Performance of white corn hybrids intended for grits in different production environments

Desempenho de híbridos de milho branco destinados a grãos em diferentes ambientes de produção

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ABSTRACT
The Brazilian market has few hybrids intended for grits production, in particular, due to companies' lack of interest in developing new white corn hybrids due to the low proportion of cultivation in yellow corn hybrids. Another complicating factor is the genotype × environment interaction for recommending superior genetic materials. For this reason, this work aimed to evaluate agronomic characteristics and grits yield of commercial white corn hybrids IPR 127 and Dow 120009HW in different production environments. The assays were carried out in the municipalities of Rolândia-PR (Brazil), Campo Novo do Parecis-MT (Brazil), and Naranjal-PY (Paraguay), in a randomized block design, with four replications in a 2 × 3 factorial scheme (white corn hybrids × production environments). The analyzed variables were plant height, main cob insertion height, lodging and breakage, grain yield, and grits yield. Data were submitted to
variance analysis by F test (p<0.05) and means compared by Tukey's test, 5% probability of error, and principal component analysis (PCA). The production environments influence the performance of white corn hybrids intended for grits, IPR 127, and Dow 12B0009WH. The variables plant height, main cob insertion height, lodging and breakage, and grits yield were favored in cultivation in the municipality of Naranjal. The grain yield variable was higher in cultivation in Rolândia, and Campo Novo do Parecis municipalities. The white corn hybrid IPR 127 has a higher grits yield than the hybrid Dow 12B0009WH, in addition to greater stability of this variable depending on the production environments.

**Keywords:** agronomic characteristics, genotype × environment interaction, grain yield, grits yield, *Zea mays.*

**RESUMO**
O mercado brasileiro tem poucos híbridos destinados à produção de grãos, principalmente devido ao desinteresse das empresas em desenvolver novos híbridos de milho branco devido à baixa proporção de cultivo em híbridos de milho amarelo. Outro fator complicador é a interação genótipo × ambiente para recomendar materiais genéticos superiores. Por essa razão, esse trabalho teve como objetivo avaliar as características agronômicas e o rendimento de grãos de híbridos comerciais de milho branco IPR 127 e Dow 120009HW em diferentes ambientes de produção. Os ensaios foram realizados nos municípios de Rolândia-PR (Brasil), Campo Novo do Parecis-MT (Brasil) e Naranjal-PY (Paraguai), em um desenho de blocos aleatórios, com quatro repicações em um esquema fatorial 2 × 3 (híbridos de milho branco × ambientes de produção). As variáveis analisadas foram altura de planta, altura de inserção da espiga principal, alojamento e quebra, rendimento de grãos e rendimento de grãos. Os dados foram submetidos à análise de variância pelo teste F (p<0,05) e as médias comparadas pelo teste de Tukey, probabilidade de erro de 5% e análise de componente principal (PCA). Os ambientes de produção influenciam o desempenho dos híbridos de milho branco destinados a grãos, IPR 127 e Dow 12B0009WH. As variáveis altura de planta, altura de inserção da espiga principal, alojamento e quebra, e rendimento de grãos foram favorecidos no cultivo no município de Naranjal. A variável rendimento de grãos foi maior no cultivo em Rolândia, e nos municípios de Campo Novo do Parecis. O híbrido de milho branco IPR 127 tem um rendimento de grãos maior do que o híbrido Dow 12B0009WH, além de maior estabilidade desta variável dependendo dos ambientes de produção.

**Palavras-chave:** características agronômicas, Genótipo × interação ambiental, rendimento de grãos, o rendimento de grãos, *Zea mays.*

**1 INTRODUCTION**
Corn (*Zea mays* L.) is a grass from the Poaceae family, originally from the Americas. Culture is one of the pillars of Brazilian agriculture, with an approximate cultivation area of 22 thousand hectares and production of 126 thousand tons, considering the 1st, 2nd, and 3rd harvests (CONAB, 2023). Corn intended for human consumption, such as green corn, popcorn, and white
corn, are called special corn and represent a specific market niche that is seen as a profit alternative for the farmer, as it presents a value higher than corn sold in the form of grains (PATERNIANI et al., 2019). Highlighting its socioeconomic importance, culture is an indispensable raw material for several segments, such as animal feed and the food industry, since it is possible to obtain various products, such as oil, bioethanol, cornmeal, and grits, among others (PEREIRA et al., 2012).

Grits are the grains or pieces of corn grains from the Zea mays L. species partially or completely absent from the germ due to the mechanical or manual scarification process. This process occurs through the degermination system, in which the corn grain is broken and separated into three parts: endosperm (grits), germ (embryo), and pericarp (skin that surrounds the grain) (SOUZA et al., 2009).

Special corn, including white corn, is a widespread hybrid in Brazil, and one of their main purposes is the production of grits. At certain times of the year, its price may be higher than that of traditional corn due to increased consumption. The most suitable type of corn for grits is hard grain, with both yellow and white colors being common. However, the color preference is white in the south region of Brazil and yellow in the northeast and midwest regions (CALLENGARO et al., 2005).

The availability of cultivars for the production of grits corn is scarce, with the need for new hybrids. In 2015, only four white corn cultivars were recommended for production among 478 corn cultivars available for commercialization, but only one is commercialized – IPR 127 (CRUZ et al., 2014).

The genotype × environment interaction makes it difficult for researchers to identify superior genotypes during selection or when indicating cultivars (FREIRIA et al., 2019). This interaction quantifies the differentiated behavior of genotypes in the face of environmental variations. Thus, the behavior of genotypes depends fundamentally on the environmental conditions to which they are subjected (FREIRIA et al., 2018).

In the literature, there are few data related to the production of special corn, given that most of the available data on productivity, cultivated area, and agricultural practices refer to yellow corn, which contributes to the scarcity of recommended cultivars of white corn (PEREIRA FILHO and BORGHI, 2018). For this reason, this work aimed to evaluate agronomic characteristics and grits yield of commercial white corn hybrids IPR 127 and Dow 120009HW.
in different production environments.

2 MATERIAL AND METHODS

The assays were carried out in the municipalities of Rolândia-PR (Brazil), Campo Novo do Parecis-MT (Brazil), and Naranjal-PY (Paraguay) (Table 1) in the 2015 cropping season in a randomized block design, with four replications. Two white corn hybrids, IPR 127 and Dow 120009HW, were used for grits (Table 2), resulting in a 2 × 3 factorial scheme with two white corn hybrids and three production environments.

The experimental units consisted of two lines of 5.0 m, spaced 0.9 m apart, making up a usable area of 9.0 m². At 25 days after plant emergence, the excess thinning of each plot was carried out, corresponding to a final population of 55,555 plants.ha⁻¹. Three production environments were conducted under center pivot irrigation and fertilization according to soil analysis and crop needs. Precipitation data during the crop cycle in the three production environments are shown in Figure 1.

During the conduction of the experiment, the following analyzed variables were evaluated:

1. Plant height (PH): the height of six plants per experimental unit was measured, from the base of the plant to the insertion of the flag leaf, with the aid of a 3 m graduated ruler. The result was expressed in meters (m) using the arithmetic mean;
2. Main cob insertion height (CH): the height from the plant's base to the upper cob's insertion was measured. For each experimental unit, the arithmetic mean of the main cob insertion height of six plants was calculated with the aid of a 3 m graduated ruler, the result being expressed in meters (m);
3. Lodging and breakage (LB): the number of lodged and broken plants per experimental unit was counted;
4. Grain yield (GrY): the grain mass of the plants of each experimental unit was measured with the aid of a precision scale, and the result was expressed in kg.ha⁻¹;
5. Grits yield (GY): the grits process was carried out using the horizontal corn degerminator, model DHZ-2/A (Zaccaria®), to extraction the corn germ, with a capacity of 600-900 kg.h⁻¹. This methodology defined the degermination of 10 kg of corn from each experimental unit, keeping the degerminator regulated for processing in 2 minutes.
and 40 seconds. After degermination, the material was separated into grits and bran, and the result was expressed in the percentage of grits (%), according to the retention on the sieve.

The data were submitted for statistical analysis. The basic assumptions were previously verified for the validity of the results obtained in the individual variance analyses using the Shapiro-Wilk test, at 5% significance, to verify normality and the Bartlett test, at 5% significance, to check the homogeneity of residual variances. Subsequently, data were submitted for variance analysis using the F test (p<0.05), and means were compared using Tukey's test, 5% probability of error, and principal component analysis (PCA). The R software (www.r-project.org/) was used for data analysis.

3 RESULTS AND DISCUSSION

It was observed based on the mean square values of the variance analysis response of the analyzed variables (Table 3). The interaction between the factors "white corn hybrid" and "production environment" showed significant differences for the variables main cob insertion height (CH), lodging and breakage (LB), and grits yield (GY). The variables plant height (PH) and grain yield (GrY) showed a significant difference for the factor "production environment" alone (Table 3). Regarding the coefficients of variation (CVs), it was verified that the registered values fall within the range reported in several works carried out with sweet and green corn, which demonstrates the reliability of the presented values (SCAPIM et al., 1995, FRITSCHENETO et al., 2010).

For the plant height variable, it was observed that Naranjal provided environmental conditions for the plants to reach a larger size. On the other hand, the grain yield variable presented an inversely proportional behavior since the municipalities of Rolândia and Campo Novo do Parecis presented averages superior to the grain yield obtained under cultivation in Naranjal (Table 4). Cavallet et al. (2000), in a study with the corn crop, found that the plant height variable does not present a significant correlation with the grain yield, showing the possibility of these variables being inversely proportional, as observed in the present study with white corn, in the three production environments.

This performance can be explained by the duration of the vegetative stages of the crop since the plants cultivated in Naranjal took a longer period to reach the reproductive stage, thus
allocating an amount of photoassimilates for vegetative growth, possibly due to the lower accumulation of precipitation in the early stages of crop development (Figure 1). In the other production environments, there was no delay in reaching the reproductive stages, and, therefore, the flow of photoassimilates adequately supplied the crop demand during grain filling, resulting in greater grain yield.

Such competition for photoassimilates is attributed to the source-sink relationship existing in the plant, which is highly influenced by the production environment. In environments that lengthen the vegetative stages, the plant prioritizes the increase in size and the emission of new leaves, the main consumers of photoassimilates (sinks) during the period. On the other hand, in corn plants that reach the reproductive phase without the elongation of the vegetative stages, the translocation of photoassimilates is directed earlier to the existing sinks in the reproductive stages, which contributes to the definition of the number of grains and their filling period (TAIZ et al., 2016).

Cargnelutti Filho et al. (2007), when observing the adaptability and stability of corn cultivars sown in different production environments and evaluating grain yield levels, found that this variable depends on the production environment. In turn, Ribeiro et al. (2000), when evaluating the grain yield of 20 corn genotypes cultivated in different environmental conditions, concluded that several factors, such as climate, temperature, relative humidity of the air, and precipitation, can influence the development of the culture.

Regarding the variables main cob insertion height and lodging and breakage, a similar behavior can be observed since both showed a significant response to the interaction between "white corn hybrid" and "production environment" (WH × PE) (Table 5). It was found that there was no significant difference in these variables for both white corn hybrids for Rolândia and Campo Novo do Parecis, differing only in Naranjal. Cultivation in Naranjal provided greater main cob insertion height in both evaluated hybrids than in other production environments. However, the cultivation of white corn IPR 127 in the Paraguayan municipality favored the increase of lodged and broken plants (Table 5).

Kostetzer et al. (2009), when evaluating different corn genetic materials (local and synthetic varieties) in two production environments (São João do Triunfo and Londrina, both located in the state of Paraná-Brazil), also observed an effect of genetic material regarding the production environment for the relative cob position variable, as observed in the present study.
However, the same authors found that the interaction effects of corn genetic material × production environment were not significant for the variables percentage of lodged and broken plants in some genetic materials evaluated, indicating different behaviors of the genotypes in the environments. In the present study, both white corn hybrids were influenced by the production environment when evaluating the number of lodged and broken plants, showing the importance of considering the genetic material when choosing the production environment.

For the grits yield variable, it was observed that the hybrid IPR 127 provided the highest averages in all production environments about the hybrid Dow 12B0009WH. However, no statistical difference was observed for the hybrid IPR 127 in the three production environments, unlike that observed for the hybrid Dow 12B0009WH, which provided a higher grits yield when cultivated in Naranjal, compared to Rolândia and Campo Novo do Parecis (Table 5). Bignotto et al. (2015), in a study with white corn genetic materials for grits, also found a significant effect of the production environment when evaluating the grits yield variable.

Finally, principal component analysis (PCA) (Figure 2) emerges as a tool responsible for analyzing and confirming existing correlations between variables based on plotting the points and the angle of the vectors that graphically represent the variables. In this sense, the angulation dynamics between the variables suggest that obtuse angles (close to 180°) represent negative correlations. In contrast, acute angles (close to 0°) and straight angles (close to 90°) refer to positive and null correlations, respectively.

In addition to these factors, there is a need for the sum of the axes used graphically to explain at least 70% of the variability found in the research and, for this case, using only Dim 1 (75.09%) and Dim 2 (15.87%) the preset value has been exceeded. The axes values found in the analyzed variables are similar to Bottega et al. (2013) and Moreira et al. (2009), who, when evaluating characteristics related to the performance of the main components, obtained accumulated values of the primary and secondary axes of 71.17 and 72.84%, respectively.

Therefore, it was found that the grain yield variable has a negative correlation with the other variables, and these present a positive correlation. This fact occurs due to the focus on the distribution of energy reserves. When the hybrids prioritized the reproductive stages to the detriment of the vegetative ones, there was a greater accumulation of dry matter in the grains. The opposite is also true, since in a scenario where the priority is the increase in plant size, the
objective is to accumulate dry matter in the vegetative structures by increasing the height and number of leaves, for example.

In this way, the characteristics PH, CH, and LB have a positive correlation of high magnitude (Figure 2) since the greater the plant height, the higher the cob insertion, generating greater weight and instability in the upper part of the dossal, which, consequently, favors the incidence of lodging and breakage of plants, since under these conditions the plants are susceptible to the deleterious action of the winds.

Thus, it is possible to infer that the correlation between grain yield and grits yield tends to be negative and of high magnitude, regardless of the analyzed hybrid. This phenomenon occurs due to the accumulation of sugars in the grains during their filling process. When a plant produces a greater amount of the final product (greater production), the reserves tend to be equally distributed to all grains, which reduces the final concentration of sugars per grain and, consequently, the grits yield. On the other hand, plants with a smaller productive structure accumulate higher concentrations of sugars in the grains, as there are less sinks (grains), which adequately supply the demand.

Regarding the production environments, it was observed that the characteristics of plant height (PH), main cob insertion height (CH), lodging and breakage (LB), grain yield (GrY), and grits yield (GY) are influenced by them. Variables PH, CH, LB, and GY were favored in white corn from Naranjal. In turn, the GrY variable showed an inversely proportional behavior, being disadvantaged in cultivation in Naranjal, not having a significant crop difference between Rolândia and Campo Novo do Parecis. The metabolic processes related to these different performances are due to the source-sink relationship combined with the duration of the vegetative and reproductive stages, as previously exposed, and independently of the evaluated hybrid.

4 CONCLUSIONS

The production environment influences the performance of white corn hybrids intended for grits, IPR 127, and Dow 12B0009WH.

The variables plant height, main cob insertion height, lodging and breakage, and grits yield were favored in cultivation in the municipality of Naranjal.

The grain yield variable was higher in cultivation in Rolândia, and Campo Novo do Parecis municipalities.
The white corn hybrid IPR 127 has a higher grits yield than the hybrid Dow 12B0009WH, in addition to greater stability of this variable depending on the production environments.
REFERENCES


Table 1. Production environments (municipality) and their characteristics: altitude (m), geographic coordinates south and west, and sowing and harvesting times of the white corn hybrids IPR 127 and Dow 12B0009WH.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Altitude (m)</th>
<th>Geographic coordinates</th>
<th>Sowing</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolândia</td>
<td>735</td>
<td>23° 19’ S 51° 33’ W</td>
<td>02/20/2015</td>
<td>07/22/2015</td>
</tr>
<tr>
<td>Campo Novo do Parecis</td>
<td>569</td>
<td>13° 40’ S 57° 53’ W</td>
<td>01/16/2015</td>
<td>06/18/2015</td>
</tr>
<tr>
<td>Naranjal</td>
<td>280</td>
<td>25° 57’ S 55° 10’ W</td>
<td>01/26/2015</td>
<td>06/29/2015</td>
</tr>
</tbody>
</table>

Table 2. Characterization of white corn hybrids with suitability for grits.

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Genetic basis</th>
<th>Cycle</th>
<th>Company</th>
<th>Type of grain</th>
<th>Grain color</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPR 127</td>
<td>Single hybrid</td>
<td>Early</td>
<td>IAPAR</td>
<td>Hard</td>
<td>White</td>
<td>Grits</td>
</tr>
<tr>
<td>Dow 12B0009WH</td>
<td>Single hybrid</td>
<td>Early</td>
<td>Dow</td>
<td>Hard</td>
<td>White</td>
<td>Grits</td>
</tr>
</tbody>
</table>

Figure 1. Precipitation during the cycle of the white corn hybrids IPR 127 and Dow 120009HW in the three production environments.
Table 3. Summary of the variance analysis for the variables: plant height (PH), main cob insertion height (CH), lodging and breakage (LB), grain yield (GrY), and grits yield (GY).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>PH</th>
<th>CH</th>
<th>LB</th>
<th>GrY</th>
<th>GY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>0.001753ns</td>
<td>0.000728ns</td>
<td>0.550ns</td>
<td>545,086.78ns</td>
<td>0.001487ns</td>
</tr>
<tr>
<td>White corn hybrid (W.H.)</td>
<td>0.000163ns</td>
<td>0.001080ns</td>
<td>34.133**</td>
<td>277,633.20ns</td>
<td>0.029453**</td>
</tr>
<tr>
<td>Production environment (PE)</td>
<td>0.457443**</td>
<td>0.051823**</td>
<td>48.533**</td>
<td>8,876,399.70**</td>
<td>0.003523*</td>
</tr>
<tr>
<td>WH × PE</td>
<td>0.000163**</td>
<td>0.006130*</td>
<td>17.733**</td>
<td>351,099.70**</td>
<td>0.003123*</td>
</tr>
<tr>
<td>Residue</td>
<td>0.000925</td>
<td>0.001612</td>
<td>1.350</td>
<td>641,334.68</td>
<td>0.000833</td>
</tr>
<tr>
<td>CV (%)</td>
<td>1.52</td>
<td>4.68</td>
<td>56.22</td>
<td>15.25</td>
<td>3.67</td>
</tr>
</tbody>
</table>

** Significant at 1% probability; * Significant at 5% probability; ns Not significant.

Source: Author

Table 4. Plant height (PH), and grain yield (GrY) of white corn hybrids under different production environments.

<table>
<thead>
<tr>
<th>Production environment</th>
<th>PH (m)</th>
<th>GrY (kg.ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolândia</td>
<td>1.77 C</td>
<td>6,075.50 A</td>
</tr>
<tr>
<td>Campo Novo do Parecis</td>
<td>2.03 B</td>
<td>5,455.40 A</td>
</tr>
<tr>
<td>Naranjal</td>
<td>2.19 A</td>
<td>4,224.50 B</td>
</tr>
</tbody>
</table>

Uppercase letters distinct from each other in the column differ by Tukey’s test (5%).

Source: Author

Table 5. Main cob insertion height (CH), lodging and breakage (LB), and grits yield (GY) of white corn hybrids under different production environments.

<table>
<thead>
<tr>
<th>White corn hybrid</th>
<th>CH (m)</th>
<th>LB</th>
<th>GY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rolândia</td>
<td>Campo Novo do Parecis</td>
<td>Naranjal</td>
</tr>
<tr>
<td>IPR 127</td>
<td>0.770 Ac</td>
<td>0.860 Ab</td>
<td>0.960 Aa</td>
</tr>
<tr>
<td>Dow 12B0009WH</td>
<td>0.810 Ab</td>
<td>0.830 Ab</td>
<td>0.910 Ba</td>
</tr>
<tr>
<td></td>
<td>Rolândia</td>
<td>Campo Novo do Parecis</td>
<td>Naranjal</td>
</tr>
<tr>
<td>IPR 127</td>
<td>0.800 Ab</td>
<td>1.400 Ab</td>
<td>7.200 Aa</td>
</tr>
<tr>
<td>Dow 12B0009WH</td>
<td>0.400 Aa</td>
<td>0.600 Aa</td>
<td>2.000 Ba</td>
</tr>
<tr>
<td></td>
<td>Rolândia</td>
<td>Campo Novo do Parecis</td>
<td>Naranjal</td>
</tr>
<tr>
<td>IPR 127</td>
<td>0.814 Aa</td>
<td>0.818 Aa</td>
<td>0.818 Aa</td>
</tr>
<tr>
<td>Dow 12B0009WH</td>
<td>0.734 Bb</td>
<td>0.732 Bb</td>
<td>0.796 Ba</td>
</tr>
</tbody>
</table>

Uppercase letters distinct from each other in the column and lowercase letters in the row differ by Tukey’s test (5%).

Source: Author
Figure 2. Principal component analysis (PCA) obtained by the variables plant height (PH), main cob insertion height (CH), lodging and breakage (LB), grain yield (GrY) and grits yield (GY) of white corn hybrids IPR 127 and Dow 12B009WH cultivated in Rolândia (L1), Campo Novo do Parecis (L2) and Naranjal (L3).

Source: Author