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Severity of foliar diseases and yield of corn varieties cultivated in the cerrado of the state of Tocantins in Brazil

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ABSTRACT
Currently, the corn crop (*Zea mays* L.) in Tocantins state in Brazil, is gaining prominence in production in the summer and off-season crops. The greater permanence of the crop in the field favors the increase of foliar diseases, which can cause negative impacts on the production and quality of the crops. The objective of this work was to evaluate the severity of foliar diseases and the yield of corn varieties cultivated in the cerrado of southern Tocantinense. Two field experiments were carried out with 36 varieties, in the municipality of Gurupi, Tocantins. The design used was a randomized block design with two replications. Weekly assessments of the progress of foliar diseases were carried out and the Area Under the Disease Progress Curve (AUDPC) was subsequently determined. The disease verified with the highest incidence and severity was the Bipolaris spot (*Bipolaris maydis*), affecting all the evaluated varieties. The severity of polysorbite rust (*Puccinia polysora*), stalk rot (*Colletotrichum graminicola*) and *Curvularia* spot (*Curvularia* sp.) in the affected varieties was low. Most of the varieties evaluated had estimated yield higher than the Brazilian state and national average for the 2014/2015 summer crop, they showed tolerance to *Bipolaris* spot and yield potential under the conditions studied. The best yield was obtained with varieties 1L1500 and 1L1411.

Keywords: adaptability, *Bipolaris maydis, Colletotrichum graminicola, Curvularia* sp.*, Zea mays*

Severidad de enfermedades foliares y rendimiento de variedades de maíz cultivados en el cerrado del estado de Tocantins en Brasil

RESUMEN
El cultivo de maíz (*Zea mays* L.) en el estado de Tocantins en Brasil, está ganando protagonismo en la producción en cultivos de verano y fuera de temporada. La mayor permanencia del cultivo en el campo favorece el aumento de enfermedades foliares, lo que puede causar impactos negativos en la producción y calidad de los cultivos. El objetivo de este trabajo fue evaluar la severidad de las enfermedades foliares y el rendimiento de variedades de maíz cultivadas en el cerrado del sur Tocantinense. Se realizaron dos experimentos de campo, con 36 variedades, en el municipio de Gurupi, Tocantins. El diseño utilizado fue un diseño de bloques al azar con dos repeticiones. Se realizaron evaluaciones semanales del progreso de las enfermedades foliares y posteriormente se determinó el Área Bajo la Curva de Progreso de la Enfermedad (AUDPC). La enfermedad verificada con mayor incidencia y severidad fue la mancha

Bipolaris (*Bipolaris maydis*), que afectó a todas las variedades evaluadas. La severidad de la roya (*Puccinia polysora*), la pudrición del tallo (*Colletotrichum graminicola*) y la mancha por *Curvularia* (*Curvularia* sp.) en las variedades afectadas fue baja. La mayoría de las variedades evaluadas presentaron rendimientos estimados superiores al promedio estatal y nacional brasileño para la cosecha de verano 2014/2015, tolerancia a la mancha *Bipolaris* y potencial de rendimiento en las condiciones estudiadas. El mejor rendimiento se obtuvo con las variedades 1L1500 y 1L1411.

Palabras clave: adaptabilidad, *Bipolaris maydis, Colletotrichum graminicola, Curvularia* sp.*, Zea mays*

INTRODUCTION

The corn (*Zea mays* L.) is a crop of great importance worldwide due to the diversity of products derived from this cereal, and its use in human and animal food is of paramount importance, ensuring every year increases in demand (Costa *et al*., 2017), especially in places where its economy depends on agriculture, as is the case in the state of Tocantins.

The state of Tocantins in Brazil is currently included among the states that make up the new Brazilian agricultural frontier, called MATOPIBA. It has shown strong growth in recent years, with productivity of 4789.67 kg ha^{-1} and planted area of 226.2 thousand ha^{-1} in the cultivation of corn (2020/2021 harvest) and it has the possibility of expanding the potential for growing in the coming years (CONAB, 2021).

This expansion of grain cultivation, although necessary, is one of the causes of the increase in diseases in all corn-producing regions, which in a few years, in the Tocantins, may have been responsible for considerable losses in productivity and quality of the grains produced. Generally, an infection caused by pathogens organisms directly affects plant development, compromising the leaf area and infections in the stalks, hindering the transport and assimilation of nutrients (Britto *et al*., 2008), directly affecting grain production.

Among the most frequently observed foliar fungal diseases in this state are *Bipolaris* spot (*Bipolaris maydis* (Nisikado and Miyake) Shoem), polysorbite rust (*Puccinia polysora* Underw*)*, stalk rot (*Colletotrichum graminicola* (Ces.) G.W. Wils.), and others (Santos *et al*., 2013; Chagas *et al*., 2015). The occurrence of these diseases is directly related to the management system employed and the climate conditions that are more favourable to fungal pathogens, which have contributed to the increase in severity and the emergence of new diseases until then considered of minor importance (Vaz de Melo *et al*., 2010).

Among the management systems used, several factors are considered favorable and aggravating to the spread of fungi and permanence of the inoculum under field conditions The use of susceptible cultivars, inadequate management of soil fertilization and control of diseases and pests, favorable climatic conditions and more extended planting period in the same area, caused by the adoption of the off-season are the principals (Reynol, 2011).

Unlike other Brazilian states, in the Tocantins, research related to diseases in the corn crop is still in its infancy, and work with the crop needs to be carried out in search of answers to the problems generated by the cultivation of the grain in the region. Thus, the objective of this work was to evaluate the severity of foliar diseases and yield of corn varieties cultivated in the cerrado of the state of Tocantins.

MATERIALS AND METHODS

Place, date, and management of the experiment

In the 2014/2015 agricultural year, two experiments were conducted in the experimental area of the Federal University of Tocantins (UFT), the campus of Gurupi, located at 11° 43' S and 49° 04' N' at 280 m altitudes. The climate is of the humid B1wA' type with a moderate water deficit according to the Koppen (1948) climate classification. The following results of the analysis of chemical properties of soils in the 0 - 20 cm layer was obtained: pH = 5.8 ($CaCl_2$), Ca, Mg, K and CTC = 2.2; 1.2; 0.25 and 5.65

(cmolc dm^{-3}), P = 22.9 (mg dm^{-3}), M.O and V = 2.4 e 65%, respectively.

Sowing was performed manually on 12/12/2014. The plots consisted of two lines of five meters, spaced by 0.5 m among lines, fully used as a functional area for the evaluations. The base fertilization consisted of the application of 450 kg ha^{-1} of NPK 5–25–15, and as a top dressing it was applied a dose of 150 kg ha^{-1} of urea in the phase between V4 (four expanded leaves) and V6 (six expanded leaves). For the control of weeds, manual weeding was performed, and a mixture of the herbicide's atrazine + nicosulfuron at a dose of 5 + 1.5 l ha^{-1} was also applied post-emergence.

Pest control was carried out by applying the insecticide methomyl at a dose of 0.6 l ha^{-1}. The climatic variables: precipitation (mm day^{-1}), maximum and minimum temperatures (°C), and average relative humidity (%), were monitored and recorded, during the entire period of the experiments, at the meteorological station of the Federal University of Tocantins.

The corncob was harvested manually in the entire plot, and the yield (kg ha^{-1}) was determined and estimated for a population of 60 thousand plants per hectare.

Experimental design and treatments

The design used in the experiments was a randomized block design with two replications. The treatments constituted 36 corn varieties in both experiments. In the first experiment, the following varieties were evaluated: BRS 1055, BRS Caimbè, BRS 4103, BR 106, Sint 10771, Sint 10717, Sint 10795, Sint 10697, Sint 10707, MC 20, MC 50, Sint 10781, Sintético 256 L, Sint 10699, VSL BS 42C60, Sintético RxS Spod, BRS 4104-Sint. Pro Vit A, 2E530, AL2013, AL2014, AL Avaré, MC 6028, BRS Gorutuba, Guepa, Capo, Sint superprecoce 1, Sint 10783, HTCMS-SP1, HTCMS771, HTCMS717, HTCMS795, HTCMS697, HTCMS707, HTCMS781, HTCMS699 and Sintético 1 X.

The varieties evaluated in the second experiment were: 1K1251, 1L1484, 1L1477, 1L1487, 1L1411, 1L1467, 1L1500, 1K1301, 1K1294, AG 8088 PROX, 1M1751, 1M1718, 1K1285, 1L1421, 1M1731, 1M1732, 1M1782, DKB 390 PRO, 1M1822, 1M1716, BRS 1055, 1M1757, 1M1810, 1M1752, 1M1764, 1M1792, 1M1737, 1M1760, 1M1812, 1M1758, 1M1804, 1M1807, M 20A78 HX, 1M1750, 1M1754 e 1L1414.

Disease assessments

The evaluation of the incidence of the diseases *Bipolaris* spot, stalk rot, polysorbite rust and *Curvularia* spot started 60 days after planting (DAP), with weekly assessments of the progress of foliar diseases at intervals of seven days, and continued until the senescence phase of the plants, approximately 120 days after planting. To assess the progression of disease severity, a visual score scale was used, ranging from 1 to 9, where 1= 0% disease; 2= 0.5% injured leaf area; 3=10%; 4=30%; 5=50%; 6=70%; 7=80%; 8=90% and 9=100% of injured leaf area, considering the average severity of diseases in the plots (Agroceres, 1996).

In grades 1 to 4, the hybrids were classified as high to medium resistance. In grades 5 to 6, they were classified as having median susceptibility, and with grades from 7 to 9, they were classified as susceptible to highly susceptible (Agroceres, 1996). The plants were evaluated considering the lower, middle, and upper third and considering the entire plot. Severity score values were transformed into the percentage of injured leaf area and used to calculate the area under the disease progress curve (AUDPC), according to Campbell and Madden (1990).

The AUDPC data for *Bipolaris* spot and productivity were subjected to analysis of variance, and the Scott-Knott test compared the means at a 5% probability level with the aid of the ASSISTAT statistical program (Silva and Azevedo, 2016).

RESULTS AND DISCUSSION

During the period which the experiments were carried out, there was the irregularity of precipitation throughout the months from December to April, with total precipitation of 595 mm, average temperatures 26 °C, maximum 32°C and minimum 22°C, 83% relative humidity media, 95% maximum and 61% minimum. These climatic conditions are considered ideal for developing of foliar diseases that attack the corn crop (Costa *et* *al*., 2009). A higher incidence of *Bipolaris* spot was detected in both experiments and all evaluated varieties, followed by stalk rot and polysorbite rust. In the first experiment, the occurrence of the *Curvularia* spot was not verified (Figure 1). According to Costa *et al.* (2009), among the diseases that occur in corn crops, the most important are *Bipolaris* spot, stalk rot, and polysorbite rust. High humidity is an essential condition for the development of these diseases. Polysorbite rust (*Puccinia polysora*) occurs predominantly in places with altitudes below 700 m, at temperatures ranging from 25 to 35°C. For *Bipolaris* spot, the optimal conditions consist of temperatures between 22 and 30°C, and the occurrence of long periods of drought and days with much sun between rainy days is unfavorable to the disease. For stalk rot (*Colletotrichum graminicola*), high temperatures (28 to 30 °C) and frequent rains favor its development.

Bipolaris spot disease has been reported in several Brazilian states and is caused by the ascomycete fungus *Bipolaris maydis*, which affects the plant leaves, and symptoms vary according to the variety and races of the fungus. In conditions of high disease pressure and attack at the flowering stage, the entire leaf blade may be affected. Under ideal conditions of temperature, humidity, and the presence of free water on the surface of the leaves, the disease is polycyclic. The germination of spores and penetration into leaf tissue occurs within six hours. This fungus survives in cultural remains in the form of mycelium and presents itself as a potential source of inoculum for future plantings (Costa *et al.*, 2009). According to Chagas *et al.* (2015), in the Tocantins, this disease is among those that occur frequently and is highly severe in susceptible varieties and in years where weather conditions are favorable, a worrying fact given the growth of crops in two seasons (summer and off-season). The use of resistant varieties and crop rotation is one of the recommended techniques to reduce the inoculum of this fungus. It is already practiced by many producers with the planting of soybean. However, the lack of information on varieties resistant to the main diseases in this state is still insufficient, given the many varieties available on the market.

Polysorbite rust is a disease that occurs widely in tropical regions and is considered one of the main diseases in corn in Brazil (Chagas *et al.,* 2020). It is caused by the fungus *Puccinia polysora* Underwood and is capable of causing significant losses in productivity. In the Tocantins, severe epidemics have already been reported (Chagas *et al*., 2015). Vieira *et al*. (2009), in their study with popcorn in Paraná, observed promising hybrids for grain yields but susceptible to polysorbite rust.

Stalk rot is also a disease widely distributed in producing regions, being also favored by the increase in planting areas in the harvest and off-season. The management of this disease consists of reducing the potential of pathogen inoculum using integrated management practices, which include crop rotation, incorporation of residues into the soil,

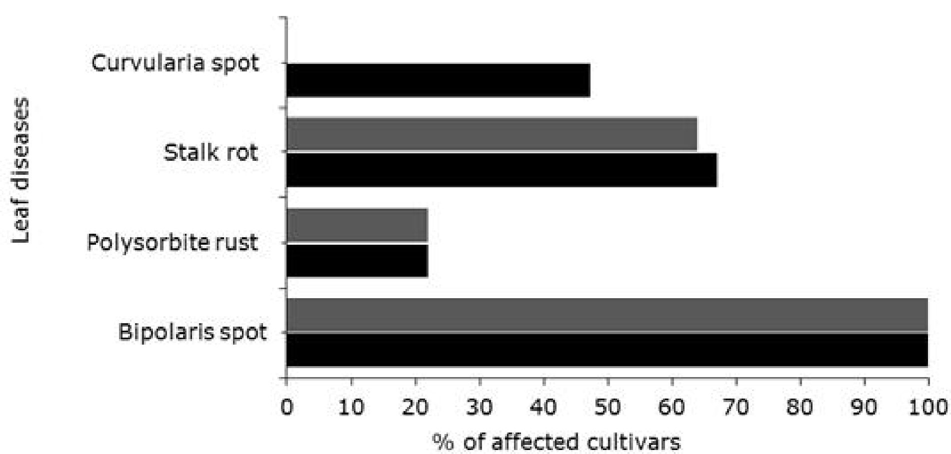

Figure 1. Incidence of foliar diseases (%) in corn varieties cultivated in the Cerrado, 2014/2015 crop year, municipality of Gurupi - Tocantins.

balanced fertilization, ideal spacing between plants and insect control (Nicole *et al*., 2016).

Experiment 1 (PPAs)

It was verified the formation of two distinct groups regarding the reaction of the varieties to the *Bipolaris* spot, according to the AUDPC (Table 1). There was wide variation in the reaction of varieties to resistance, as observed in the BRS 4104-Sint. Pro Vit A variety showed resistance throughout the evaluation period, and Sint 10717 and BRS Gorutuba, had 90% of its leaf area injured at the end of the evaluations (Table 1).

Table 1. Reaction of corn varieties to *Bipolaris* spot disease evaluated by the AUDPC and yield (kg ha^{-1}) cultivated in Gurupi, Tocantins, 2014/2015.

Varieties	AUDPC		Severity (%)		Yield	
			FLO	GM	kg ha^{-1}	
Sint 10717	3170	a	10.0	90	4860	a
HTCMS717	3051	a	5.25	75	7214	a
Sintético 1 X	2841	a	5.25	75	5528	a
BR 106	2579	a	5.25	75	5913	a
HTCMS781	2545	a	5.25	80	6836	a
HTCMS697	2506	a	5.25	80	5877	a
Sint 10707	2435	a	5.25	70	5463	a
Sint 10781	2301	a	0	40	9556	a
Sint 10697	2297	a	5.25	70	6486	a
HTCMS795	2262	a	0.5	80	6184	a
BRS 4103	2176	a	0.5	50	5001	a
Sint super-precoce 1	2161	a	0	70	6238	a
BRS 1055	2159	a	0.5	70	6947	a
Sint 10771	2128	a	0.5	80	6971	a
HTCMS699	2121	a	5.25	40	5743	a
HTCMS-SP1	2076	a	0.5	70	7386	a
Sint 10795	2054	a	0.5	30	9036	a
Sintético 256 L	2019	a	0.5	75	5680	a
HTCMS707	1985	a	5.25	70	6602	a
Sintético RxS Spod	1969	a	0.5	40	4882	a
VSL BS 42C60	1932	a	0.5	40	4839	a
Sint 10699	1917	a	0.5	75	6217	a
MC 20	1808	a	0.5	20	4045	a
BRS Caimbè	1660	a	0.5	50	6525	a
HTCMS771	1635	a	5.25	40	5721	a
MC 50	1584	a	0.5	10	7726	a
Guepa	1215	b	5.25	50	6385	a
BRS Gorutuba	1158	b	0.5	90	4630	a
AL Avaré	1137	b	0.5	85	6840	a
Sint 10783	991	b	0	50	7027	a
Capo	791	b	0.5	60	6790	a
AL2014	613	b	0.25	30	6068	a
2E530	537	b	0	10	7664	a
AL2013	454	b	0	20	7893	a
BRS 4104-Sint. Pro Vit A	412	b	0	5.25	6180	a
MC 6028	264	b	0.5	10	7014	a
CV%	27				23	

Letters in the column indicate that values do not differ significantly by the Scott-Knott test at the 5% probability level. Flowering (FLO) and Ripe Grains (RG)

Between the varieties Sint 10717 and BRS Gorutuba that showed the highest final severity, the AUDPC was higher in the first and they presented AUDPC values of 3170 and 1158, respectively. Thus, it is observed that higher final severity does not necessarily imply a higher AUDPC, a fact that can be observed with the HTCMS717 variety, which presented a final severity of 75%, but presented the second-highest value of AUDPC (3051). This divergence between the values of AUDPC and final severity is probably due to differences in the rate of disease progression, which depends on the horizontal resistance of the varieties.

According to the results from the final severity of *Bipolaris* spot (Table 1), twelve varieties (BRS Gorutuba, Avaré Sint 10717, AL, HTCMS781, HTCMS697, HTCMS795, Sint 10771, BR 106, Synthetic 256 L, Sint 10699, HTCMS717 and Syntético 1 X) were classified as susceptible to very susceptible, and nine were resistant (BRS 4104-Sint. Pro Vit A, MC 50, 2E530, MC 6028, AL2013, MC 20, Sint 10795, AL2014). The others were considered moderately susceptible.

The results obtained in this work prove the great importance of *Bipolaris* spot, requiring the use of resistant cultivars for better disease control, especially in places with favorable environmental conditions for the development of the disease, as is the case in the state of Tocantins, where other authors have also verified this disease (Chagas *et al*., 2015).

For polysorbite rust and stalk rot diseases, there was no incidence in some of the varieties evaluated (Figure 1), and in the varieties in which they were observed, the severity was considered low.

Regarding yield, no significantly difference was detected among the varieties (Table 1). This result can be attributed to factors that increase the sources of variation, such as the significant variability among the materials and abiotic factors, such as the irregularity of rainfall and dry spells.

Sint 10717 and BRS Gorutuba varieties were significantly affected by *Bipolaris* spot at the end of the evaluations, with 90% of their leaf area damaged (Table 1). That fact possibly contributed to their low yield, compared to the other varieties. Sint 10795, AL 2013, MC 6028, MC 50, and 2E530 varieties considered resistant to the diseases were the ones that produced the most. One of the objectives of the Cultivation and Use Value (VCU) tests is to evaluate cultivars in diversified environmental conditions in order to obtain agronomic information relevant to a specific objective, such as disease resistance and productivity, for selection purposes, registration, and release for a given location. The recommendation of corn cultivars provides the farmer with alternatives to choose the most suitable cultivars for the production system in use (Valentini, 2014).

Experiment 2 (Elite)

Bipolaris spot occurred in all evaluated varieties, with severity ranging from zero to 80% of the affected leaf area (Table 2). The AUDPC values ranged from 985.3 to 3836. However, no significantly difference was detected among them. Of the 36 varieties evaluated, four showed a susceptibility reaction (1M1732, DKB 390 PRO 1M1822, 1M1737), and 12 varieties showed a median resistance response, with AG8088 PROX being the most resistant.

The same trend was observed for the diseases that occurred in the first experiment, where varieties were evaluated, emphasizing the *Curvularia* spot detected in some varieties in this trial, although with low severity.

Considering the productive performance of the evaluated varieties (Table 2), higher yields were observed in varieties 1L1500 and 1L1411, being allocated separately in the first two groups, in a total of five groups formed by the Scott-Knott test, at the level of 5% of probability.

Lower yields were obtained with elite cultivars 1M1782, 1M1718, 1L1477, and 1L1487, with values ranging from 5640 to 4920 kg ha^{-1}. These varieties had more than 50% of their leaf area affected by *Bipolaris* spot, which probably contributed to the low productivity achieved. In this phase of the experiment, the attack of animals made it impossible to obtain consistent productivity data in some of the varieties, which were not represented. Chagas *et al.* (2020) observed in their study that, generally, corn productivity in the Tocantins is indirectly related to the susceptibility of the cultivar to certain diseases, which can be true when a plant is attacked early with high severity.

Table 2. Reaction of corn (*Zea mays* L.) varieties to *Bipolaris* spot disease and yield (kg ha^{-1}) cultivated in Gurupi, Tocantins, in the 2014/2015 harvest.

Varieties	AUDPC		Severity (%)		Varieties	Yield kg ha^{-1}	
			FLO	RG			
1M1732	3836.0	a	20	80	1L1500	11760	a
1M1754	3135.1	a	0.5	70	1L1411	9840	b
1L1487	3107.1	a	0.5	50	1K1294	9240	c
1K1301	3097.5	a	10	40	1K1251	8760	c
1M1718	3087.0	a	0.5	70	DKB 390 PRO	8160	c
1L1414	3052.0	a	0.5	60	1L1467	8040	c
1L1477	3048.5	a	0.5	60	AG 8088 PROX	7920	c
1M1750	2838.5	a	0.5	40	1M1751	7800	c
1L1411	2626.8	a	10	30	1L1484	7560	c
1L1421	2625.0	a	10	50	1M1731	7200	d
BRS 1055	2590.0	a	30	50	1M1732	6840	d
1L1500	2577.8	a	0.5	30	1K1285	6660	d
1K1285	2508.6	a	0.5	40	1K1301	6540	d
DKB 390 PRO	2420.3	a	0.5	80	1L1421	6520	d
1M1822	2380.9	a	30	80	1M1782	5640	e
1M1757	2330.1	a	5.25	50	1M1718	5610	e
M 20A78 HX	2315.3	a	0.5	60	1L1477	5040	e
1M1810	2295.1	a	5.25	60	1L1487	4920	e
1M1812	2264.5	a	0.5	70		-	
1M1782	2261.0	a	30	70		-	
1K1294	1260.0	a	10	20		-	
1L1467	2247.0	a	0.5	10		-	
1M1752	2191.9	a	0.5	30		-	
1M1792	2140.3	a	0.5	30		-	
1M1751	2140.3	a	0.5	50		-	
1M1737	2138.5	a	0.5	80		-	
1M1760	2123.6	a	5.25	50		-	
1L1484	2103.5	a	0.25	40		-	
1M1807	2101.8	a	5.25	40		-	
1M1716	2082.5	a	10	30		-	
1M1764	1618.8	a	0.5	10		-	
1M1758	1386.9	a	0.5	30		-	
AG 8088PROX	1320.4	a	0.5	5.25		-	
1K1251	1301.1	a	0.25	30		-	
1M1731	1075.4	a	0.5	50		-	
1M1804	985.3	a	0.5	10		-	
CV%	19.18		-			7.35	

Letters in the column indicate that values do not differ significantly by the Scott-Knott test at the 5% probability level. Flowering (FLO) and Ripe Grains (RG)

In addition to the importance of the different plants reactions to diseases observed in the two experiments, the typical Indian summers in the Tocantins, with high temperatures, associated with low rainfall, and poorly distributed among the regions, limit the achievement of better yields. In this context, corn varieties must be continuously tested in these regions. Knowledge of the interaction between these climatic variables in the adaptability and stability of different varieties is necessary for recommendation purposes since adapted varieties can bring several benefits to the producers.

In the state of Tocantins, there are two harvests a year (summer and off-season), which makes research related to the choice of varieties essential for the success of corn crops in both planting seasons.

CONCLUSION

In corn crop in the *cerrado* of the state of Tocantins, in Brazil, *Bipolaris* spot disease has great importance on the productivity of varieties with low and medium resistance. The disease occurred in all evaluated varieties. Nevertheless, there was no high severity of polysorbite rust, stalk rot, and *Curvularia* spot diseases in the tested varieties. Most varieties showed tolerance to *Bipolaris* spot and productive potential under the conditions studied, but 1L1500 and 1L1411 varieties have the better yield.

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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, ACPMF and HRFB, Writing—original draft JCRC, GRS and MVAV, Writing—review & editing JCRC, GRS, ACPMF and HRFB.

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