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Temporal progression of foliar plant diseases in corn hybrids

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Abstract

The environment's impact on foliar disease growth in annual crops and the various types of differentiation must be investigated to adapt effective disease control strategies. We studied the temporal progression of foliar disease complexes in 14 commercial corn (*Zea mays* L.) hybrids during the 2015/2016 crop season (Ipameri, Goiás, Brazil). The experiment consisted of 10 blocks and evaluated foliar disease severity using a diagrammatic scale. The evaluations occurred at 47, 53, 59, 74, 81 and 95 days after planting. At each time point, a plant was chosen randomly from each block (10 plants total), and the diseases causing foliar damage were identified. The areas under the disease progression curves (AUDPCs) and yields were calculated. Dependent variables were evaluated using a principal component analysis to study relationships between the hybrids and the disease severity on each leaf (biplot). Heatmaps were used to determine which leaves demonstrated the greatest disease severity and temporal disease progression, and an adjusted linear correlation model was used to predict yield relative to AUDPC. The foliar disease complex consisted of helmintosporiosis, common rust, macrospora leaf spot, cercosporiosis and maize white spot. The Ns90PRO© hybrid showed limited disease progression and; therefore, was considered more resistant and consequently had a lower AUDPC value. The Dow2B610PW© hybrid showed greater disease progression. Agroceres7098PRO2© had a greater yield and consequently a lower AUDPC value, while Lg6050PRO2© had a lower yield and a higher AUDPC value. In general, the more advanced the phenological stage, the more severe the leaf disease; however, disease progression (from plant base to plant tip) was genotype- dependent.

Keywords: genetic control; incidence; leaf spot; severity; *Zea mays*.

Introduction

Disease is a significant cause of low yields in corn (*Zea mays* L.). Several factors allow diseases to spread to previously unaffected regions. These include changes in cropping systems, expansion of area under cultivation, planting in summer and winter without crop rotations, inadequate management of no-till systems, increased soil inocula, expanded use of irrigation and the use of susceptible materials (Cota et al., 2015).
According to Pereira et al. (2005), the most common foliar diseases in corn are: common rust (*Puccinia sorghi,* Schwein, 1832), polissora rust (*Puccinia polysora*, Underw, 1897), tropical rust or white rust (*Physopella zeae*, Cummins and Ramachar, 1959), helminthosporiosis (*Exserohilum turcicum*, Leonard and Suggs, 1974; *Bipolaris maydis,* Shoemaker, 1959; *B. zeicola,* Shoemaker, 1959*),* stenocarpela leaf spot (*Stenocarpella macrospora* Sutton, 1977), cercospora leaf spot (*Cercospora zeae-maydis*, Tehon and Daniels, 1925), antracnosis leaf spot (*Colletotrichum graminicola*, Messiaen, Lafon and Molot, 1959) and white leaf spot (*Phaeosphaeria maydis*/*Pantoea ananatis*, Paccola-Meirelles, 2001; Index Fungorum, 2016). The importance and relevance of any one of these diseases depends on the planting season, region, year and weather. Thus, a disease that is significant in a very humid year may not be in a drier year (Casela et al., 2006, Fernandes and Balmer, 1990).
In general, foliar plant pathogens reduce plant energy production and consequently crop yield by colonizing leaf surfaces that are responsible for intercepting solar radiation that is converted into energy (Brito et al., 2008).
The epidemiological process in the field involves a cycle of infection that results in injury to the plant. Polycyclic diseases cause greater damage because overlapping cycles within the same crop affect the inoculum source, the diseased plants that were previously damaged by the pathogen. Monocyclic diseases have only one infection cycle within a crop and their inocula come from the previous harvest (Bergamin Filho et al., 2011).
Cercosporiosis caused significant losses in corn yield in the Brazilian state of Goiás and was later found in other regions (1999/2000 crop season). Cercosporiosis was a significant disease that affected crops in the state of São Paulo from 2004 to 2008 and is typically associated with susceptible hybrids and environmental conditions that favored the pathogen (Casela et al., 2003, Fantin et al., 2008). This disease reduces corn yield to a greater degree than maize white spot (Brito et al., 2013).

In São Paulo State, from the 2002/2003 to the 2011/2012 crop season, the severity of macrospora leaf spot was greater at altitudes above 498 m (Dudienas et al., 2012). Furthermore, corn was more commonly and significantly affected at higher altitudes than other crops (Casa et al., 2016). Altitudes below 700 m are associated with higher temperatures and relative humidity levels that predispose corn to the pathogen that causes polissora rust (Cota et al., 2015).

Among the plant diseases in Santa Catarina State, common rust causes large economic losses and is the most studied disease of maize (Sangoi et al., 2000). However, the same region is not considered favorable for polissora rust (Cota et al., 2015). In the Brazilian states of Paraná and Rio Grande do Sul (2009/2010 crop), polissora rust severely affects maize cultivars adapted to the region.

Maize white spot is associated with late plantings of corn (Cota et al., 2015) while polissora rust, tropical rust and helmintosporiosis are associated with early planting dates (Juliatti et al., 2005).

Several corn hybrids are available that have different levels of resistance to various diseases. Thus, hybrid selection is an effective and practical step towards reducing damage from plant pathogens (Brito et al., 2013).

Manerba et al. (2013) revealed that chemical control is the most effective method for controlling foliar diseases; however, exclusive or incorrect use can increase the resistance of pathogens to fungicides. Another consideration is crop height, which can hinder the accessibility of land to equipment used for chemical applications (Zambolim et al., 2014).

Engelsing et al. (2011) and Piletti et al. (2014) reported that genetic control through resistant cultivars is an effective method of controlling foliar diseases and may be essential for integrating other control methods (Camargo, 1995).

Vertical and horizontal resistance are under genetic control. Vertical resistance acts on the initial inoculum of the infection cycle, while horizontal resistance acts on the rate at which the disease spreads through the crop (Zambolim et al, 2014).

An accurate disease diagnosis in the field is important for effective epidemiological studies and determining the best forms of control (Malagi et al., 2012).

Our objectives were to observe and study the temporal progress of a foliar disease complex in 14 commercial corn hybrids grown during the 2015/2016 crop season.

Results and discussion

Each vector in Fig. 1 represents the leaf of a corn plant. The longer vectors represent greater variation among hybrids and better explains the behavior of diseases in the field. The closer the hybrids are to the vectors, the more susceptible the leaves are to the disease in question. The smaller the distance between the hybrids, the more similar they are in relation to susceptibility to the disease complex. Thus, the farther the hybrids are from the vectors, the more resistant they are to the disease complex.

First evaluation of hybrid behavior

At 47 d after planting (DAP), first and second leaves showed greater representativeness and greater variation among the hybrids, which may explain the epidemiological behavior of the disease complex. The first leaves of Dekalb 310PRO2© hybrid showed the greatest susceptibility, whereas the second leaves of Dow 2B633PW© and Agroeste 1633PRO2© were the most susceptible to the disease complex. The third leaves did not provide information that explained the epidemiological condition of the disease complex (Fig 1A).

Second evaluation of hybrid behavior

At 56 DAP, the greatest variation levels were found among hybrids between the first and second leaves. The first leaves, of hybrids Ms 552PW©, Dow 2B6810PW© and Ms 30A37PW© best explained the disease susceptibility of the evaluated hybrids, while for Dekalb 310PRO2©, Dekalb 290PRO3© and Dow 2B633PW© the second leaves best explained the susceptibility. The remaining hybrids, in particular NS 90PRO©, Agroceres8677© and LG 6050PRO2©, were the most resistant (least susceptible) at this stage of the analysis (Fig. 1B).

Third evaluation of hybrid behavior

At 65 DAP, the first leaves of Ms 552PW© and Dekalb 290PRO3© were most susceptible to the disease complex, while the second leaves of Dekalb 310PRO2© and Dow2B633PW© were most susceptible. Again, the variation among hybrids between the first and second leaves was high, while the remaining leaves did not explain the epidemiology of the disease complex. Dow 2B610PW©, NS 90PRO© and Syngenta Supremo Viptera© were more resistant to leaf spot (Fig. 1C). In general, conditions that increase disease susceptibility in the lowest leaves are associated with external factors, such as high humidity, mild temperatures, excess or absence of nutrients, inadequate plant spacing, pests and a lack of aeration (Amorim et al., 2011, Kluthcouski, 2000). On the evaluation days, the temperature varied from 20 to 30°C, humidity ranged from 40% to 90% and the precipitation was greatest in January, followed by March and was less than 50 mm in the interim.

Fourth evaluation of hybrid behavior

At 74 DAP, the disease susceptibility/resistance of the hybrids was explained by the second, third and fourth leaves, which showed greater levels of variation among the hybrids. Here, the hybrids that were most susceptible to the foliar disease complex were Dow 2B633PW© and Agroceres 7098PRO2© at the second leaf, Dekalb 310PRO2© at the third leaf and Agroeste 1633PRO2© at the fourth leaf. The remaining hybrids, especially Syngenta Status Viptera 3© and Syngenta Supremo Viptera©, showed lower levels of disease susceptibility (Fig. 1D). Plant pathogens in corn normally spread to other foliar surfaces during the reproductive stage (Bedendo et al., 2011) in which our evaluations occurred. The IB (2013) evaluated the resistance of commercial corn cultivars during the winter crop in São Paulo State and found that diseases were more severe after the R2 stage (*sensu* Fehr et al., 1971). Thus, the more advanced the phenological stage, the greater the severity of the foliar diseases (spreading from plant base to apex, but at different rates depending on cultivar), mainly because of an accumulation of specialized resistance structures in the plant pathogen found in crop residue and soil (Amorim et al., 2011).

Fifth evaluation of hybrid behavior

At 81 DAP, the first, second, third and fourth leaves showed that Dow 2B810PW©, Agroeste1633PRO2©, Dow2B633PW©, and Agroceres8677PRO2©, respectively, were the most susceptible hybrids. The first and third leaves showed the greatest variations among the hybrids. The remaining hybrids, especially Ns90PRO© and Agroceres7098PRO2©, were considered more resistant (Fig. 1E). The delayed appearance of symptoms in Agroceres 8677PRO2© is characteristic of horizontal resistance. This hybrid was resistant during early evaluations but became more susceptible as the environmental conditions changed, which is a characteristic of horizontal resistance (Zambolim et al., 2014).

Final evaluation of hybrid behavior

At 95 DAP, the hybrids had reached some stage of physiological maturity (R6 *sensu* Fehr et al. 1971). At this point, the foliar disease complex had spread to leaves that had not previously shown any disease symptoms. The fourth, fifth, sixth and seventh leaves showed increased susceptibility levels, Dekalb310PRO2© and Ms30A37PW© were more susceptible, and the twelfth, thirteenth and fourteenth leaves were more relevant, while Agroceres 8677PRO2©, Dekalb 290PRO3©, Dow 2B633PW©, Lg 6050PRO2© and Syngenta Supremo Viptera© were more susceptible to leaf spot (Fig. 1F).

In the last evaluation period, the fourth, fifth and sixth leaves showed the greatest variation levels. Lg 6050PRO2© and Agroceres8677PRO2© demonstrated horizontal resistance, with the first disease symptoms appearing relatively late. Zambolim et al. (2014) stated that horizontal resistance quantitatively reduces the intensity and progression rate of diseases. Throughout the entire evaluation period, Ns 90PRO© behaved contrary to the vectors and, therefore, showed the least disease severity and was the least susceptible/most resistant to the plant pathogen.

The corn crop evaluated in the present study was planted late relative to the usual planting time, which typically occurs between October and November, in the state of Goiás (Cruz et al., 2015). Planting time and external environmental factors determine disease severity. Costa et al. (2009) reported that increased disease severity is associated with late planting, making hybrids more susceptible. According to Santos et al. (2002), a relative humidity above 60% and mild nocturnal temperatures contribute to more disease occurrences in late plantings, which contradicts Juliatti et al. (2005) who found that late plantings reduce disease severity.

The maize hybrid Dow2B633PW© was highly susceptible to foliar diseases. Dudienas et al. (1997) evaluated the resistance of corn hybrids to a given foliar disease and observed that earlier hybrids showed less disease severity, even if the disease in question is considered an early cycle disease.

Thus, the corn hybrids showed diverse levels of resistance to foliar disease. According to the IB (2013), the market offers many corn hybrids with varying levels of resistance to foliar diseases. Juliatti et al. (2005) pointed out that these levels of resistance also identified allow the identification of genotypes with different levels of resistance. By understanding the resistance levels of commercial corn hybrids, specific recommendations can be made for a given region to optimize yield (Piletti et al., 2014). At the beginning of the evaluation period, the lowest leaves on the corn plants were more significant in explaining the resistance/susceptibility of the hybrids under study. By the end of the evaluation period, this significance had spread to a greater number of leaves, but with correlations that varied by hybrid.

Leaves of corn versus resistance/susceptibility

At 47 DAP, the disease severity of Agroeste 1633PRO2©, Dekalb 310PRO2© and Dow 2B633PW© had reached critical levels from the first to the sixth leaf. None of the hybrids at this evaluation period showed signs of immunity (absence of damage) (Fig. 2A).

At 53 DAP, the disease severity of Dekalb 290PRO3©, Dekalb 310PRO2©, Dow 2B810PW© and Ms30A37PW© had reached critical levels in the first leaves, with symptoms spreading up to the sixth leaf. Again, none of the hybrids showed signs of immunity (absence of damage) (Fig. 2B).

At 59 DAP, the disease severity levels of all of the hybrids were critical levels in the first leaf, while the second leaves of Dekalb 310PRO2© and Dow 2B633PW© also presented critical levels of disease. Damage was observed in the first to ninth leaves, but not in the ninth to sixteenth leaves. None of the hybrids showed signs of immunity (absence of damage) (Fig. 2C).

The greatest moisture levels are retained in the soil and are more concentrated in the lower part of the plant. This part of the plant is also associated with more limited leaf aeration and residue from the previous harvest, which is a source of plant pathogen inoculum. When combined with more susceptible cultivars, these conditions allow the proliferation, growth and development of plant pathogens (Amorim et al., 2011; Fancelli, 2015).

At 74 DAP, the disease severity levels were critical in the first and second leaves and reached the third leaves in Dekalb 310PRO2©. Depending on the hybrid, the severity was found at varying levels up to the ninth leaf, but no damage was found between leaves nine and sixteen. None of the hybrids showed signs of immunity (absence of damage) (Fig. 2D).

At 81 DAP, the hybrids behaved in the same way as in the previous evaluation (Fig. 2E).

At 95 DAP, the disease severity levels were critical and, depending on the hybrid, could be found up to the fourth leaf. At this stage, damage was found in all 16 leaves. Ns 90PRO© received the lowest severity score, indicating that this hybrid is resistant to the disease complex (Fig. 2F). Badly damaged leaves usually drop from plants. Alvim et al. (2010) found yield losses of up to 20% in corn plants that had lost all of the leaves above the ears of corn. When plants are severely weakened by disease, leaves fall and yields decrease.

The early-maturing hybrid Ns 90PRO© initially exhibited little disease development, but the disease rapidly progressed after 81 DAP. Normally, early-maturity hybrids are

Table 1. List of manufacturers of commercial hybrid corn brands, as well as their cycles and grain types, evaluated during the 2015/2016 harvest.

Ord.	Company	Commercial maize hybrids	Phenological Cycle	Type of grain
1	Limagran	Lg6050PRO2©	Early	Semi-hard
2	Dow Agrosciences	Dow2B610PW©	Early	Semi-toothed
3	Dow Agrosciences	Dow2B633PW©	Early	Semi-hard
4	Dow Agrosciences	Dow2B810PW©	Normal	Semi-hard
5	Dekalb	Dekalb310PRO2©	Normal	Semi-hard
6	Dekalb	Dekalb290PRO3©	Early	Semi-toothed
7	Syngenta	Syngenta Supremo Viptera©	Early	Hard
8	Syngenta	Syngenta Status Viptera3©	Early	Hard
9	Agroceres	Agroceres7098PRO2©	Early	Semi-toothed
10	Agroceres	Agroceres8677PRO2©	Early	Semi-toothed
11	Morgan	Ms30A37PW©	Early	Semi-hard
12	Morgan	Ms552PW©	Early	Semi-hard
13	Agroeste	Agroeste1633PRO2©	Early	Semi-toothed
14	Nidera	Ns90PRO©	Super early	Semi-hard

Source: Ministry of Agriculture Livestock and Supply. Cultivar Web (2016).

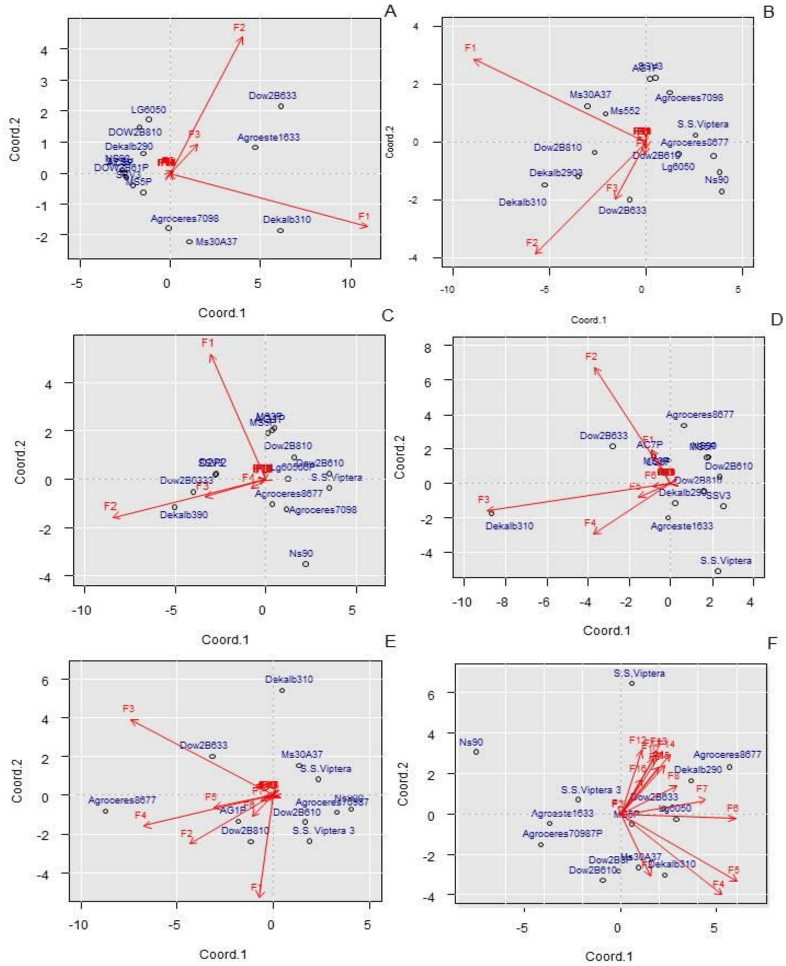

Fig 1. Main components of the disease severity plant score data on each leaf of 14 maize hybrids from different evaluation time points. A. 47 DAP; B. 53 DAP; C. 59 DAP; D. 74 DAP; E. 81 DAP; and F. 95 DAP. Fn, the leaf at the n position; Lg6050, Lg6050PRO2; Dow2B633, Dow2B633PW; Dow2B810, Dow2B810PW; Dow2B610, Dow2B610PW; Dekalb310, Dekalb310PRO2; Dekalb290, Dekalb290PRO3; S.S.Viptera, Syngenta Supremo Viptera; S.S. Viptera3, Syngenta Supremo Viptera3; Agroceres8677, Agroceres8677PRO2; Agroceres7098, Agroceres7098PRO2; Ns90, Ns90PRO; Ms552, Ms552PW; Ms30A37, Ms30A37PW; and Agroeste1633, Agroeste1633PRO2.

Table 2. Averages of productivity (kg·ha^{-1}), AUDPC and productivity efficiency based on the national averages and those of the state of Goiás for 14 commercial maize hybrids grown in the 2015/2016 season.

Ord.	Hybrids	Yield (kg·ha^{-1})		AUDPC		Yield Efficiency kg·ha^{-1}BR (%)	kg·ha^{-1} GO (%)	sc·ha^{-1}BR (%)	sc·ha^{-1}GO (%)
1	Lg6050PRO2©	1852.3	j	9353.25	a	39	30	39	30
2	Dow2B610PW©	5172.4	h	12069.9	a	108	84	108	85
3	Dow2B633PW©	3898.7	i	10344.3	a	81	63	81	64
4	Dow2B810PW©	8455.7	c	8057.3	b	176	137	176	138
5	Dekalb310PRO2©	5032.8	h	10645.1	a	105	82	105	82
6	Dekalb290PRO3©	7343.8	e	10395.55	a	153	119	153	120
7	Syngenta Supremo Viptera©	7421.8	e	7413.9	b	155	120	155	121
8	Syngenta Status Viptera 3©	9079.1	b	7561.95	b	189	147	189	148
9	Agroceres7098PRO2©	10039.6	a	6272.55	c	209	163	209	164
10	Agroceres8677PRO2©	7917.9	d	9850.3	a	165	128	165	129
11	Ms30A37PW©	6467.9	g	8276.05	b	135	105	135	106
12	Ms552PW©	6952.9	f	8903.25	a	145	113	145	114
13	Agroeste1633PRO2©	7802	d	7293.95	b	163	127	163	128
14	Ns90PRO©	7002.6	f	4740.65	c	146	114	146	114
	Value F	319.89**		9.27**		nd	nd	nd	nd
	CV %	2.52		23.42		nd	nd	nd	nd

Averages followed by the same lowercase letters in columns do not differ from each other; **Significant at the 1% probability level ($p < 0.01$); nd-not determined

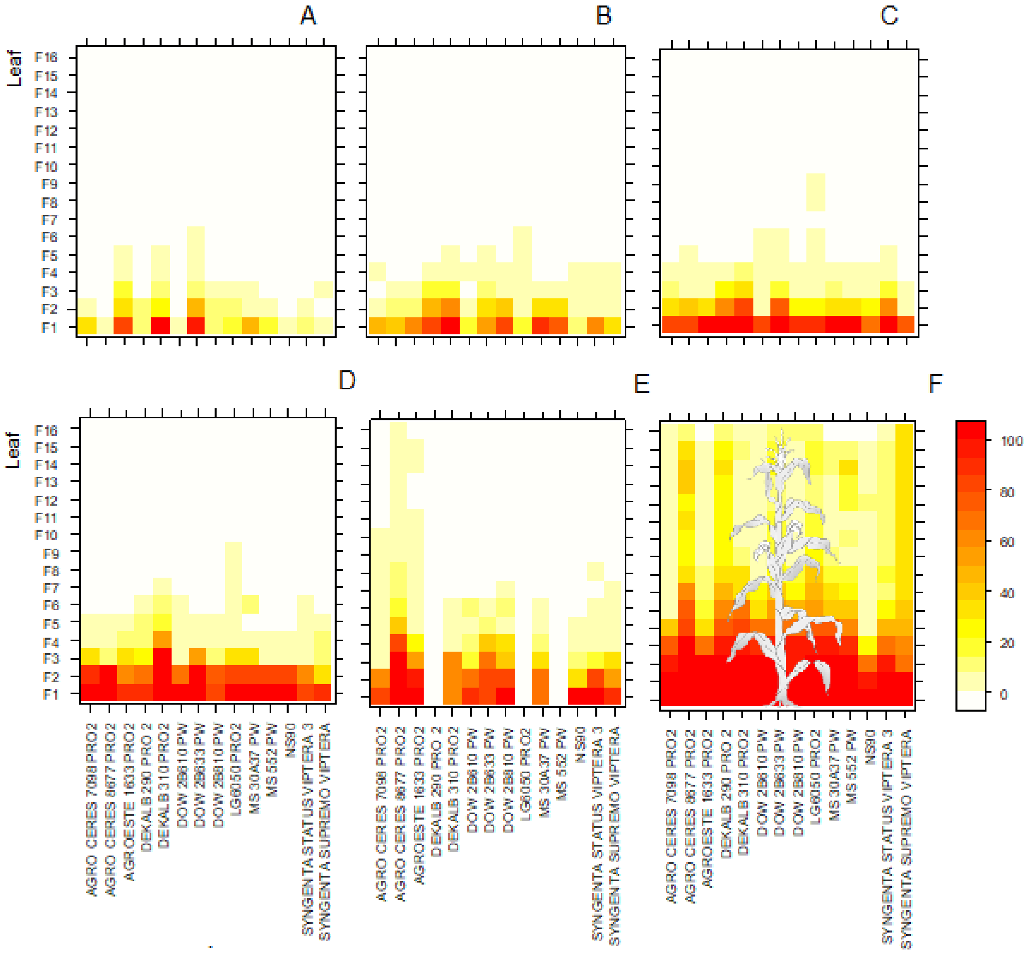

Fig 2. Disease severity score heatmap (diagrammatic scale: 0, totally healthy tissue, to 100, dead tissue) of leaves of 14 corn hybrids at different days after planting (DAP). A. 47 DAP; B. 53 DAP; C. 59 DAP; D. 74 DAP; E. 81 DAP; and F. 95 DAP.

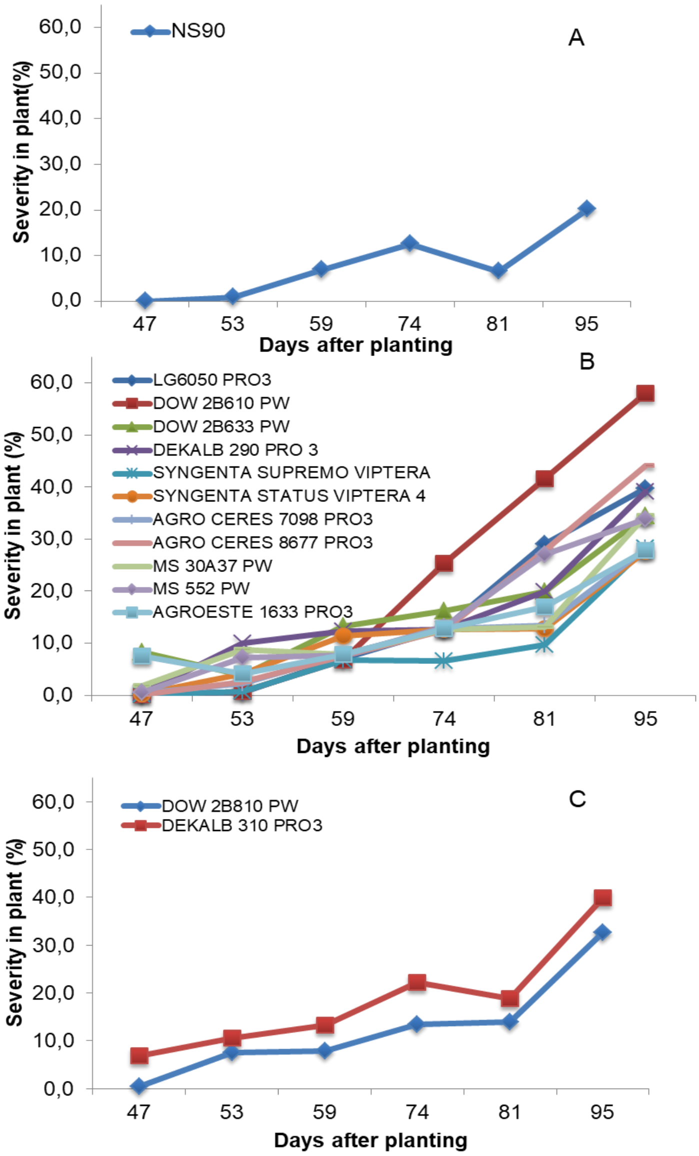

Fig 3. Foliar disease complex progression curves of 14 commercial corn hybrids at 47, 53, 59, 74, 81 and 95 DAP. A. Supercoil cycle; B. Early cycle; and C. Normal cycle.

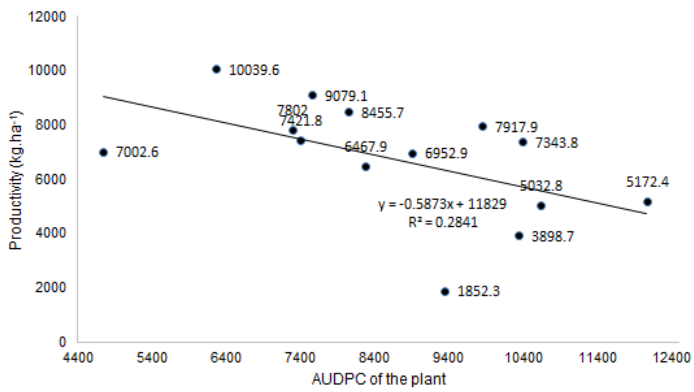

Fig 4. Correlation of area averages below the progress curve (AUDPC) values of foliar diseases versus yield (kg·ha^{-1}) of maize hybrids grown in the 2015/2016 season.

recommended for late plantings (Fig. 3A). Group I hybrids reach maturity in less than 120 d (from emergence to physiological maturation), group II between 120 and 145 d and group III hybrids at greater than 145 d (MAP, 2014).
The normal-cycle hybrids Dow 2B810PW© and Dekalb 310PRO2© showed similar and proportional foliar disease complex progressions (Fig. 3C), which markedly increased at 81 DAP.
The hybrid Dow 2B610PW© demonstrated the greatest disease progress among the early-cycle hybrids (group II), with especially notable growth at 59 DAP. This hybrid may be genetically predisposed to have less resistance to the foliar disease complex (Fig. 3B). Most of the hybrids available in the market are early-stage (group I) hybrids that spend less time in the field and are, therefore, subjected to fewer pathogens and less inclement weather. However, late-cycle hybrids spend a longer time in the field and, therefore, have a greater risk of exposure to pathogens and adverse weather conditions.
Any change in environmental conditions is likely to interfere with disease progression. In the current study, greater rainfall and humidity levels may have accelerated disease progression during the period that included the last two evaluation time points.
Furthermore, fungicide applications in the early stages helped eliminate pathogens and consequently decreased the levels of the foliar diseases. In the present study, fungicide applications were carried out three times: at the V8 vegetative stage, before bolting and 30 d after bolting. According to Vilela et al. (2012), fungicide applications do not increase yields, which contradicted the conclusion of Brito et al. (2013).
The yield of Agroceres 7098PRO2© was statistically greater than those of the other hybrids, while the yield of Lg 6050PRO2© was statistically lower (Table 1).

Area averages below the progress curve (AUDPC)

The hybrids Lg 6050PRO2©, Dow 2B610PW©, Dow 2B633PW©, Dekalb 310PRO2©, Dekalb 290PRO3©, Agroceres 8677PRO2© and Ms 552PW© produced greater AUDPC values, which were statistically the same, while Agroceres7098PRO2© and Ns 90PRO© presented lower AUDPC values (Table 1).

Correlation of AUDPC and productivity

AUDPC was negatively correlated to yield (Fig. 4). Syngenta Supremo Viptera©, Agroceres 1633PRO2©, Ms 552PW©, Ms 30A37PW©, Dekalb 310PRO2© and Dow 2B610PW© were located closer to the central trend line of AUDPC and, therefore, had greater weight in explaining yield. Hybrids that were farther from the central trend line of AUDPC had less weight. For these hybrids, yield would be better explained by other factors, such as water deficit, temperatures outside of the appropriate range, planting density, inadequate spacing, excess or absence of nutrients, pests and chemical phytotoxicity. Silva et al. (2005) observed yield increases by incorporating nitrogen at sowing and at 15 dafter emergence.
In our experiment, corn was planted during a summer crop season that experienced a high rainfall level, temperatures between 21 and 25°C and a relative air humidity above 80%. Juliatti et al. (2005) observed that helmintoporiosis is related to higher AUDPC values during the summer crop season, possibly owing to ideal climatic conditions (high humidity and temperatures between 18 and 27°C) for fungal infection and proliferation (Pereira et al., 2005).
Hybrids that are more susceptible or moderately resistant and sown in the winter experience more severe cercosporiosis, possibly owing to inocula from the previous crops and environmental conditions that allow pathogens to contribute to greater AUDPC values (Brito et al., 2008).
The hybrid Agroceres 7098PRO2© had statistically higher yields than the other hybrids in our study and had a greater yield than the national average in the state of Goiás (2012/2013 crop season) (Table 1), presentation yields of 4,800 kg ha^{-1} and 6,164 kg ha^{-1}, respectively. Conversely, Lg 6050PRO2© also differed statistically from the other hybrids with the lowest performance and a yield increase of less than 40% (Table 1).
The average yield of the hybrids in our study was 6,745.68 kg ha^{-1}, which was 1,945 kg ha^{-1} greater than the Brazilian national average in the 2012/2013 harvest and 58.68 kg ha^{-1}greater than the average yield in the state of Goiás, Brazil. This yield was also 24% greater than the 2015/2016 harvest, which was 5,411 kg ha^{-1} (Conab, 2016). Santos et al. (2002) tested 23 corn hybrids in the middle-west region of Brazil, and they produced an average yield of 7,071 kg ha^{-1}.
Brito et al. (2008) found that summer crops had greater yields than winter crops. Therefore, planting delays could cause yield losses. Conversely, Juliatti et al. (2005) studied 14 corn hybrids grown in the summer and winter, and found that the latter had a greater yield.
Brito et al. (2008) observed that severe cercosporiosis in hybrids did not necessarily reduce the yield. The same was found in a current study on Dow 2B610PW©, Dow 2B633PW©, Dekalb 310RO2©, Dekalb 290PRO3© and Agroceres 7098PRO2©, which produced intermediate yields and high AUDPC values.
Hybrids that are resistant to diseases may have yield losses of 5% to 9%, while hybrids with moderate resistance (intermediates) may present losses of 6% to 20%. Hybrids that are considered totally susceptible to foliar diseases may have yield losses reaching 20% (Brito et al., 2007).
Brito et al. (2013) observed that fungicide applications on corn crops can reduce the severity of foliar diseases and increase the yield by 12%. In the current experiment, fungicides were applied during the V8 vegetative stage and then repeated before bolting and 30 d after bolting. Applications at the beginning of disease development ensure more successful disease control (Juliatti et al., 2004).

Material and Methods

Experimental site

The experiment was carried out on the 2015/2016 crop at the RC Cruz Experimental Station, Esmeralda Farm, (Highway Br 050, latitude: 17° 29' 31.35'' S, longitude: 48° 12' 56.93'', altitude: 908 m), located in Ipameri, Goiás, Brazil. The soil was characterized as a dystrophic red-yellow latossol. This disease progression study was based on an amount of initial inoculum from the experimental area (soil and soil residues) and from dispersed spores of neighboring farms, which generated primary and secondary cycles of infection on maize the hybrids.

Hybrids evaluated and experimental design

In total, 14 commercially available corn hybrids (Table 2) were evaluated (Fig. 1). Sowing was carried out on the 7th of December 2015, in which the climatic conditions characteristic of spring predominated. The experiment was established with 10 blocks that consisted of 16 rows each and measured 20 m × 8 m.

Experimental field management

Fertilizers were applied using a broadcast spreader and consisted of 100 and 180 kg ha^{-1}of 5-37-00 (N-P-K) and 120 kg ha^{-1} of KCl.

The seeds were treated with cytokinin + gibberiline + indolanoic acid (Stimulate©) at 300 mL ha^{-1}. To increase the growth and development of the crop, as well as increase the rooting and consequently the productivity, the herbicides benzoylcyclohexanedione (Soberan©) at 240 mL ha^{-1} and atrazine (Atrazine Nortox©) at 3 L ha^{-1} were used to control pre-emergence weeds. Insects were controlled with oxime methylcarbamate (Lannate©) at 1 L ha^{-1} (applied at the V4 vegetative state), neonicotinoid + pyrethroid (Engeo Pleno©) at 300 mL ha^{-1} (applied at the V8 stage) and fatty acid esters (Natur'l óleo©) at 1 L ha^{-1}. Fertilizers were applied at the V4 vegetative stage. The applications consisted of three foliar fertilizers: zinc and molybdenum (Cellerate®) at 300 mL ha^{-1}, manganese (Stoller©) at 3 L ha^{-1}, and phosphorus, cobalt and molybdenum (Co-Mo Platinum©) at 150 mL ha^{-1}, as well as liquid nitrogen at 3 L ha^{-1}.

Nitrogen (urea) was applied (150 kg ha^{-1}) to the soil two times between the V2 and V4 stages. Azoxystrobin + flutriafol (Authority©) at 600 mL ha^{-1} and dithiocarbamates (Mancozeb©) at 2 kg ha^{-1} were used to control diseases and were applied at three stages (V8, pre-bolting and 30 d after bolting). Insects were controlled using neonicotinoid + pyrethroid (Engeo Pleno©) at 400 mL ha^{-1} and oxime methylcarbamate (Bakuza©) at 1.5 L ha^{-1}, applied at the V8 stage. Liquid nitrogen (4 L ha^{-1}) was applied as a foliar fertilizer at the V4 stage.

Field evaluations

Symptom severity was determined at 47, 53, 59, 74, 81 and 95 DAP. At these time points, one plant was randomly chosen from each block, for a total of 10 plants per hybrid. Diseases were then identified, and the severity determined by counting the number of leaves affected by the disease complex (starting from the base of the plant), using a diagrammatic scale (Azevedo, 1997) that ranged from 0% to 100%. The severity of each leaf was assessed by two evaluators. Figure 1shows the climatic data (temperature, humidity and precipitation) during the evaluation period.

Five diseases, helmintosporiosis, common rust, macrospora leaf spot, cercosporiosis and maize white spot, were identified based on morphology and a direct diagnosis of each leaf in the field. Symptoms that could not be identified in the field were diagnosed in the laboratory.

Severity measurements over time were used to calculate the AUDPC by integrating the following formula for each hybrid:

$$\text{AUDCP} = \sum_{i}^{n-1} \frac{(X_i + X_{i+1})(t_{i+1} - t_i)}{2}$$

Where; *n* represents the number of severity evaluations and *Xi* represents the severity of the disease (complex) at the i^{th} evaluation (*ti*) (Campbell and Madden, 1990).

Yield was determined by first counting the number of ears in 4 m² (8 m linear), and then selecting three representative ears and counting the number of rows per ear and the number of kernels per row. Yield was estimated as follows: number of ears in 4 m² × number of rows per ear × number of kernels per row = kg ha^{-1}. The estimated average yield of the three ears was then estimated. This procedure was carried out at different locations within each of the four blocks, and the results were averaged to achieve the estimated yield of each hybrid (Reetz, 2003).

Statistical analyses

The progression curves were obtained from the severity values. Severity was calculated from the sum of average leaf severity values (16 leaves considered), and the proportional severity was calculated for the different hybrids, in which each leaf represented 6.25% (6.25 × 16 leaves = 100%). Thus, 6.25% represented the part of the total area of a plant in which partial severity was calculated, the sum of which represented plant severity.

The data regarding the distribution of disease severity were compared using a principal component analysis to study the relationships between the hybrids and the severity in each leaf. The data were also fit to a linear correlation model that could predict yield as a function of AUDPC.

The data were subjected to an analysis of variance F-test, and the AUDCP values and yield averages were compared using the Scott–Knott test at 5%.

Conclusions

The progression of the foliar disease complex was greatest in the Dow 2B610PW© hybrid, which also produced one of the highest AUDPC values. The Ns 90PRO© hybrid was the most resistant, showing a limited progression of the foliar disease and consequently lower AUDPC value. Agroceres 7098PRO2© also had a lower AUDPC value and was statistically equal to Ns 90PRO©. Agroceres 7098PRO2© produced the greatest yield, while LG 6050PRO2© showed a lower yield and greater AUDPC value.

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