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Diseases impact the performance of maize hybrids in southern Minas Gerais, Brazil

Guilherme Vieira Pimentel[1], Natalia Costa[2], Luiz Daniel Rodrigues da Silva[3], Amanda Santana Chales[4], Elisabete da Cruz Silva Watanabe[5], Silvino Guimarães Moreira[6]

[1] Universidade Federal de Lavras, Plant Science Department, professor, guilherme.pimentel@ufla.br
[2] Universidade Federal de Lavras, Plant Science Department, doctoral student, nataliacrocga.sd@gmail.com
[3] Universidade Federal de Lavras, Plant Science Department, doctoral student, danel.luiz06@hotmail.com
[4] Universidade Federal de Lavras, Soil Science Department, doctoral student, amandaachales@gmail.com
[5] Universidade Federal de Lavras, Plant Science Department, master's degree student, watanabe@outlook.com.br
[6] Universidade Federal de Lavras, Plant Science Department, professor, silvinomoreira@ufla.br

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Abstract

Maize (*Zea mays* L.) is a profitable crop for rural producers, but grain yield is still limited by factors such as not choosing a hybrid resistant to major diseases that cause leaf and pre-harvest damage. Thus, this study was developed with the objective of evaluating the agronomic performance; reaction to the attack of brown spot, white spot, and ear rot complex; and the grain health of maize hybrids. A randomized block experimental design was used, with treatments consisting of eight maize hybrids (DKB 390, DKB 230, DKB 177, 30F53, KWS 9110, KWS 9006, KWS 9004, and Supremo) in five replications. The following traits were evaluated: severity (%) of foliar and ear diseases, incidence (%) of grain pathogens, plant and ear height, yield, 100-seed weight, and final stand. There were significant differences among the hybrids for plant height (PH), yield (YD), and 100-seed weight (SW). The most severe leaf damage was caused by *Cercospora zeae-maydis* and *Pantoea ananatis*. *Fusarium graminearum* occurred in 80 % of the grain of the hybrids, except for DKB 390 and KWS 9110. High grain yield and satisfactory levels of disease resistance were found for the hybrids DKB 177 and KWS 9006.

Keywords: phytopathogens, grain quality, yield, *Zea mays*.

Introduction

Maize (*Zea mays* L.) is considered one of the most nutritious cereal crops for human consumption. It also has socioeconomic importance, as it generates employment and income, especially for the rural population (ROLIM et al., 2019). Its versatile uses include consumption of grain in its natural form or in various products derived from dried grain; it is also a primary ingredient in animal feed formulations (LIMA et al., 2019).

Maize is grown in countries throughout the Americas, Asia, Europe, and Africa, with most production located in the Americas at one-third and Asia at one-fifth, while Europe represents one-tenth of the cultivated area (ERENSTEIN et al., 2022). In Brazil, the highest yields are found in the states of Mato Grosso, Paraná, Goiás, Mato Grosso do Sul, Santa Catarina, and Minas Gerais, with a national average yield of 6,160 kg ha^{-1} (CONAB, 2023).

Maize is sown in Brazil in two growing seasons: the first crop, in the summer, from October to December; and the second crop, from February to April, creating a "green bridge". The second crop is the most extensive and important for Brazilian agriculture, and planted area has increased over the years (SILVA et al., 2021). However, grain yield is still limited by factors such as inadequate choice of hybrids for adaptation to the edaphic and climatic conditions of different regions and for resistant to the main diseases that cause leaf and pre-harvest damage.

The main diseases affecting maize in Brazil include rust (*Puccinia* spp.), gray leaf spot (*Cercospora zeae-maydis*), maize white spot (*Pantoea ananatis*), leaf blight (*Exserohilum turcicum*), diplodia leaf streak (*Stenocarpella spp.), anthracnose (*Colletotrichum graminicola*), scab (*Gibberella zeae*), and ear rot (*Fusarium verticillioides*) (SOUSA et al., 2023). These diseases are some of the main factors causing economic losses in maize through reduced yield from toxigenic fungi, decreased harvest value, and losses in animal production due to health issues caused by mycotoxins (MUNKVOLD et al., 2019).

The literature presents some studies focusing on the occurrence and severity of diseases that compromise the agricultural yield of maize in a tropical and subtropical climate zone (CUNHA et al., 2019; ROSSI et al., 2022). However, due to the extensive range of hybrids in the Brazilian market, the choice is difficult for growers; yet it is important to verify the agronomic performance of the available materials when they are under biotic stress conditions.

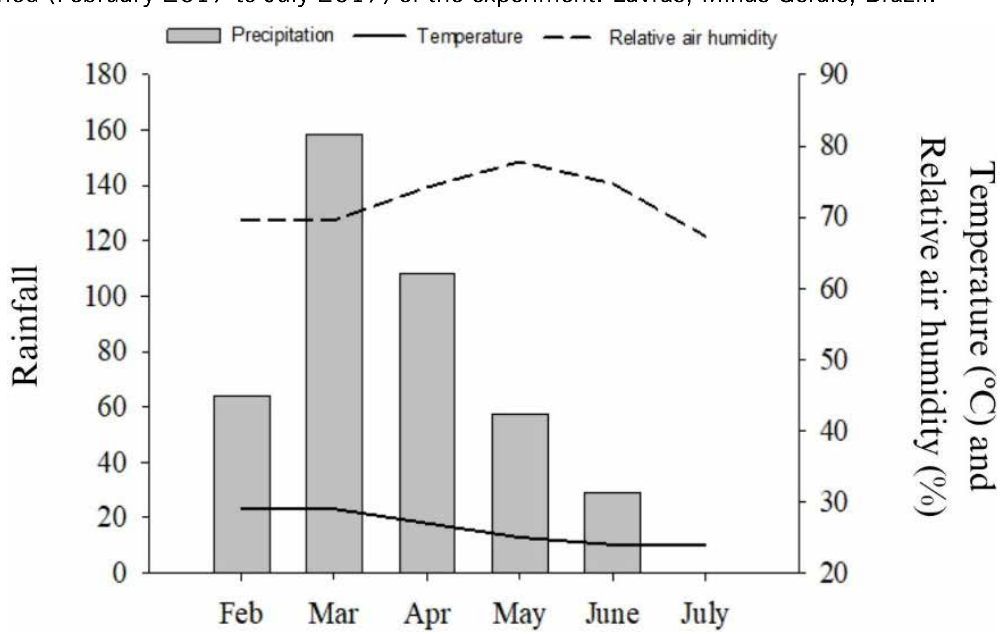
Therefore, this study was developed with the objective of evaluating the agronomic performance; the resistance response to cercosporiosis, white spot, and ear rot complex; and the grain health of maize hybrids.

Material and methods

The experiment was carried out in the experimental area of the Muquém Farm of the Universidade Federal de Lavras, in the municipality/county of Lavras, state of Minas Gerais, Brazil, at an altitude of 918.8 m (21°75'00'' S and 45°00'00'' W). The climate of the region is type Cwa, according to the Köppen classification, with an average annual rainfall of 1,500 mm. Meteorological conditions were collected during the experimental period. Average wind speed was from 2 to 3 $m\,s^{-1}$ (Figure 1).

The soil of the experimental area was classified as a Red Latosol. Before implementing the project in the field, soil samples were collected at a depth of 0-20 cm and the following determinations were made of their chemical characteristics: pH (H_2O) 5.8; O.M. 2.60 $dag\,kg^{-1}$; P 9.90 $mg\,dm^{-3}$; K 80.60 $mg\,dm^{-3}$; H + Al 3.30 $cmol_c\,dm^{-3}$; Al 0.50 $cmol_c\,dm^{-3}$; Ca 2.46 $cmol_c\,dm^{3}$; Mg 0.45 $cmol_c\,dm^{-3}$; SB 3.12 $cmol_c\,dm^{-3}$; CEC (T) 6.40 $cmol_c\,dm^{-3}$; V 48.75 %; m 13.81 %.

Figure 1. Monthly rainfall (mm), average temperature (°C), and relative humidity (%) during the agricultural harvest period (February 2017 to July 2017) of the experiment. Lavras, Minas Gerais, Brazil.



Source: National Institute of Meteorology - INMET (2017)

A randomized complete block experimental design was used, with the treatments consisting of eight maize hybrids (DKB 390, DKB 230, DKB 177, 30F53, KWS 9110, KWS 9006, KWS 9004, and Supremo), with five replications. The experimental units consisted of six rows, each 6 m in length and spaced 0.6 m apart, for a total of 21.6 m^2. The two central rows, corresponding to an area of 7.2 m^2, were used for data collection.

Before sowing, on February 10, 2017, the area was desiccated, to control/eradicate infesting weeds, with 1680 g a.i. ha^{-1} of glyphosate herbicide and 1047.8 g a.i. ha^{-1} of 2,4-D herbicide, with a spray volume of 250 L ha^{-1}. Fertilization was based on soil analysis and recommendations for a projected yield of 9,000 kg ha^{-1}, with 286 kg ha^{-1} of the fertilizer formulation NPK 08-28-16 in the planting furrow before sowing. Potassium (65 kg ha^{-1} of K_2O) and nitrogen (120 kg ha^{-1} of N) were topdressed over the total area at the V 4 phenological stage (four open leaves) of the maize plants.

Atrazine + tembotrione (1250 + 100.8 g a.i. ha^{-1}) was applied at the V 4 phenological stage, with a spray volume of 200 L ha^{-1}, for post-emergence weed management To control insect pests (*Frankliniella williamsi* and *Dalbulus maidis*) in the crop, three applications were made: the first was methomyl + thiamethoxam + lambda-cyhalothrin (129 + 35.3 + 26.5 g a.i. ha^{-1}), the second was acephate (525 g a.i. ha^{-1}), and the third was thiamethoxam + lambda-cyhalothrin + spinosad (35.3 + 26.5 + 48 g a.i. ha^{-1}), with a spray volume of 200 L ha^{-1}. Fungicides were not applied, since the objective of the study was to evaluate the reactions of the hybrids to the main diseases.

The following traits were evaluated: severity (%) of foliar and ear diseases, incidence (%) of grain pathogens, plant and ear height, yield, 100-seed weight, and final stand. The evaluations of foliar disease severity (*Cercospora zeae-maydis* and *Pantoea ananatis*) were carried out for each maize hybrid at the R3 phenological stage. For this evaluation, a random sample of ten plants was taken, and the diagrammatic scale proposed by Reid and Zhu (2005) was used, with scores ranging from 1 to 7 (1: no symptoms; 2: <1 % of leaf area with symptoms; 3: 1-5 % of leaf area with symptoms; 4: 6-20 % of leaf area with symptoms; 5: 21-50 % of leaf area with symptoms; 6: >50 % of leaf area with symptoms; 7: plant dead due to disease action).

For the severity of ear rot of maize (maize ear rot complex), evaluations were performed for each maize hybrid after harvest, taking a sample of 10 ears per hybrid. The diagrammatic scale proposed by Reid and Zhu (2005) was used, with scores ranging from 1 to 7 (1: no symptoms; 2: 1-3 % of maize ear area with symptoms; 3: 4-10 % of maize ear area with symptoms; 4: 11-25 % of maize ear area with symptoms; 5: 26-50 % of maize ear area with symptoms; 6: 51-75 % of maize ear area with symptoms; 7: 76-100 % of maize ear area with symptoms).

The seed health test was conducted with 25 seeds in eight replicates (a total of 200 seeds). The seeds were placed in autoclaved plates with filter paper in a 2 % agar/water medium, and the plates were kept for 15 days in a growth chamber at a constant temperature of 20 ºC. Fungi on the seeds were identified with the aid of a stereomicroscope based on their morphological characteristics (Seifert et al., 2011). The plates were then kept in the growth chamber for an additional 24 hours at -20 °C to prevent seed germination.

Plant height was measured at the VT (tasseling) phenological stage from soil level to the base of the panicle in ten plants per plot using a tape measure, and results were expressed in meters. Maize ear height was measured from soil level to the base of the ear, in ten plants per plot using a tape measure, and results were expressed in meters.

Yield was determined by harvesting the two central rows of each plot. The ears were mechanically shelled for each plot. The results were expressed in kilograms per hectare (kg ha^{-1}). The moisture content of the samples was measured to correct the total grain weight per plot to 13 % moisture.

From each plot, a random 100-seed sample was taken from the harvested volume and weighed, and its moisture content was also corrected to 13 %. The results were expressed in grams (g). The final stand was obtained at the end of the crop cycle by counting the number of plants in the center 5 meters of the 4 central rows of the plots, and calculating the estimated population per hectare.

For statistical analysis, count data were transformed using the square root (x + 0.5) transformation and percentage; data were transformed using the arcsine square root transformation (x / 100) to meet the assumptions of ANOVA. The data were statistically analyzed using the F-test for analysis of variance, followed by the Scott-Knott test, with a significance level of 5 % (R DEVELOPMENT CORE TEAM, 2023). The means presented in the tables are the original, non-transformed data.

Results and discussion

According to the results, there were significant differences among the hybrids in the plant height (PH), yield (YD), and 100-seed weight (SW) traits. However, there were no differences among the hybrids for ear height (EH) and final stand (FS) (Table 1).

The hybrids DKB 177, 30F53, KWS 9006, and Supremo exhibited the greatest plant heights (Table 1). However, it is noteworthy that the heights varied within the standard range (1.50-2.20 m) for maize hybrids in the population used (FOLONI et al., 2014). There was a consistent pattern among the hybrids for ear height, showing that it was not affected by plant population (Table 1). This result differs from Fromme et al. (2019), who described that as plant population increased, ear height also increased, in their study on three maize hybrids.

Table 1. Plant height (PH), ear height (EH), final stand (FS; plants ha^{-1}), yield (YD), and 100-seed weight (SW) of eight maize hybrids.

Hybrid	PH (m)	EH (m)	FS	YD (kg ha^{-1})	SW (g)
DKB 390	2.00 c	1.10 a	55000.00 a	4471.60 b	25.40 d
DKB 230	2.10 b	1.10 a	55000.00 a	5494.00 a	23.70 d
DKB 177	2.20 a	1.10 a	51944.40 a	6068.60 a	33.70 b
30F53	2.20 a	1.10 a	57391.10 a	4510.50 b	27.40 c
KWS 9110	2.10 b	1.10 a	50416.70 a	4050.70 b	27.10 c
KWS 9006	2.20 a	1.10 a	50833.30 a	5951.20 a	33.40 b
KWS 9004	2.10 b	1.10 a	54723.40 a	6068.70 a	36.30 a
Supremo	2.20 a	1.10 a	56250.00 a	5054.50 b	27.50 c
Average	2.20	1.10	56250.00	5201.20	29.40
C.V. (%)	7.30	1.10	6.10	12.30	5.90
p-value	> 0.0001*	0.5510^{ns}	0.4904^{ns}	> 0.0001*	> 0.0001*

*Significant at the 5 % probability level; **Significant at the 1 % probability level; ns - Not significant; Means followed by the same letter in the column do not differ statistically from each other according to the Scott-Knott test.

Source: authors (2024)

The hybrids KWS 9110 and KWS 9006 had the lowest average values for final stand. It's important to highlight that the final plant population depends on to the genetic traits the hybrid has to withstand environmental conditions and stresses associated with higher populations, and that final plant population affects yield (FOLONI et al., 2014; FROMME et al., 2019).

The hybrids DKB 230, DKB 177, KWS 9006 and KWS 9004 achieved the best yield results (Table 1). These hybrids had values higher than the Brazilian average yield (5,650 kg ha^{-1}) (CONAB, 2023), except for DKB 230. However, the high genetic potential of DKB 230 stands out, because even with high severity of white spot, *cercospora*, and ear rot complex, it remained among the highest yielding hybrids (Figures 2 and 3). DKB 177 and KWS 9004 achieved the highest average yields, possibly due to their lower susceptibility to the diseases under evaluation and greater resistance to *C. zeae-maydis* attack (Figures 2 and 3).

Greater resistance of maize hybrids to major foliar diseases can be attributed to allelic variation in gene expression. Amino acid levels and the amino acid sequence led to differences in the levels of lignin and of other metabolites of the phenylpropanoid pathway and differences in regulation of programmed cell death (YANG et al., 2017). Sousa et al. (2020) worked with maize half-sib families to identify groups with greater potential for resistance to the main foliar diseases and groups with higher yield, and they described that gray spot (*C. zeae-maydis*) caused less damage and yield losses compared to white spot. However, under the conditions of the present study, *C.* zeae-maydis was most severe, as it exceeded score 4 (6-20%) in all hybrids (Figure 2).

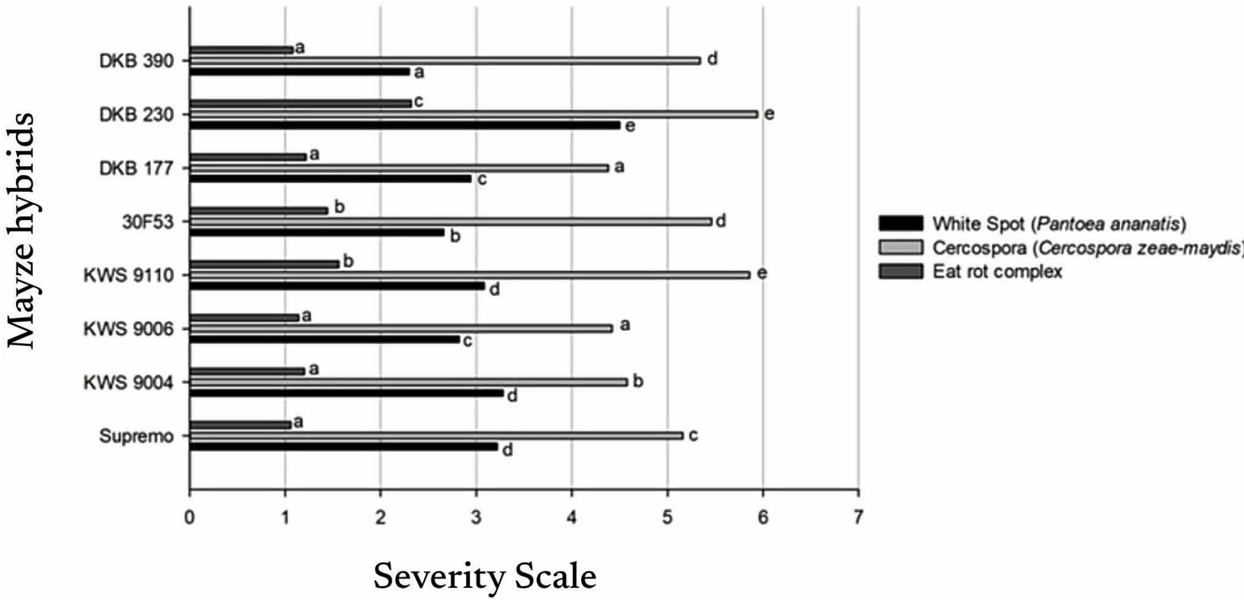
The 100-seed weight was highest for the hybrid KWS 9004 and lowest for DKB 390 and DKB 230 (Table 1). This trait coincided with the yield pattern when observing the hybrids KWS 9004 and DKB 390. Grain weight is one of the components that determine yield and it has a complex relationships with the morphological characteristics of the ear, which depend on the cultivars (GUERRA et al., 2017). Thus, better results for grain weight can be attributed to low susceptibility of a hybrid to diseases. Healthier leaves provide for greater translocation of photosynthates to the storage organs due to increased capture of incident light (CHEN et al., 2020).

In contrast, the low performance of DKB 390 may have been due to the high incidence of cercospora and low tolerance of the hybrid to even minimal severities of white spot and ear rot complex. Therefore, hybrids with resistance and adequate yield should be selected for sowing to reduce the spread of diseases in agricultural areas (WANI et al., 2022). For the hybrid DKB 230, high disease severity, especially the ear rot complex disease, was the decisive factor in suppressing 100-seed weight, even though it obtained good yield. This can be attributed to the genetic composition of the hybrids, which in most cases have a high grain yield capacity with worse resistance parameters (SWARUP et al., 2021).

The hybrids KWS 9110 and DKB 230 showed greater severity of leaf damage from *C. zeae-maydis*, while DKB 230 was more affected by *P. ananatis* and ear rot complex (Figure 2). Cercospora attack is among the main causes of leaf damage in the world, leading to maize yield losses (REHMAN et al., 2021).

At the phenological stage of R3, the leaf area of the hybrids DKB 390, DKB 230, 30F53, KWS 9110, and Supremo was compromised by cercospora. This causes a physiological disorder in the maize in the vegetative stage (V6-V7) through the conidia present in the detritus of the crop, which are dispersed by climatic agents, such as rain and wind. These conidia cause loss of chlorophyll and, consequently, reduction in accumulation of photoassimilates by the plants (REHMAN et al., 2021). For DKB 230, white

Figure 2. Severity (%) of cercospora, white spot, and ear rot complex in maize hybrids



Source: authors (2024)

spot led to 20% infestation of the leaf area, and ear rot complex led to greater severity of ear damage. Therefore, DKB 230 was the hybrid with the greatest susceptibility to the diseases under evaluation, but it still remained among the hybrids with the highest yields, demonstrating its high genetic potential against foliar diseases.

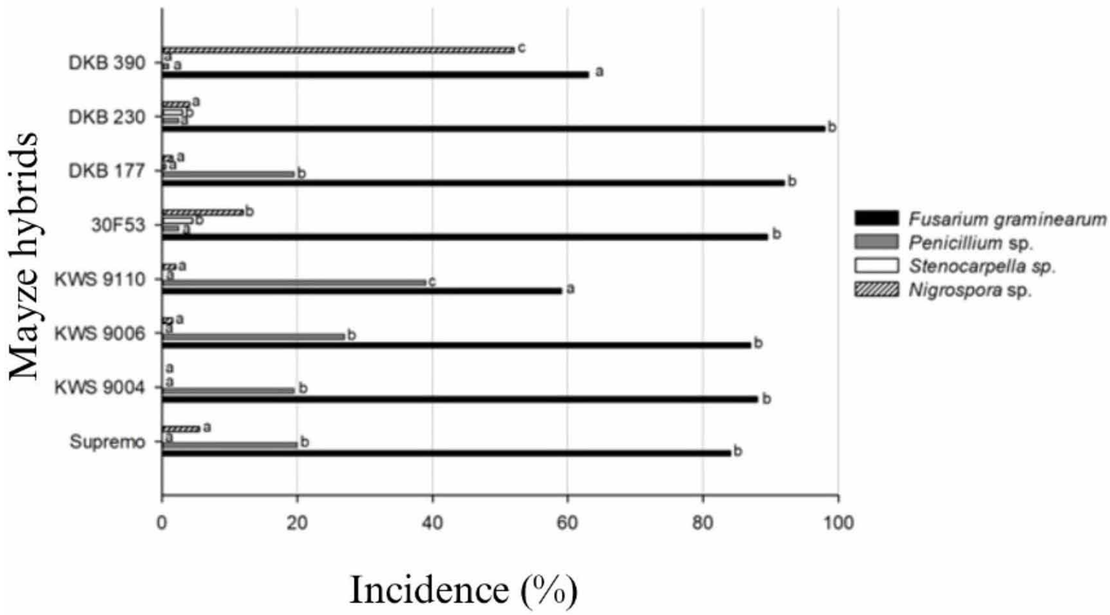
In addition, it is noteworthy that KWS 9004 had the highest values for both 100-seed weight and average yield, despite the attack by *P. ananatis* and fungi causing the ear rot complex (Table 1). This can be attributed to the intrinsic genetic characteristics of the hybrid, as well as to the fact that plants in the grain-setting stage (V4-V7) and in the period of determination of number of kernel rows (V9) likely did not have cercosporiosis severity greater than 1% (score 2). Rainfall during these stages also emerges as a determinant factor, as the germination tube of the cercosporiosis fungus retracts due to the presence of free water on the leaf surface (WORDELL FILHO; STADNIK, 2009).

The identification of hybrids less susceptible to foliar diseases, in association with rotation with non-host crops, such as soybeans and wheat, and the application of foliar fungicides are essential to achieve high grain yield (NEVES; BRADLEY, 2019; NEGA et al., 2020). However, it is noteworthy that a hybrid with high yield potential in the region but susceptibility to some diseases may be used, as long as phytosanitary management occurs at the correct time.

Regarding grain health in the hybrids, *Fusarium graminearum* occurred at a level of more than 80%, except for DKB 390 and KWS 9110; *Stenocarpella* sp. showed greater colonization in 30F53 (4.5%) and DKB 230 (4.0%); the highest incidence of *Nigrospora* sp. was in DKB 390 (52%); and *Penicillium* sp. mainly affected the hybrid KWS 9110 (39%) (Figure 3).

In the present study, the cultivation history of the area emerges as the main factor for the incidence of various fungi, regardless of the hybrid. In consecutive crop seasons, only the main annual crops (maize, soybean, and common bean) are grown, which is the main explanation for the high incidence of *F. graminearum*. Gimeno et al. (2020) described that the high colonization of *F. graminearum* in grain is related to the abundance and type of host-crop residues

Figure 3. Incidence (%) of *Fusarium graminearum, Penicillium* sp., *Stenocarpella* sp., and *Nigrospora* sp. in the grain of maize hybrids



Source: authors (2024)

that remain in the field. The pathogen survives saprophytically during the winter in cereal crop residues, waiting for the next growing season.

The *Fusarium* genus prevails in asymptomatic and moldy grain, encompassing a wide range of pathogenic species that penetrate the maize silk, causing damage to ears and grain (YUAN et al., 2020; SUCIU et al., 2021). Stefanello et al. (2012) evaluated the incidence of fungi in maize hybrid grain in relation to fungicide application, and they also observed the highest fungal percentages for the *Fusarium* sp. genus in the grain.

Despite the low incidence of *Stenocarpella* sp. in the hybrids evaluated, it is commonly found in maize grain grown in the Cerrado and Southern regions of Brazil (MÁRIO et al., 2017). This low incidence may be attributed to the low amount of moldy grain, as this pathogen is associated with the complex of diseases responsible for causing ear rot and moldy grain, especially in susceptible hybrids (CHAVES NETO et al., 2019). Mendes et al. (2011) evaluated the incidence of two *Stenocarpella* species in maize grain and also observed a higher incidence in DKB 230.

The high incidence of *Nigrospora* sp. may be associated with the effect of high relative air humidity (>70%) in June when the grain was close to physiological maturity. This genus generally has a low level of incidence, due to intermediate development at the time of early harvest of mature or immature maize grains, but its growth increases under optimal conditions of relative humidity (CHAGAS et al., 2018). This fungus develops more in grain around the post-harvest period or during storage, affecting grain health, causing weight loss/discoloration/necrosis of grain, and producing mycotoxins, which are decisive factors for the international maize market (SZILAGYI-ZECCHIN et al., 2016). Some authors mention the presence of *Nigrospora* sp. in maize grain, but the incidences did not exceed 20% for analyses performed immediately after harvest (SZILAGYI-ZECCHIN et al., 2016; CHAGAS et al., 2018).

For *Penicillium* sp., high incidence was observed in the hybrid KWS 9110 (39%), although this fungus is more associated with storage conditions (Figure 3). This incidence can be attributed to dispersion from winds that reached an average speed of 2.0 $m\,s^{-1}$ (July/2017) in the month of harvest and its capacity is present in different locations. Yadav et al. (2018) described that *Penicillium* is ubiquitous in many environments, and it is found in a range of habitats, including soil, air, and even extreme environments (extremes of temperature, salinity, water deficiency, and pH). Chagas et al. (2018) identified and quantified the fungi present in asymptomatic and damaged maize grain and also observed a high (20 %) presence of this fungus in immediate analysis after harvest. Ramos et al. (2010) carried out studies on the health of maize grain and found high incidence of *Penicillium* sp. (>40 %).

The environmental conditions of the study region include high rainfall, temperature, and relative humidity, which favor the development of phytopathogenic fungi. Therefore, the identification of high-yielding hybrids with low susceptibility to the main grain and foliar diseases is essential to increase the yield and profitability of the crop in the region.

Conclusion

High grain yield was observed for the hybrids DKB 177, DKB 230, KWS 9004, and KWS 9006. Regarding disease reaction, satisfactory levels of resistance to white spot, cercosporiosis, and the ear rot complex were identified in the hybrids DKB 177 and KWS 9006.

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