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Foliar fungal diseases control and productivity depending on the phosphite and fungicide application in two corn hybrids

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ABSTRACT
Foliar diseases are among the main factors of losses in productivity and grain quality in all corn (*Zea mays* L.) producing regions. The objective of this work was to evaluate the control of corn foliar fungal diseases and yield as a function of phosphite and fungicide application. Two experiments were generated in the agricultural years 2014/2015 and 2015/2016, under ´cerrado´ area, in the municipality of Gurupi, Tocantins, Brazil. It was used a randomized block design in a factorial scheme of 4 (foliar treatment with fungicide, phosphite, fungicide mixture plus phosphite and water), x 2 (corn hybrids, AG7088 PROX and 30F53YH), with three replications. The products were applied in the stages with leaves and tasseling. For evaluating the disease severity, it was used a scale of visual grades. With severity, the Area Under Disease Progress Curve (AUDPC) was calculated. Besides, were determined the mass of thousand grains (kg ha^{-1}) and the productivity (kg ha^{-1}). The hybrid AG7088 PROX showed low severity of the diseases found: *Bipolaris maydis*, polysorbital rust and *Curvularia* spot. In the genotype 30F53YH, it was verified a higher AUDPC of the polysor rust, being its control more effective with an application of the fungicide and in mixture with the phosphite. The application of phosphite did little to reduce the AUDPC of the diseases when compared to the fungicide, alone or in mixture with the phosphite, but high productivity was obtained with the use of phosphite alone or in mixture with the fungicide.

Keywords: alternative control, *Bipolaris maydis*, *Curvularia* sp*., Puccinia polysora*, *Zea mays*

Control de las enfermedades foliares fúngicas y productividad dependiendo de la aplicación de fosfito y fungicida en dos híbridos de maíz

RESUMEN
Las enfermedades foliares se encuentran entre los factores principales de pérdidas en productividad y calidad del grano en las regiones productoras de maíz (*Zea mays* L.). El objetivo de este trabajo fue verificar el control de enfermedades foliares fúngicas del maíz y el rendimiento en función de la aplicación de fosfito y fungicida. Se generaron dos experimentos en los años agrícolas 2014/2015 y 2015/2016, en el área ´cerrado´, en el municipio de Gurupi, Tocantins, Brasil. Se empleó un diseño de bloques al azar en un esquema factorial de 4 (tratamiento foliar con fungicida, fosfito, mezcla de fungicida más fosfito y agua), x 2 (híbridos

de maíz, AG7088 PROX y 30F53YH), con tres repeticiones. Los productos se aplicaron en etapas con hojas y borla. Para la evaluación de la severidad de la enfermedad se utilizó una escala de grados visuales. La severidad se empleó para calcular el Área bajo la curva de progreso de la enfermedad (AUDPC) para las enfermedades encontradas. Además, se determinó la masa de mil granos (kg ha^{-1}) y la productividad (kg ha^{-1}). El híbrido AG7088 PROX mostró una severidad baja de las enfermedades encontradas: mancha *Bipolaris* (*Bipolaris maydis*), roya (*Puccinia polysora*) y mancha por *Curvularia* (*Curvularia* sp.). En el híbrido 30F53YH, se verificó una mayor AUDPC de roya, siendo su control más efectivo con una aplicación del fungicida y en mezcla con el fosfito. Una aplicación de fosfito hizo poco para reducir el AUDPC de las enfermedades en comparación con el fungicida, solo o en mezcla con el fosfito, pero se obtuvo más productividad con el uso de fosfito solo o en mezcla con el fungicida.

Palabras clave: *Bipolaris maydis*, control alternativo, *Curvularia* sp*., Puccinia polysora*, *Zea mays*

INTRODUCTION

The growth in cultivated area and corn (*Zea mays* L.) productivity can favor the increase of the severity of foliar diseases and contribute to the fact that diseases considered of little importance become a cause of concern for the producers. Foliar diseases are among the main factors of losses in productivity and grain quality in all corn producing regions, being the *Bipolaris* spot (*Bipolaris maydis* (Nisik. & Miyake) Shoemaker) and polysorbite rust (*Puccinia polysora* Underw*)*, those of greater occurrence in Tocantins, as observed by Santos *et al.* (2013) and Chagas *et al.* (2015).

These diseases are favored by high temperature and high humidity, planting in more than one season, adoption of no-tillage and susceptible cultivars (Reis *et al*., 2011). These practices contribute to the survival of pathogens in cultural remains, which corresponds to new sources of contamination in subsequent plantations (Parreira *et al.*, 2014).

The control of foliar diseases is increasingly done through the use of pesticides (Costa *et al.,* 2012) due to more effective responses in reducing the severity of the diseases and to provide greater increases in productivity. However, the use of foliar phosphites as an alternative or complementary control method should be tested in the corn crop, as they may improve the nutritional aspects of the crop, especially in the stages of increased metabolic activity, where the application of the product represents a supplementation of nutrients and quick absorption of phosphorus and potassium (Nojosa *et al.,* 2009).

Phosphites are capable of directly or indirectly activating the natural defense mechanism of plants by the production of phytoalexins, which confer resistance against phytopathogens microorganisms. According to Daniel & Guest (2005), this activation can occur due to the high mobility of the phosphites, which are rapidly absorbed, have a systemic action, act to reduce mycelial growth, sporangia formation and release of zoospores of phytopathogens, such as rust. Countless studies report stimulating the formation of natural substances of self-defense of the plant, protecting it from the attack of fungi, as well as presenting fungicidal effect, acting directly on the fungus (Meneghetti *et al.*, 2010; Silva *et al.*, 2013; Neves & Blum, 2014; Ventura *et al.,* 2018).

Studies related to the effect of phosphites on disease reduction and yield increase on corn crop under ´cerrado´ conditions are still scarce, so that products that activate the defense mechanisms of corn plants and favor increased efficiency of fungicides should be tested, since they may add to the more efficient and economical control of foliar fungal diseases. Thus, the objective of this work was to evaluate the control of foliar fungal diseases and corn productivity as a function of the application of phosphite alone or in mixture with fungicides.

MATERIAL AND METHODS

Plant material

Seeds of two hybrids (30F53YH, simple hybrid by Pionner and AG7088 PROX MAX, simple hybrid by Agroceres) from *Zea mays* L., with a cycle of 120 to 130 days, flowering at 65 days were used for field experiments.

Experimental conditions

The experiments were conducted in the ´cerrado´ field in the rainy season in 2014/2015 and in 2015/2016 in Gurupi (TO), in the experimental area of the Federal University of Tocantins (UFT), 11° 43' S e 49° 04 N' at 280 m altitude. The climate is kind of B1wA' with moderate water deficiency according to the climatic classification of Koppen (1948).

Seeding was done manually in conventionally prepared soil in order to obtain a population of approximately 60 000 plants in both experiments. The basic fertilization consisted of the application of 450 kg ha^{-1} of the formulation NPK 05-25-15 in the planting groove and in the cover was applied the dose of 150 kg ha^{-1} of urea in the phase between V4 (four expanded leaves) and V6 (six expanded leaves) in an open groove next to the planting lines. For the control of invasive plants, a mixture of atrazine + nicosulfuron herbicides at a dose of 5 + 1.5 l ha^{-1} respectively and with manual weeding was applied in emergent powders.

Pest control was carried out through the application of the insecticide methomyl at a dose of 0.6 l ha^{-1}. Harvesting was done manually, in the useful area of the plots. In order to obtain the data of productivity (kg ha^{-1}) and mass of one thousand grains expressed (kg ha^{-1}), the ears were threshed in a harvester.

The climatic variables of the period of conduction of the experiments were: average precipitation (mm dia^{-1}), mean, maximum and minimum temperatures (°C) and average relative humidity (%), obtained at the meteorological station of the Federal University of Tocantins.

A randomized complete block design was used in a 2 x 4 factorial scheme, with three replications, two hybrids and four leaf treatments. Each experimental unit consisted of four lines, spacing 0.7 m between plants and a length of five meters, with the two central lines as the useful area for evaluations. The hybrids used were the 30F53YH (simple hybrid of the Pionner company) and the AG7088 PROX MAX (simple hybrid of the company Agroceres). The treatments used to control the diseases were: 1 (Phosphite), 2 (Fungicide), 3 (Fungicide + Phosphite) and 4 (Water - control), applied in eight - leaf stages and in pre - a constant pressure costal CO_2 based spray with fan-like tips spaced 0.5 cm across a 3-meter wide bar.

The fungicide used was PRIORI XTRA (chemical group: Azoxystrobin-Strobilurin; Ciproconazole-Triazole) and phosphite was UBYPHÓS + K, whose composition is 30% Phosphorus (P_2O_5) plus 20% Potassium (K_2O) at the recommended doses for corn crop.

The severity of the foliar diseases with incidence began at 60 days after planting in the first year and at 58 days in the second year. It were repeated every seven days until the beginning of the formation of pasty grains. For this, a scale of visual scores ranging from 1 to 9 grades proposed by Agroceres (1996) was used. The severity notes were used to calculate the Area under Disease Progression Curve (AUDPC), as indicating for Campbell & Madden (1990).

Stadistical analysis

The test of normality and homogeneity of variances was performed. When significant, the average data obtained from AUDPC, mass of thousand grains and productivity were submitted to analysis of variance and the means were compared by means of the Tukey test at 5% of probability, with the aid of the software ASSISTAT 7.7.

RESULTS AND DISCUSSION

A variation in the total precipitation during the months of December to April was observed in the 2014/2015 harvest, with a total precipitation of 595 mm, average temperatures of 26 °C, maximum of 32 °C and minimum of 22 °C; relative humidity: mean ± 83%, maximum 95% and minimum 61%. In places where this climatic condition prevails, the emergence of foliar fungal diseases is usually very favorable (Chagas *et al.*, 2015)

In the 2015/2016 harvest, a total precipitation of 577 mm was observed, accumulated from the planting until the last day of April, and of this total, 302 mm occurred in the month of January, where there was intense precipitation. During the period of evaluation of the diseases a daily precipitation average

of 4.5 mm was observed, maximum temperature of 34 °C, minimum of 23 °C and average of 28 °C and average relative humidity of 75%.

In the agricultural year 2014/2015, the AG7088 PROX MAX hybrid had lower AUDPC for the *Bipolaris* spot (*B. maydis*) disease where the mixture of phosphite and fungicide was used, differing from the other treatments (Table 1). There was no significant difference between the treatments isolated from fungicide and phosphite and both did not differ from the control. In the 2015/2016 crop, the statistical difference between treatments for this hybrid was also verified. The application of the fungicide or the phosphite provided better control on *Bipolaris* spot in comparison with the two product mix and the control, which presented the highest AUDPC.

In the hybrid 30F53YH the highest AUDPC of the *Bipolaris* spot occurred with the application of the fungicide mixture with the phosphite in the first crop (2014/15). In the second harvest (2015/16), there was an increase of AUDPC in the control and with application of phosphite alone. Better control occurred where the fungicide was used alone or in mixture with the phosphite. The use of fungicides in the aerial part of the plant provides better physiological conditions for the translocation of photoassimilates and greater productivity (Cunha *et al.*, 2010). In the works by Oliveira *et al.* (2011) and Wise & Mueller (2011) observed satisfactory results for the control of leaf diseases in the corn crop associated with a higher yield of productivity. Positive results in the control of leaf diseases in corn through the application of fungicides have been found in Brazil (Donato & Bonaldo, 2013; Manfroi *et al.*, 2016).

In the 2014/2015 crop, the AG7088 PROX hybrid had a low leaf area affected by polysorbite rust (*P. polysora*). According to Belusso *et al.* (2012), the AG7088 PROX hybrid has good resistance to foliar diseases. The severity of the *Bipolaris* spot in the 30F53YH hybrid was also low than in the control.

Table 1. Area under the foliar diseases progression curve (AUDPC) of corn hybrids, submitted to treatment with fungicide and potassium phosphite, harvest 2014/2015 and 2015/2016, Gurupi - Tocantins.

Crop 2014/2015						
	Bipolaris maydis		*Puccinia polysora*		*Curvularia* sp.	
Treatment	AG7088	30F53YH	AG7088	30F53YH	AG7088	30F53YH
Fungicide (F)	76 a	65 b	53 a	58 c	70 a	72 b
Phosphite (P)	84 a	66 b	42 a	74 b	74 a	84 a
F + P	64 b	89 a	53 a	51 c	64 a	84 a
Water (Witness)	85 a	70 b	42 a	133 a	65 a	70 b
CV%	5.34		8.27		6.08	
Crop 2015/2016						
	Bipolaris maydis		*Puccinia polysora*		*Curvularia* sp.	
Treatment	AG7088	30F53YH	AG7088	30F53YH	AG7088	30F53YH
Fungicide (F)	42 b	42 b	45 a	42 a	142 a	63 c
Phosphite (P)	44 b	106 a	42 a	42 a	95 b	116 a
F + P	69 a	42 b	42 a	42 a	98 b	104 a
Water (Witness)	82 a	95 a	45 a	45 a	108 b	90 b
CV%	14.00		6.23		8.23	

Means followed by equal letters in the column in each period do not differ significantly from each other by the Tukey test at 5% probability

In the hybrid AG7088 PROX no difference was verified among the treatments for the AUDPC of polysorbite rust (*P. polysora*) in the harvests evaluated. It was observed low disease severity in this hybrid, a fact that may be related to hybrid resistance, in addition to the climatic conditions already mentioned above. Rust develops best at temperatures around 23 to 28 °C, high relative humidity and water available on the leaf surface (Casela & Ferreira, 2002). Conditions not verified in the 2015/2016 harvest, where, in general, high temperatures and low rainfall were recorded, mainly between the periods from flowering to grain maturation.

In the hybrid 30F53YH, in the 2014/15 crop, the phosphite + fungicide and fungicide mixture applied provided lower AUDPC (Table 1). Thus, the use of the fungicide in mixture with the phosphite was the most effective in the control of the polysorbite rust, since the application of the phosphite did not maintain the same average of AUDPC as that observed when only the fungicide. In the following harvest (2015/16) there was no difference among the treatments, due to the low incidence of rust in all disease evaluation periods.

Normally, higher levels of disease severity occur when corn reaches flowering, so, in order to have a lower incidence of diseases in plantations, management should preferably be done in a preventive way. The time of application of the treatments in the vegetative phase (eight leaves) and in the pre-plowing, occurred induced the resistance to pollinating rust disease, mainly in the susceptible hybrid 30F53YH. Neves & Blum (2014) studying the influence of fungicides and potassium phosphite on the control of Asian rust and soybean (*Glycine max* L.) yield verified that all the treatments reduced the severity of the disease, but the fungicides were more efficient.

Regarding the *Curvularia* spot (*Curvularia* sp.), in the harvest (2014/15) there was no difference for the hybrid AG7088, probably due to the low severity. In the later harvest (2015/16), there was an increase in AUDPC values in all treatments. The highest AUDPC was observed with the application of the fungicide in this hybrid (Table 1).

The increase of *Curvularia* spot in plants where a control effect was expected is a notable fact (Table 1), since treatments with fungicide and phosphite alone or in mixture were not determinant to reduce the levels of disease severity when compared to the control in the AG7088 PROX hybrid. In this sense, Mourão (2015) evaluated the mycelial growth of *Curvularia* sp. under the effect of the systemic fungicide thiophanate-methyl in *in vitro* tests and observed that even using twice the recommended dosage there was no inhibition of colony growth when compared to the control. This species of *Curvularia* sp. was isolated from leaf lesions of corn plants in experimental field. It was thus shown that the fungus *Curvularia* sp. presented resistance to the fungicide molecule under these conditions. The same may have occurred in the field, where the fungicide used in these tests did not demonstrate efficient control when applied in the hybrid AG 7088 PROX considered more susceptible.

In the 30F53YH hybrid, the treatment Phosphite + Fungicide and Phosphite differed from the others, presenting higher AUDPC (Table 1). In the second crop, the fungicide presented greater efficiency in the control of the *Curvularia* spot. The greater control response with fungicide used may be due to the increased incidence of *Curvularia* spot in this crop, which allowed to verify with more clarity the effects of the treatments.

Vaz-de-Melo *et al.* (2010) evaluated the severity of the *Curvularia* spot in 23 corn hybrids and reported that at that time, although the damages were low when compared to those caused by other diseases, the increase of this disease in the southern region of Tocantins was already verified. It is worth mentioning that according to the scientific literature consulted it can be affirmed that there is a lack of further studies in relation to the *Curvularia* spot in the Brazilian conditions.

According to Sobrinho & Cardoso (1997), the highest temperatures and leaf wetness were the factors that had higher levels of *Curvularia* spot in corn in Parnaíba in the state of Piauí, a fact also observed in this last experiment, since high temperature occurred during almost throughout the long evaluation period.

The results found in this study corroborate with those found in a study by Chagas *et al.* (2015) in municipalities of the state of Tocantins. Although polysorbite rust has been verified with lower severity, these authors emphasize the importance of these diseases in more susceptible cultivars in climatic conditions favorable for their development.

Regarding productivity, there was a difference among the treatments tested in the hybrids AG7088 PRO MAX and 30F53YH in the year 2014/2015, which was not detected in the year 2015/2016. However, hybrids productivity in this crop (2015/2016) was lower than the previous test (Table 2). As mentioned before, the severity of foliar diseases in both crops was low, probably due to the genetic resistance of the hybrids and the irregularity of the rains, which also affected the productivity of the hybrids in the second harvest.

In general, applications in plants with phosphite in admixture with the fungicide or alone provided the highest yields (Table 2). It is known that plants respond differently to the presence of threats to their tissues and that the responses expressed by them are directly related to their nutritional status. According to Carmona & Sautua (2011), phosphite can contribute to the plant having a greater amount of important nutrients, such as P (phosphorus), K (potassium) and micronutrients and in a more readily absorbable way, acting beneficially in the plants. However, these authors reports that the effect of phosphite on the fertilization of plants is still quite contradictory, since several authors argue that phosphite is a poor source of P available, especially in plantations where phosphate fertilization is inadequate. Responses vary from culture to culture and should not be related to phosphorus alone. Considering that corn is a

Table 2. Productivity and mass of one thousand grains in kg ha^{-1} of corn hybrids submitted to fungicide and potassium phosphite applications for the control of foliar fungal diseases, crop 2014/2015 and 2015/2016, Gurupi-Tocantins.

Crop 2014/2015				
Treatments	Productivity (kg ha^{-1})		Mass of a thousand grains (kg ha^{-1})	
	AG7088	30F53YH	AG7088	30F53YH
Fungicide (F)	6755 ab	7494 ab	0.317 a	0.308 a
Phosphite (P)	7302 a	9577 a	0.261 b	0.284 a
F + P	7813 a	8310 a	0.276 b	0.280 a
Water (Witness)	4443 b	5557 b	0.266 b	0.283 a
CV%	15.71		5.02	
Crop 2015/2016				
Treatments	Productivity (kg ha^{-1})		Mass of a thousand grains (kg ha^{-1})	
	AG7088	30F53YH	AG7088	30F53YH
Fungicide (F)	4710 a	4833 a	0.258 a	0.260 a
Phosphite (P)	4725 a	5088 a	0.308 a	0.247 a
F + P	4734 a	4501 a	0.285 a	0.270 a
Water (Witness)	4051 a	4329 a	0.251 a	0.255 a
CV%	7.56		12.72	

Means followed by equal letters in the column do not differ statistically from each other by the Tukey test at 5% probability

fast growing plant and requires nutrients in greater quantity and speed, the use of phosphite should be better studied to verify this interaction (Borin *et al.,* 2017).

Generally, corn productivity is indirectly related to susceptibility levels of the cultivar to certain diseases, which in fact may be true when a plant is attacked early with high severity. In this case, the application of the fungicide has a greater effect on the control of diseases in these plants, contributing to increase productivity (Cunha *et al.*, 2010). In resistant cultivars, the application of fungicides does not result in higher yields (Costa *et al.,* 2012), as observed in the present work with hybrid AG 7088 PROX.

In relation to the mass of a thousand grains, for the AG7088 hybrid there was a difference between the fungicide treatment and the others, which presented a larger mass of one thousand grains. For the hybrid 30F53YH there was no difference among the treatments tested for this variable (Table 2). In the later harvest there was no difference treatments.

In general, the results obtained only with the application of phosphite suggest that there has been a benefit of the use of phosphite in the reduction of diseases in the corn crop when applied preferentially in a preventive way, being able to become an in the reduction of diseases and to improve the aspects nutritional characteristics of the crop. In this sense, Meneghetti (2009) reports many advantages of using phosphite in soybean (*Glycine max* L.), such as: high mobility and rapid absorption of nutrients, easy application through agricultural equipment, high systemicity, low inherent toxicity, improved nutritional status of plants and high efficiency against various diseases and all of this together with the low cost. Besides, according to Nojosa *et al.* (2009), these positive effects are greater especially in the stages of higher metabolic activity of the plants, where the application of the product represents a supplement of nutrients and a faster absorption of phosphorus and potassium, influencing increases in productivity in crops as well conducted.

According to Costa *et al.* (2012), in view of the enormous diversity of diseases in corn, fungicide use should be used in crops where there are favorable conditions for disease development (climate, management and production system), prevalence of disease history in the area, use of susceptible cultivars and greater cost benefit of the application.

In cases where planting occurs under these conditions, mixing the phosphite with the fungicide may be a viable alternative in preventing or reducing disease progression and increasing corn productivity, due to the factors previously observed in this study. According to Scott *et al.* (2015), phosphorus- and silicon-based fertilizers are cited in the literature as inducers of resistance, however few results are found on the use of phosphites in disease control (Borin *et al.*, 2017).

CONCLUSIONS

The application of phosphite and fungicide (PRIORI XTRA) alone or in combination do not control the incidence of *Bipolaris* spot (*Bipolaris maydis*) and polysorbite rust (*Puccinia polysora*) in rice cultivation (hybrid AG7088 and hybrid 30F53YH). Nevertheless, is possible the control of *Curvularia* spot (*Curvularia* sp.), using fungicide in hybrid AG7088. In the hybrid 30F53YH both treatment, phosphite alone or combined with fungicide permit it. Besides, the phosphite alone and combined with fungicide produce an increase in productivity in the first harvest, with no effect in the second harvest.

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Conflict of interest
There are no conflicts of interest.

Authors contributions

Conceptualization JFRC and GRS. Data curation JFRC, GRS and RVC. Formal analysis JFRC. Investigation JCFR and RVC. Methodology JCFR and RVC. Project administration GRS. Resources GRS and RVC. Supervision GRS and RVC. Validation JFRC, GRS and MVAV. Visualization JFRC, GRS, MVAV and EMC. Writing—original draft JCRC, GRS, MVAV and EMC. Writing—review & editing JCRC, GRS and MVAV.

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