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CROP PRODUCTION

Agronomic performance associated with fungicide use in subtropical corn farming

Felipe Tascheto Bolzan[1] **Diego Nicolau Follmann**[1*] **Alberto Cargnelutti Filho**[1]
Volmir Sergio Marchioro[2] **Ivan Carlos Maldaner**[3]
Guilherme Bergeijer da Rosa[1] **Henrique Schaf Eggers**[1] **Luís Antônio Klein**[2]

[1]Departamento de fitotecnia, Universidade Federal de Santa Maria (UFSM), 97105-900, Santa Maria, RS, Brasil. E-mail: diego.follmann@ufsm.br. [*]Corresponding author.
[2]Departamento de Ciências Agronômicas e Ambientais, Universidade federal de Santa Maria (UFSM), Frederico Westphalen, RS, Brasil.
[3]Instituto Federal de Educação, Ciência e Tecnologia Farroupilha (IFFAR), São Vicente do Sul, RS, Brasil.

ABSTRACT: Fungal diseases in Brazilian regions with tropical and subtropical climates reduce the production potential of corn crops. The use of fungicides is one of the strategies to maintain productivity. This study evaluated the agronomic performance and grain quality of corn hybrids associated with the preventive use of fungicides in subtropical environments. Six experiments were conducted in Santa Maria-RS, São Vicente do Sul-RS, and Frederico Westphalen-RS during two sowing seasons. The experiment was conducted in a randomized complete block design with a split-plot arrangement, in which the main plot consisted of two levels of the fungicide factor (with and without) and the sub-plot consisted of six levels of corn hybrids (AG9025, AS1730, P3016, MG300, DKB230, and FEROZ). A total of 216 experimental plots were evaluated for grain productivity, and eight plants per plot were evaluated for other traits, totaling 1,728 evaluated plants. Therefore, environmental conditions influence the interaction between the factors of fungicide use and hybrid cultivar positioning, with no significant interaction in years with a water deficit. Early sowings in subtropical environments indicate better agronomic performance and a lower percentage of moldy grains regardless of the cultivation location, contributing to grain quality.
Key words: *Zea mays* L., cultural management, grain productivity, preventive chemical control, corn cultivars.

Desempenho agronômico associado a utilização de fungicida na cultura do milho em ambiente subtropical

RESUMO: No Brasil, em regiões de clima tropical e subtropical, as doenças fúngicas reduzem o potencial produtivo da cultura do milho. Uma das estratégias utilizadas para manutenção do potencial produtivo é o uso de fungicidas. O objetivo deste trabalho foi avaliar o desempenho agronômico e qualidade de grãos de hibridos de milho, associado ao uso preventivo de fungicida em ambientes subtropicais. Foram conduzidos seis experimentos, em Santa Maria - RS, São Vicente do Sul - RS e Frederico Westphalen – RS em duas épocas de semeadura. O delineamento experimental foi de blocos ao acaso com parcelas subdivididas, onde a parcela principal foi formada pelos dois níveis do fator fungicida (com e sem) e a subparcela pelos seis níveis do fator híbridos de milho (AG9025, AS1730, P3016, MG300, DKB230 e FEROZ). Foram avaliados 216 parcelas experimentais para a variável produtividade de grãos e oito plantas por parcela para os demais caracteres, totalizando 1.728 plantas avaliadas. Portanto, as condições ambientais interferem na interação entre os fatores uso de fungicidas e posicionamento de cultivares híbridas, não ocorrendo interação significativa entre os fatores em ano com a presença de déficit hídrico. Independentemente do local de cultivo, semeaduras precoces em ambiente subtropical, indicam melhor desempenho agronômico e menor percentual de grãos deteriorados contribuindo com a qualidade dos grãos.
Palavras-chave: *Zea mays* L., manejo cultural, produtividade de grãos, controle químico preventivo, cultivares de milho.

INTRODUCTION

Brazil is consolidated as the third-largest corn (*Zea mays* L.) producer, with an area of 21 million hectares cultivated in the 2021/2022 growing season. It is due to improvements in crop genetics and enhancements in agronomic management practices. These improvements are correlated to the need to increase grain productivity due to the growth of the world population, aiming to meet the demand for food and income in many countries (GRASSINI et al., 2015). To this end, the genetic improvement of corn hybrids has selected hybrids with higher production potential, which allows an increase in plant density per hectare (ASSEFA et al., 2018). It may be related to several factors, such as the use of irrigation in cultivation areas, which often pose a greater risk of loss of production potential due to fungal diseases that affect corn crops.

Other factors can be considered as potential for the emergence of diseases in corn, such as the expansion of sowing times in Brazil and the use of new cultivation techniques, such as early sowing under irrigation and sowing of the first and second growing seasons, which provide temporal continuity of the crop in the field. Furthermore, monoculture,

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associated with a large cultivation area, increases inoculum density and favorable environments, contributing to the development and increase in losses caused by diseases in corn crops (REIS et al., 2011).

Pathogens are constantly evolving, and the presence of natural mutation causes higher genetic susceptibility in plants, with the frequency of these mutations being related to the population size (MCDONALD & LINDE, 2002). In this sense, the launch time of a cultivar, associated with a large cultivation area, provides a higher risk of genetic resistance to fungal diseases in corn (GRALAK et al., 2015). Thus, it conditions the need for integrated disease management based on the use of genetic resistance, good agronomic cultivation practices, and the use of fungicides when necessary.

The use of fungicide in most crops is conducted as a preventive measure against epidemics of fungal diseases in corn due to limitations in agricultural mechanization and the fact that the corn plant is more than 2 m tall after flowering. Most properties in southern Brazil have trailed sprayers for disease management, limiting the critical period for disease monitoring and fungicide application between the beginning of grain filling and physiological maturity to more than 50 days. This difficulty in applying fungicide at the end of the cycle justifies preventive management when there are fungal disease inocula, such as *Puccinia sorghi*, *Physopella zeae*, *Puccinia polysora*, *Exserohilum turcicum*, and *Cercospora zeae-maydis*, helping to reduce the disease progression rate.

The literature presents studies that point to the use of fungicides as a favorable measure to maintain production potential. PENNEY et al. (2021) reported that treatments with fungicides had a lower incidence and severity of fungal diseases compared to not using fungicides, highlighting the positive effect of applying fungicides on corn crops. SILVA et al. (2020) also discussed the relevance of using fungicides to reduce losses caused by diseases in crops, demonstrating that it is an effective management method. Conversely, VILELA et al. (2012) pointed out that the use of fungicides reduced the incidence of leaf diseases. However, it did not result in a significant increase in grain productivity. In addition to maintaining the production potential of corn hybrids, the use of fungicides can reduce the percentage of moldy grains and reduce the presence of mycotoxins.

The preventive use of fungicides is a reality in corn cultivation and is adopted by rural producers when there is the presence of pathogens that cause fungal diseases, but this practice is not adopted by all producers. The use of hybrids with good genetic resistance to the main fungal diseases, reduced disease pressure in certain regions, low water availability in the cultivation environment, and high cost of preventive fungicide application are some of the reasons for not using fungicides (CHAVAGLIA et al., 2020). In this sense, to expand knowledge about the agronomic potential of corn crops and contribute to studies on the crop, this study evaluated the agronomic performance and grain quality of corn hybrids associated with the preventive use of fungicides in subtropical environments.

MATERIALS AND METHODS

This study was conducted under different climate conditions in areas cultivated with corn in the state of Rio Grande do Sul located in the municipalities of Santa Maria (SM), Frederico Westphalen (FW), and São Vicente do Sul (SVS) in the agricultural year 2020/2021 during two sowing seasons. The experiment in SM was conducted in the physiographic region of the Central Depression (29°43′28″ S, 53°43′41″ W, and altitude of 95 m). The climate is Cfa and characterized as humid subtropical, with no defined dry season, and an average rainfall of 1616 mm (ALVARES et al., 2013). The characteristic soil of the experimental site is classified as sandy-textured dystrophic Red Argisol (SANTOS et al., 2018).

The experiment in FW was set up in the Upper Uruguai region (27°23′42″ S, 53°25′43″ W, and altitude of 480 m). The regional climate according to Köppen is classified as Cfa, characterized as humid subtropical, with an average annual precipitation of 1881 mm (ALVARES et al., 2013). The soil in the experimental area is classified as a typic dystrophic Red Latosol (SANTOS et al., 2018).

Finally, the experiment in SVS was conducted in an experimental area located in the Central Depression (29°42′27″ S, 54°41′34″ W, and altitude of 129 m) and had supplementary irrigation. According to the Köppen classification, the regional climate is Cfa, characterized as humid subtropical, with an annual precipitation of 1561 mm (ALVARES et al., 2013). The soil is classified as gray-brown dystrophic Argisol (SANTOS et al., 2018), with a surface Ap horizon and a transition to the textural B horizon at 0.3 m depth.

The first sowing season was conducted on September 14, 18, and 22, 2020, while the second season was conducted on October 23, 31, and November 6, 2020, in SM, FW, and SVS, respectively. The experimental design consisted of a randomized complete block design with a split-plot arrangement. The fungicide management factor was evaluated in the main plot and the cultivar factor was evaluated in the subplot, with three replications in both sites and sowing seasons. The experimental unit consisted of six rows with a spacing of 0.50 m between rows and 5 m in length.

The twelve treatments were formed by combining the two levels of the fungicide management factor (with and without fungicide) and the six levels of the cultivar factor (hybrids AG9025, AS1730, P3016, MG300, DKB230, and FEROZ). Sowing was carried out manually to increase experimental precision and, after emergence, manual thinning was conducted to adjust the density to 70 thousand plants per hectare. Fertilization was performed in the furrow before sowing using a seed drill.

The cultivars have a good production potential and belong to similar maturity groups, representing the cultivars used by producers in the SM, FW, and SVS regions. The cultivars present different disease tolerance levels. AG9025 is characterized by being moderately tolerant to *Puccinia polysora* and tolerant to *Cercospora zeae-maydis*. However, it is moderately susceptible to *Exserohilum turcicum*. AS1730 is moderately tolerant to *Puccinia polysora* and *Cercospora zeae-maydis*. P3016 is moderately susceptible to *Exserohilum turcicum*. MG300 is moderately resistant to *Puccinia sorghi*, *Puccinia polysora*, *Exserohilum turcicum*, and *Cercospora zeae-maydis*. DKB230 is tolerant to *Puccinia polysora* and *Exserohilum turcicum* and moderately tolerant to *Cercospora zeae-maydis*. No information is available for the cultivar FEROZ (EMBRAPA, 2020).

The experimental units were fertilized based on the soil analysis conducted in the experimental area before setting up the experiment and considering the recommendations of the Fertilization and Liming Manual for an expected production of 12 Mg ha^{-1} of grains. Phosphorus and potassium fertilizers were deposited in the sowing furrow with the help of furrow openers. Nitrogen fertilizer consisted of urea, which was top-dressed applied when the plants were at the V4 and V8 stages.

The fungicide application was conducted by simulating a trailed sprayer, corresponding to the management adopted by corn producers in southern Brazil. Two fungicide applications were performed at V8 + VT (pre-flowering), following technical recommendations (MOTERLE & SANTOS, 2019). The fungicides propiconazole and picoxystrobin + cyproconazole were applied to control the main fungal diseases in corn crops. Other cultural treatments were adopted following the technical indications for corn cultivation in the State of Rio Grande do Sul.

The technological level used in this study can be considered medium/high, as irrigation was only conducted in two sowing seasons of the SVS experiments even using good agronomic practices for high production potential. Supplemental irrigation in SVS was performed using a center pivot. This site was irrigated due to the characteristics of the sandy soil and because it presents the lowest historical series of precipitation among the studied environments. The soil water balance was considered to define the correct time to use supplementary irrigation.

Single hybrids were used because their genetic constitution provides greater uniformity between plants, which allowed the use of a sample size of eight plants per plot. The following traits were measured in the study: plant height (PH, in cm – distance from the base to the apex of the plant); number of rows per ear (NR); number of grains per row (NGR); thousand-grain weight (TGW, in g); percentage of moldy grains due to fungal attack (PMG, in %, visually from 0 to 100); and grain productivity (PROD, in Mg ha^{-1}).

A useful area of 8 m^2 (4 central rows × 4 m in the central row) of the 216 plots was used to measure grain mass. The harvest was conducted when the grains reached 20% moisture and the grain mass was corrected for 13% moisture. The data from each environment were analyzed using the software Sisvar with a 5% probability of error by the Scott-Knott mean grouping test.

RESULTS AND DISCUSSION

Meteorological data from the cultivation environments in this field experiment showed low rainfall volumes (Figure 1) during the corn crop cycle. Importantly, the agronomic performance of corn crops is responsive to climate conditions, precipitation, and air temperature to express the production potential (EVANS & FISCHER, 1999).

The low rainfall volumes led to a reduction in grain productivity of the cultivars in the SM and FW environments, as these sites had irrigation during the crop cycle. The experiments conducted in SVS led to better plant development due to the use of supplementary irrigation. The environmental conditions of the current agricultural year provide for fewer hours of wetting the crop. Consequently, these factors were unfavorable for the development of leaf diseases. Thus, there was little incidence of

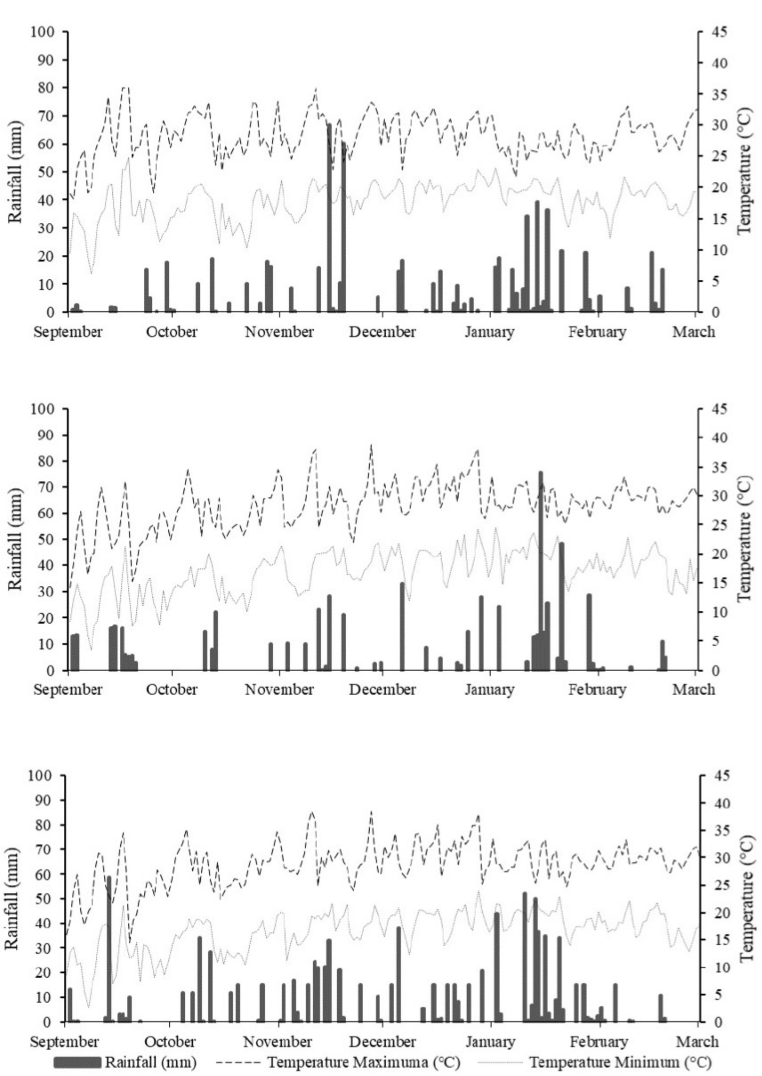

Figure 1 - Maximum and minimum temperatures and rainfall in Frederico Westphalen (A), Santa Maria (B), and São Vicente do Sul (C) in the state of Rio Grande do Sul during the 2020/2021 agricultural year, Santa Maria - RS, Brazil, 2023.

damage to the corn crop for the hybrids evaluated in the present study.

The analysis of variance indicates that fungicide application at the V8 and VT stages provided no significant effect on the variables evaluated in the 2020/21 growing season in the experimental cultivation sites. However, preventive applications are still necessary when plants are at vegetative stages, as the height of plants can represent a challenge for access by conventional machines within the fields at phenological stages in which fungicide applications provide significant technical and economic benefits (BOLLER et al., 2008). The coefficients of variation of the plot and subplot were low, standing out the good experimental precision. The fungicide factor showed no significant effects between treatments.

The cultivar factor showed significant differences between treatments for the analyzed traits, except for PMG in season 1 in SM and NGR in season 2 both in FW. The fungicide x cultivar interaction was significant for the variables NR in season 1 in SM, NR and PROD in season 2 in SM, and TGW and PMG in season 1 in SVS, indicating that these factors behaved independently.

All traits were influenced by the cultivar factor and this effect may be associated with genetic factors of the cultivars used in the study. MADDONNI et al. (2001) emphasized that these are specific traits of each cultivar that may vary due to environmental conditions or agricultural years.

A significant difference was observed for the cultivar factor in the SM environment in the first sowing season, except for the variable PMG (Table 1). Studies have indicated that PH is a trait resulting from the interaction of the genetic composition of the cultivar with the effects of cultivation environments and management systems, and its correlation with productivity components such as NGR can lead to different meanings (DOURADO NETO, 2003). The cultivar P3016 presented the highest PH for this environment, while plants of the cultivar MG300 presented the lowest PH, a characteristic typical of these cultivars and interesting for the management of fungicide with ground sprayers, as it allows entry into the crop at more advanced stages of development.

The lower PH has been a desirable trait among corn producers, as it allows crops at higher densities. The cultivars AG9025, AS1730, P3016, and DKB230 showed higher NGR, which is directly related to the average ear length (VILELA et al., 2012).

The cultivar MG300 showed the highest NR in the treatment with fungicide. The cultivars AG9025 and AS1730 had the highest averages for the variable TGW, which is one of the determining traits in the grain productivity potential of a cultivar and can be used in the indirect selection of cultivars with superior agronomic performance (KUMAR et al., 2015).

The cultivars AS1730, AG9025, P3016, and DKB 230 presented the highest values of PROD,

Table 1 - Average plant height, number of rows per ear, number of grains per row, thousand-grain weight, percentage of moldy grains, and grain productivity of six corn cultivars evaluated in Santa Maria-RS in season 1 (09/14/2020) with and without fungicide application.

Fungicide	---AG9025---	---AS1730---	----P3016----	---MG300---	--DKB230--	---FEROZ---	---Medium---
	-----Plant height, in cm-----						
With	213.96	226.58	241.54	194.21	221.08	228.46	220.97A
Without	231.79	230.54	243.00	217.46	228.91	231.58	230.55A
Mean	222.87b	228.56b	242.27a	205.83c	225.00b	230.02b	
	-----Number of rows per ear-----						
With	14.25Ac	13.83Ac	16.08Aa	15.75Aa	14.91Ab	14.66Bb	14.91
Without	13.75Ac	14.25Ac	16.25Aa	14.91Bb	15.50Ab	15.50Ab	15.02
Mean	14.00	14.04	16.16	15.33	15.20	15.08	
	-----Number of grains per row-----						
With	32.42	31.58	35.67	28.46	33.42	26.71	31.37A
Without	33.29	30.83	34.08	30.71	31.25	23.25	30.57A
Mean	32.85a	31.21b	34.87a	29.58b	32.33a	24.98c	
	-----Thousand-grain weight, in g-----						
With	354.39	377.19	279.03	263.79	348.21	273.07	315.95A
Without	356.02	353.45	289.70	314.33	299.07	262.99	312.59A
Mean	355.21a	365.32a	284.37c	289.06c	323.64b	268.02c	
	-----Percentage of moldy grains, in %-----						
With	0.71	0.96	0.63	1.29	1.33	0.04	0.82A
Without	0.29	0.54	1.33	0.96	0.37	1.66	0.86A
Mean	0.50a	0.75a	0.98a	1.12a	0.85a	0.85a	
	-----Grain productivity, in Mg ha^{-1}-----						
With	9.85	10.77	9.94	8.09	10.26	6.60	9.85A
Without	10.31	9.93	9.21	8.88	9.75	6.28	10.31A
Mean	10.08a	10.35a	9.58a	8.49b	10.01a	6.44c	

Means followed by the same uppercase letter in the column (comparison of fungicides) and lowercase letter in the row (comparison of cultivars) do not differ from each other by the Scott-Knott mean grouping test at a 5% probability of error.

with averages of 10.35, 10.08, 10.01, and 9.58 Mg ha^{-1}, respectively. The second sowing season in SM (Table 2) showed a significant interaction for the analyzed variables for the cultivar factor and a significant interaction for the cultivar x fungicide factor for NR and PROD variables. The cultivars P3016 and AS1730 had the highest NR values in the treatments with fungicide applications. The variable PROD showed a response to the use of the fungicide. The cultivar AS1730 was the most productive (10.14 Mg ha^{-1}) with fungicide application, whereas the best-performing cultivars without the use of fungicide were P3016, AS1730, and DKB230, with PROD values of 9.38, 8.36, and 8.29 Mg ha^{-1}, respectively.

The cultivar P3016 presented the highest value for the variable HP, while the cultivars AG9025 and FEROZ presented the lowest averages. A lower PH is one of the modifications observed in the architecture of corn plants, which allows greater efficiency in mechanical harvesting. Furthermore, it reduces problems related to lodging and plant breakage before harvesting, which is commonly seen in tall plants.

NGR was lower for the cultivar FEROZ, differing significantly from the others. Lower NGR values result in ears with a lower number of grains, which can negatively influence the production potential of cultivars (SANGOI et al., 2010). The cultivars AG9025, AS1730, and FEROZ presented the highest averages for the variable TGW, corroborating the results of other studies, which found variation in TGW depending on the cultivar (HANASHIRO et al., 2013).

The cultivar factor presented a significant difference in the first sowing season in FW (Table 3). The cultivars P3016 and FEROZ presented the highest

Table 2 - Average plant height, number of rows per ear, number of grains per row, thousand-grain weight, percentage of moldy grains, and grain productivity of six corn cultivars evaluated in Santa Maria-RS in season 2 (10/23/2020) with and without fungicide application.

Fungicide	---AG9025---	---AS1730---	----P3016----	---MG300---	--DKB230--	---FEROZ---	---Medium---
	-----Plant height, in cm-----						
With	264.12	268.87	284.04	266.54	260.33	165.12	251.5A
Without	246.92	260.08	285.12	252.16	250.42	262.00	253.3A
Mean	255.52c	264.47b	284.58a	259.35b	255.37b	213.56c	
	-----Number of rows per ear-----						
With	13.75Ac	15.58Ab	17.41Aa	16.41Ab	15.75Ab	14.16Ac	15.51
Without	13.66Ac	14.66Bb	16.50Ba	16.58Aa	16.08Aa	14.58Ab	15.34
Mean	13.70	15.12	16.95	16.49	15.91	14.37	
	-----Number of grains per row-----						
With	28.75	27.71	28.79	27.50	25.79	19.96	26.41A
Without	25.58	28.79	30.96	26.96	27.62	24.04	27.32A
Mean	27.17a	28.25a	29.87a	27.23a	26.71a	22.00b	
	-----Thousand-grain weight, in g-----						
With	389.98	399.59	284.62	298.64	330.69	344.08	341.2A
Without	385.53	354.80	317.12	309.74	324.60	354.07	340.9A
Mean	387.75a	377.19a	300.87b	303.19b	327.64b	349.08a	
	-----Percentage of moldy grains, in %-----						
With	17.17	4.58	21.96	6.92	9.62	11.92	12.03A
Without	22.12	8.83	12.21	4.83	9.58	11.25	11.47A
Mean	19.64a	6.71b	17.08b	5.87b	9.60b	11.58a	
	-----Grain productivity, in Mg ha^{-1}-----						
With	7.36Ab	10.14Aa	8.37Ab	7.73Ab	8.68Ab	5.16Ac	7.91
Without	6.45Ab	8.36Ba	9.38Aa	7.16Ab	8.29Aa	5.02Ac	7.44
Mean	6.90	9.25	8.87	7.45	8.48	5.09	

Means followed by the same uppercase letter in the column (comparison of fungicides) and lowercase letter in the row (comparison of cultivars) do not differ from each other by the Scott-Knott mean grouping test at a 5% probability of error.

Table 3 - Average plant height, number of rows per ear, number of grains per row, thousand-grain weight, percentage of moldy grains, and grain productivity of six corn cultivars evaluated in em Frederico Westphalen-RS in season 1 (09/18/2020) with and without fungicide application.

Fungicide	---AG9025---	---AS1730---	---P3016---	---MG300---	---DKB230---	---FEROZ---	---Medium---
	------Plant height, in cm------						
With	197.33	220.12	246.00	209.21	211.08	234.08	219.64A
Without	196.42	219.29	240.00	200.29	207.00	232.00	215.83A
Mean	196.87c	219.71b	243.00a	204.75c	209.04c	233.04a	
	------Number of rows per ear------						
With	13.91	15.58	15.25	16.12	14.91	14.58	15.06A
Without	14.50	14.83	15.66	15.50	14.66	15.41	15.09A
Mean	14.20b	15.20a	15.45a	15.81a	14.79b	15.00b	
	------Number of grains per row------						
With	29.88	30.17	33.37	29.83	32.91	27.00	30.53A
Without	29.91	32.83	32.33	28.08	32.29	26.17	30.27A
Mean	29.89b	31.50a	32.85a	28.96b	32.60a	26.58b	
	------Thousand-grain weight, in g------						
With	294.97	369.91	324.97	344.97	355.74	360.05	341.69A
Without	287.56	345.50	306.87	360.22	369.91	336.62	334.44A
Mean	291.26b	357.70a	315.92b	352.36a	362.82a	348.33a	
	------Percentage of moldy grains, in %------						
With	10.42	1.04	10.58	5.83	11.37	4.04	7.21A
Without	9.79	2.00	7.71	9.00	7.25	6.04	6.96A
Mean	10.10a	1.52b	9.14a	7.41a	9.31a	5.04b	
	------Grain productivity, in Mg ha^{-1}------						
With	6.69	10.28	10.37	9.19	9.19	8.19	9.00A
Without	6.64	11.09	9.68	6.92	9.42	8.00	8.63A
Mean	6.67c	10.69a	10.02a	8.05b	9.34a	8.10b	

Means followed by the same uppercase letter in the column (comparison of fungicides) and lowercase letter in the row (comparison of cultivars) do not differ from each other by the Scott-Knott mean grouping test at a 5% probability of error.

averages of PH. The cultivars AG9025, MG300, and DKB230 had the lowest PH averages. The lower PH allows greater light penetration into the canopy and reduces intraspecific competition for natural resources under high plant populations (KAPPES et al., 2011).

The cultivars AS1730, P3016, and MG300 presented the highest averages between treatments for the variable NR. In contrast, the cultivars AS1730, P3016, and DKB230 stood out for NGR. Studies with single hybrid cultivars have indicated that an increase in NGR results in a higher number of grains per ear but these grains tend to have a lower specific mass (LOPES et al., 2007).

TGW was higher for the cultivars AS1730, MG300, DKB230, and FEROZ. However, a variation was observed between treatments depending on the hybrids, corroborating the results found by SILVA et al. (2015). The cultivars AS1730 and FEROZ showed lower PMG for this study environment. The highest PROD values were reported in the cultivars AS1730, P3016, and DKB 230, with averages of 10.69, 10.02, and 9.34 Mg ha^{-1}, respectively. Biotic and abiotic factors have a great influence on PROD, with water seasonality being one of the main difficulties in obtaining high PROD levels (CARVALHO et al., 2014).

The second sowing season in FW showed a significant difference in the cultivar factor (Table 4). The cultivars AS1730, P3016, DKB230, and FEROZ presented the highest averages of PH, which allows us to infer that there is an influence of the environment on the expression of this trait, as the cultivation system was similar at all sites. Similarly, CARVALHO et al. (2014) observed higher PH values in corn cultivars when grown in a rainfed system.

NR was higher for the cultivars P3016, MG300, and FEROZ and may be associated with the genetic factors of each cultivar. Conversely, NGR has a strong relationship with environmental conditions, not differing significantly between cultivars, and may be associated with the strong water restriction present at that site and growing season.

Table 4 - Average plant height, number of rows per ear, number of grains per row, thousand-grain weight, percentage of moldy grains, and grain productivity of six corn cultivars evaluated in Frederico Westphalen-RS in season 2 (11/06/2020) with and without fungicide application.

Fungicide	---AG9025---	---AS1730---	---P3016---	---MG300---	---DKB230---	---FEROZ---	---Medium---
	---Plant height, in cm---						
With	202.08	228.71	234.83	204.71	231.38	235.71	222.90A
Without	196.04	235.00	241.79	211.42	237.25	229.79	225.21A
Mean	199.06b	231.85a	238.31a	208.06b	234.31a	232.75a	
	---Number of rows per ear---						
With	13.33	14.33	14.58	14.66	13.62	14.66	14.20A
Without	13.50	13.58	15.83	15.25	13.91	14.83	14.48A
Mean	13.41b	13.95b	15.20a	14.94a	13.77b	14.75a	
	---Number of grains per row---						
With	25.37	26.50	25.67	26.54	25.92	27.92	26.32A
Without	25.67	26.83	28.80	27.37	27.08	25.71	26.91A
Mean	25.52a	26.66a	27.23a	26.96a	26.50a	26.81a	
	---Thousand-grain weight, in g---						
With	235.71	281.39	303.92	231.59	239.40	179.66	245.28A
Without	192.29	266.44	262.20	282.53	246.40	205.28	242.52A
Mean	214.00b	273.92a	283.06a	257.06a	242.90a	192.47b	
	---Percentage of moldy grains, in %---						
With	18.29	8.46	10.16	6.71	12.29	7.50	10.57A
Without	12.71	7.00	7.29	8.08	10.54	5.46	8.51A
Mean	15.50a	7.73b	8.73b	7.40b	11.41a	6.48b	
	---Grain productivity, in Mg ha^{-1}---						
With	1.87	5.29	3.78	3.38	3.92	4.08	3.72A
Without	1.69	5.32	4.56	4.14	4.66	3.85	4.04A
Mean	1.78c	5.31a	4.17b	3.76b	4.29b	3.96b	

Means followed by the same uppercase letter in the column (comparison of fungicides) and lowercase letter in the row (comparison of cultivars) do not differ from each other by the Scott-Knott mean grouping test at a 5% probability of error.

The cultivars AS1730, P3016, M300, and DKB230 had the highest averages for the variable TGW. According to SERPA et al. (2012), the reduction in grain mass per ear is attributed to increased intraspecific competition for water and nutritional resources. Cultivars that are defining this component may undergo higher effects if water stress occurs during the NGR definition phase, damaging their production potential.

The cultivar AS1730 stood out for PROD in this environment, with an average of 5.31 Mg ha^{-1}. The cultivars AG9025 and DKB 230 presented the highest PMG in this environment, which is related to environmental factors, with the presence of a high incidence of water deficit during the period of greatest water need.

The corn crop was irrigated in all sowing seasons in SVS, which provided better conditions for its development. The environment sown in the first season (Table 5) showed a significant difference in the cultivar factor. The highest PH averages were observed for the cultivars P3016 and FEROZ. The cultivars AS1730, P3016, MG300, and DKB230 had the highest averages for the variable NR. NGR was higher for the cultivar P3016, while PMG was higher for the cultivar DKB230. The cultivars P3016 and AG9025 presented the highest PROD values for this environment, with averages of 12.69 and 12.62 Mg ha^{-1}, respectively, reaching the expectation of 12 Mg ha^{-1} planned with fertilization in the furrow.

The second sowing season (Table 6) showed a significant difference in the cultivar factor and interaction between fungicide x cultivar for the variables TGW and PMG. The cultivar AG9025 stood out with the highest averages for the variables TGW and PMG. The cultivars P3016 and FEROZ

Table 5 - Average plant height, number of rows per ear, number of grains per row, thousand-grain weight, percentage of moldy grains, and grain productivity of six corn cultivars evaluated in São Vicente do Sul in season 1 (09/22/2020) with and without fungicide application.

Fungicide	---AG9025---	---AS1730---	---P3016---	---MG300---	---DKB230---	---FEROZ---	---Medium---
	---Plant height, in cm---						
With	238.66	235.75	256.21	225.62	234.33	243.54	239.02A
Without	245.33	237.50	252.25	239.29	241.83	254.50	245.12A
Mean	242.00b	236.62b	254.23a	232.46b	238.08b	249.02a	
	---Number of rows per ear---						
With	14.25	15.08	15.91	15.16	15.58	15.00	15.16A
Without	14.33	15.41	16.08	15.50	15.58	14.91	15.30A
Mean	14.29b	15.25a	16.00a	15.33a	15.58a	14.95b	
	---Number of grains per row---						
With	37.08	35.25	38.75	30.83	32.71	29.63	34.04A
Without	37.83	32.50	41.42	34.58	32.29	30.21	34.80A
Mean	37.46b	33.87c	40.08a	32.71c	32.50c	29.92d	
	---Thousand-grain weight, in g---						
With	449.31	403.04	349.19	356.66	381.64	391.99	388.64A
Without	443.03	388.91	331.39	379.08	373.16	382.18	382.96A
Mean	446.17a	395.97b	340.29c	367.87b	377.40b	387.09b	
	---Percentage of moldy grains, in %---						
With	2.54	1.12	2.21	0.29	7.90	0.29	2.39A
Without	1.17	1.42	0.67	0.67	5.83	0.92	1.78A
Mean	1.85b	1.27b	1.44b	0.48b	6.86a	0.60b	
	---Grain productivity, in Mg ha^{-1}---						
With	13.19	10.71	12.49	9.72	10.21	8.39	10.80A
Without	12.06	10.48	12.89	10.66	9.57	9.09	10.79A
Mean	12.62a	10.59b	12.69a	10.19b	9.94b	8.74c	

Means followed by the same uppercase letter in the column (comparison of fungicides), and lowercase letter in the row (comparison of cultivars) do not differ from each other by the Scott-Knott mean grouping test at a 5% probability of error.

presented the highest averages of the variable PH. The cultivar P3016 presented the highest averages for the variables NR and NGR. The cultivars AS1730, P3016, and MG300 showed the highest PROD values for this environment, with averages of 10.07, 9.76, and 9.62 Mg ha^{-1}, respectively. The cultivars with the lowest PROD values were AG9025, FEROZ, and DKB230, respectively.

Even though there was no significant difference for PROD, the grain quality measured by PMG can be a decisive factor for the use of fungicides, as PMG can be related to the presence of fungi that damage the grain and; consequently, produce mycotoxins, which can make the use of corn grains for human food and animal feed unfeasible. The use of fungicides by producers who do not have access to preventive applications can be an important tool to improve grain quality and reduce the risk of problems with the presence of mycotoxins although there were no significant differences in PROD.

Fungicides consist of a complementary way to assist in the integrated management of fungal diseases in corn crops mainly due to the efficient control of the main diseases that affect the crop when they are applied correctly (LAGO & NUNES, 2008). In the present study, the agronomic performance of corn cultivars grown in the first growing season in locations with a subtropical climate showed no response to fungicide management for the variable PROD. Factors such as lower precipitation and relative air humidity in this agricultural year together with the good genetic resistance of the hybrids used by producers in the SM, FW, and SVS regions favored the absence of disease occurrence.

Table 6 - Average plant height, number of rows per ear, number of grains per row, thousand-grain weight, percentage of moldy grains, and grain productivity of six corn cultivars evaluated in São Vicente do Sul - RS in season 2 (10/31/2020) with and without fungicide application.

Fungicide	---AG9025---	---AS1730---	---P3016---	---MG300---	--DKB230--	---FEROZ---	---Medium---
	----------Plant height, in cm----------						
With	242.54	243.75	270.96	244.08	235.33	275.17	251.97A
Without	243.33	242.58	282.54	250.71	260.87	279.87	259.98A
Mean	242.94b	243.16b	276.75a	247.39b	248.10b	27752a	
	----------Number of rows per ear----------						
With	13.83	14.58	16.83	16.00	14.50	14.50	15.04A
Without	14.33	14.41	16.66	15.66	15.25	15.08	15.23A
Mean	14.08d	14.50c	16.75a	15.83b	14.87c	14.79c	
	----------Number of grains per row----------						
With	31.25	32.29	35.62	30.29	30.91	31.17	31.92A
Without	33.12	32.00	38.87	29.00	33.54	30.83	32.87A
Mean	32.18b	32.14b	37.25a	29.64b	32.23b	31.00b	
	----------Thousand-grain weight, in g----------						
With	459.57a	419.07Aa	291.01c	367.41b	365.16b	348.78b	375.16
Without	350.10a	403.70Aa	342.60a	366.62a	368.26a	334.38a	360.94
Mean	404.83	411.38	316.80	367.01	366.71	341.58	
	----------Percentage of moldy grains, in %----------						
With	14.41Aa	2.04Ab	2.96Ab	3.58Ab	3.29Ab	1.83Ab	4.68
Without	6.04Ba	2.91Aa	3.41Aa	3.08Aa	4.37Aa	0.41Aa	3.37
Mean	10.22	2.47	3.18	3.33	3.83	1.12	
	----------Grain productivity, in Mg ha^{-1}----------						
With	8.12	10.42	9.47	9.63	8.94	8.31	9.15A
Without	8.43	9.73	10.05	9.61	8.85	8.75	9.23A
Mean	8.27b	10.07a	9.76a	9.62a	8.89b	8.53b	

Means followed by the same uppercase letter in the column (comparison of fungicides) and lowercase letter in the row (comparison of cultivars) do not differ from each other by the Scott-Knott mean grouping test at a 5% probability of error.

A direct relationship was found for the variables NR and TGW with PROD. Moreover, the influence of sowing season and air temperature could be observed on the agronomic performance. Importantly, the benefits of using fungicides in corn cultivation are related to the genetic resistance of the cultivars, the sowing season, and climate conditions. Thus, correctly choosing and positioning corn cultivars according to the producer's technological level, sowing site, and sowing time is important to obtain positive results in grain production.

The genetic resistance of the cultivars, low rainfall, and lower fungal inoculum pressure in the cultivation area contributed to reducing the incidence and rate of progress of fungal diseases in corn crops even in the irrigated environment. The decision to use preventive fungicides even if there is no significant response to grain production can be taken due to a reduction in the incidence of moldy grains in hybrids with low genetic resistance and can be considered a complementary measure to reduce the incidence of grains with mycotoxins, commonly present in grains moldy by fungal diseases in corn.

CONCLUSION

Therefore, for the agronomic performance of first-crop corn in a subtropical environment, there was no interaction between the factors use of fungicides and hybrids, showing no responses to the preventive use of fungicide in a year with low rainfall.

The relationship between agronomic performance and sowing season in the three cultivation sites indicated the highest average grain productivity and yield components for the first sowing season, suggesting the anticipation of the sowing time in a subtropical environment for better use of resources, such as radiation, water availability, and air temperature.

The second sowing season presented the highest percentage of moldy grains in the three cultivation sites, with greater potential for problems with mycotoxins in the grains.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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