Data analysis and interpretation: Galvino-Costa, S.B.F.; Figueira, A.R., and Writing and editing: Galvino-Costa, S.B.F.; Figueira, A.R.; Silveira, A.T.L.

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