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YIELD POTENTIAL AND SELECTION OF OFF-SEASON MAIZE FOR SILAGE AND GRAIN USING GT BIPLOT UNDER LIMITED WATER AND FROST

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Abstract
Maize silage has been used as a forage reserve strategy for critical periods or continuous use in animal feed. However, new genotypes and their potential must be identified. Thus, this study aimed to evaluate the potential of maize genotypes for silage and grain in one off-season in the midwest region of Brazil, under limited water and frost, and select them for this dual purpose (silage and grain) using the GT Biplot tool. The experiment was performed at Embrapa Western Agriculture in the autumn-winter season of 2021 in Dourados, Mato Grosso do Sul, Brazil. The experimental design consisted of randomized blocks of six maize genotypes (BRS1010, KWS9606, 1P2224, 1Q2383, BRS3046, and CAPO) with five replications under no-tillage. Silage points were evaluated at harvest when the grain milk line was at ¾ and maize grains at the maturation stage (dry plant). The 1P2224 and 1Q2383 maize genotypes present silage (high green and dry biomass) and grain yield potential. The GT Biplot tool identified the 1P2224 genotype as superior and suitable for cultivation or as a parent in a breeding program in the midwest region of Brazil for silage and grain yield evaluations of one off-season under limited water and frost.

Keywords: Forage. Multivariate. Yield. *Zea mays*.

1. Introduction

Maize (*Zea mays*) is one of the world's most cultivated and consumed cereals, meant for producing grains or industrialized products and supplied to human and animal food (Pereira et al. 2020). The cultivation of off-season maize in the autumn-winter season has evolved in the midwest region of Brazil, with an increase in the planted area from 1551.3 hectares in 2003/2004 to 8926.2 hectares in 2019/2020 (Conab 2021a). Although this region produces the most maize in the off-season, grain yields were low (6040 kg ha^{-1}) compared to 2019/2020 summer crop (8168 kg ha^{-1}) (Conab 2021a).

As an economic crop yield in the off-season, maize can be used as roughage for animal feed due to the high yield potential of dry matter and grain production capacity (Crevelari et al. 2018). This process is called silage and has been used as a forage reserve strategy for periods of the dry season or continuous use in animal feed to prevent animal production hazards (Neumann et al. 2010).

There is a high diversity of maize cultivars for grain and silage production, but different types of commercial and developing maize must be characterized to expand their crops and select those with a dual-consumption purpose (grain and silage) in a given crop area and subjected to certain soil and climate conditions. In the absence of regional evaluation data on maize cultivars for silage, there is the alternative of cultivars with dented or semi-dented grains with larger biomass and size and higher green and dry mass production; also, grain characteristics such as ear length, the number of grain rows, the number of grains per row, and grain yield are essential for selecting genotypes (Duarte et al. 2014; Crevelari et al. 2018; Pereira et al. 2018a). The genotype by trait (GT) biplot tool is a method to analyze several traits in genotype selection and the relationship between genotypes and traits with graphical visualization (Sharifi and Ebadi 2018; Yan and Frégeau-Reid 2018).

The GT biplot tool analyzes the genotypes selected, which may be used as parents in breeding programs or even potential commercial cultivars, and identifies appropriate traits for an indirect selection (Mohammadi and Amri 2013; Oliveira et al. 2018). The GT biplot technique has been applied to green beans (Oliveira et al. 2018), rice (Sharifi and Ebadi 2018), spinach (Sabaghnia et al. 2015), wheat (Sabaghnia and Janmohammadi 2014), and maize (Dolatabad et al. 2010) to identify the relationship among traits and evaluate genotypes based on multiple traits. Considering that the environment can change crop yield performance, using this statistical tool in a specific crop and season can help select the best genotypes for the traits of interest (Sharifi and Ebadi 2018; Sabaghnia et al. 2015).

Based on the data above, there is little information on the cultivation of off-season commercial maize genotypes and the development stage for grain and/or silage in the midwest region of Brazil. Thus, this study aimed to evaluate the potential of maize genotypes for silage and grain in one off-season in the midwest region of Brazil, under limited water and frost, and select them for this dual purpose (silage and grain).

2. Material and Methods

The experiment was performed at the Brazilian Agricultural Research Corporation (Embrapa) - Western Agriculture in a field in Dourados, Mato Grosso do Sul, Brazil (22°16 S; 54°49 W; and 408 m), in the autumn-winter season of 2021. The soil was classified as Dystrophic Red Latosol, with a very clayey texture (Santos et al. 2018). The climate of the region is Cwa (humid mesothermal climate), according to the Köppen classification, with hot summers and dry winters, maximum temperatures in December and January, and minimum temperatures between July and June coinciding with excess rain in the spring-summer season and water deficit in the autumn-winter season (Fietz et al. 2017).

During the experiment, temperatures and precipitation were collected and compared with the historical series and the year before the study (Figure 1) (Fietz et al. 2017; Guia Clima 2021; Guia Clima 2020). There was a lower precipitation accumulation during the experiment in 2021 (244.6 mm) than in 2020 (362 mm) and 1980-2016 (433 mm). As for maximum and minimum temperatures, the year of the experiment was close to the historical average (2001-2016) (Fietz et al. 2017; Guia Clima 2021; Guia Clima 2020). In the month of June of the experiment, frost occurred due to the entry of a polar mass in the south-central region of Brazil, with temperatures reaching zero degrees Celsius. Frosts have been reported in the region, but predominantly in July according to the history of the area (1980-2015) (Fietz et al. 2017). Thus, the types of maize with higher yield potential under less precipitation and frost must also be studied.

The experimental design consisted of randomized blocks of six maize genotypes - three commercial (BRS1010, KWS9606, BRS3046) and three in the development stage (1P2224, 1Q2383, CAPO) - with five replications under no-tillage. The plots included five lines of 10 m in length (5 m for evaluation at the silage point and another 5 m for harvesting maize grains). The experiment was implemented on March 2, 2021, with a seeder for the simultaneous direct seeding of maize and *Panicum maximum* grass cv. BRS Zuri broadcast (PST4 seeder - Tatu Marchesan Flex Suprema), and a 0.5-m spacing between maize rows and five plants per linear meter. There was no fertilization for planting or covering because the area uses the no-tillage system under straw, and there was no irrigation, simulating small rural producers.

The BRS3046 genotype, according to the registration in the Ministry of Agriculture, Livestock, and Supply (MAPA) (nº 35276) of 2017, is a triple super early hybrid developed by Embrapa, classified as dent maize, suitable for silage and grain, with 60.5 days of flowering in season and off-season crops, and recommended for the midwest, southeast, and northeast regions of Brazil, and the state of Paraná (north, northwest, and west). The BRS1010 genotype, according to the MAPA registration (nº 11986) of 2016, is an early simple hybrid developed by Embrapa, classified as semi-hard, suitable for grains, with 61 days of flowering, good adaptation to the southeast, midwest, and north regions of Paraná, southwest of Bahia, and south of Maranhão and Piauí. The KWS9606 VIP3 genotype, according to the MAPA registration (nº 37430) of 2017, is a genetically-modified early single hybrid (Viptera 3 biotechnology) developed by Riber - KWS seeds, classified as semi-hard, suitable for silage and grain in season and off-season crops, used in the north, south, northeast, midwest, and southeast regions of Brazil. The 1P2224 and 1Q2383 genotypes are strains under improvement at Embrapa Maize and Sorghum, and the CAPO genotype is a super early strain under development at Embrapa Western Agriculture; these genotypes have not been registered in MAPA and have little available information.

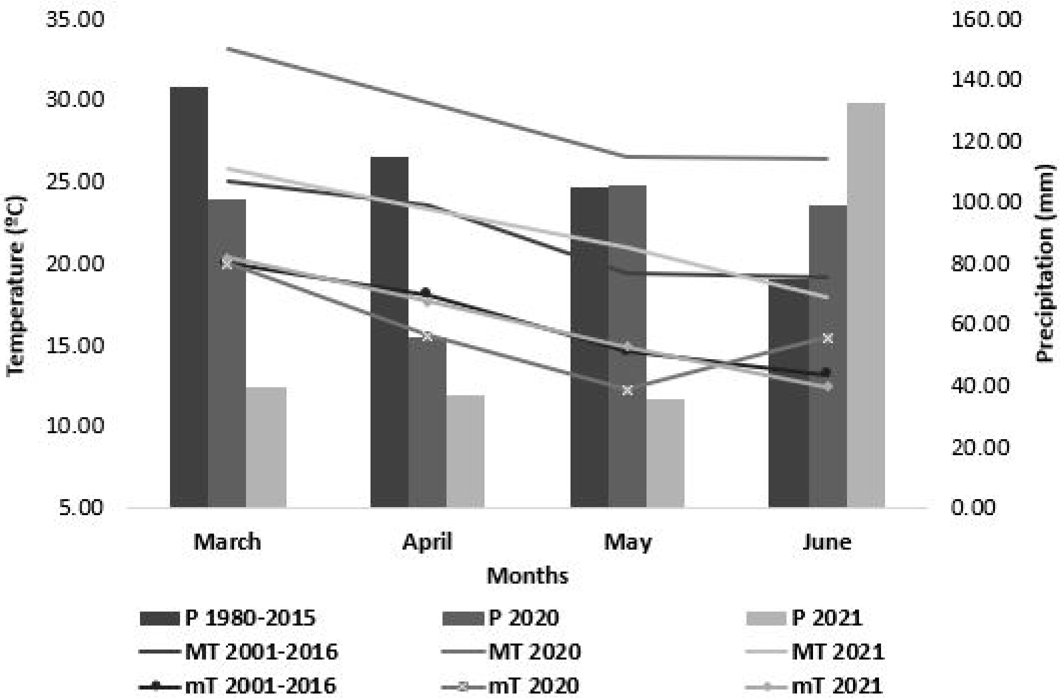

Figure 1. Precipitation (P), maximum (MT °C), and minimum (mT °C) temperatures obtained by the experimental station of Embrapa Western Agriculture during the study (2021), in 2020, and historical series. Dourados-MS, 2021. Source: Fietz et al. (2017), Guia Clima (2021), Guia Clima (2020).

The characteristics of maize for silage were evaluated when the plants were at the R4 grain stage, in the farinaceous stage (¾ of the milk line). The CAPO genotype plots were harvested 84 days after sowing (May 28, 2021) and the other genotypes at 104 days after sowing (June 17, 2021). The cutting used for evaluation was performed 0.05 m from the ground, with a 5-m linear row of plants harvested at a 0.5-m spacing between rows, totaling 2.5 m² of the area to carry the weight of green mass and calculate the green mass yield (GMY) (kg ha^{-1}) of each maize genotype.

Five plants per treatment were collected to evaluate the means of i) plant height (PH, cm), measured from the base of the last leaves; ii) ear height (EH, cm), measured from the base of the first ear; iii) the number of leaves (NL) per plant; iv) stem diameter (SD, cm), 0.5 m above ground level, determined with a digital caliper; v) green leaf mass yield (GLMY); vi) green stem plus tassel yield (GSTY); vii) green ear yield (GEY, kg ha^{-1}). The percentage of the dry mass of the plant (PDMP) in each genotype was determined with the ratio of green plant weight and plant dry weight multiplied by 100. The dry matter yield in the plant (DMYP, kg ha^{-1}) was obtained with GMY multiplied by PDMP and divided by 100. Land-use efficiency (Ef) was calculated with the ratio between DMYP and the total number of days from sowing to harvesting. For the dry mass analysis, the plants were placed in a forced-air circulation oven at 60°C for 72 hours.

The characteristics of maize grains were evaluated when all genotypes were harvested (natural plant drying conditions) on the same day, 126 days after sowing (July 6, 2021), because there was a frost in the last week of June that anticipated the harvest of genotypes. Five ears per treatment were considered to analyze the means of i) diameter (ED, mm), measured with a digital caliper; ii) length (EL, cm), defined with the help of a graduated ruler; iii) the number of grain rows per ear (NGRE); iv) the number of grains per row in ears (NGE). Ten grains were considered to evaluate length (GL), width (GH), and thickness (GT, mm) using a digital caliper. After the defoliation and removal of the cob, the average hundred seed weight (HSW, g) was evaluated and quantified on a weighing machine in each treatment, and in 10 ears grain yield (GY, kg ha^{-1}) was determined by weighing the grains.

The data were subjected to analysis of variance and if a significant difference between the corn genotypes was detected by the F test at 5% probability, the Tukey mean test was performed at 5% probability using the Genes software (Cruz 2016). The two main components (MC1 and MC2) were used to identify the best genotypes and group them using the means of each characteristic and the genotype by trait biplot analysis (GT Biplot) with the GGEBiplotGUI package in the R software (R Core Team 2020).

3. Results

For the silage traits (Table 1), the 1P2224 and 1Q2383 genotypes showed the highest values, respectively, of plant height (155.8 and 150 cm), ear height (68.8 and 65.8 cm), and the number of leaves (12.6 and 13.2), not differing from the BRS3046 genotype for ear height (62.8 cm) and the number of leaves per plant (13.4). The CAPO genotype showed the lowest values of plant height (96.72 cm) and ear height (35.68 cm) and the lowest number of leaves (10) compared to the other genotypes. The BRS1010 maize genotype had the smallest stem diameter (15.6 mm), differing only from the 1P2224 (18.9 mm) and BRS3046 (19.1 mm) genotypes.

The plant dry matter (DM) content at harvest for silage ranged from 33.27 to 40.21% (Table 1). The 1P2224 and 1Q2383 maize genotypes showed potential yields of green mass (plant, stem, tassel, and ear) and dry matter (Table 1). As for the land-use efficiency of dry matter yield, these genotypes were also superior to the others (Table 1).

Table 1. Characteristics evaluated at stage R4 for silage in six maize genotypes, in Dourados, Mato Grosso do Sul, Brazil, 2021.

Genotypes	PH (cm)	EH (cm)	SD (cm)	NL	GMY (kg ha^{-1})				PDMP (%)	DMYP (kg ha^{-1})	Ef kg ha^{-1}dia^{-1}
					P	L	ST	E			
1P2224	155 a	68.8 a	18.98 a	12.6 abc	23924 a	3808	10053 a	10061 a	40.1 a	9.645 a	92.7 a
1Q2383	150 ab	65.8 a	18.86 ab	13.2 ab	22024 ab	3792	9411 ab	8820 abc	36.18 ab	7.938 ab	76.3 ab
BRS1010	119 c	51.8 b	15.63 b	12 c	17588 bc	2871	7380 bc	7336 c	37.46 ab	6.551 b	63.0 b
BRS3046	135 bc	62.8 ab	19.10 a	13.4 a	20572 abc	3262	8604 ab	8705 abc	35.61 ab	7.280 b	70.0 b
CAPO	96 d	35.6 c	16.40 ab	10.0 d	16624 c	3542	5003 c	8077 bc	35.27 ab	5.854 b	69.7 b
KWS9606	121 c	51.2 b	17.32 ab	12.4 bc	21760 ab	3437	8754 ab	9567 ab	33.27 b	7.269 b	69.9 b
Mean	129.7	56.0	17.71	12.26	20415	3452	8201	8761	36.33	7.423	73.6
CV (%)	7.26	10.53	9.48	3.73	11.03	15.7	15.95	10.11	8.23	14.4	14.1

Means, in the column, followed by the same letter do not differ from each other ($p < 0.05$) by Tukey's test. CV: coefficient of variation. PH: plant height, EH: ear height, SD: steam diameter, NL: number leaves, GMY: green mass yield, P: plant, L: leaf, ST: steam more tassel, E: ear, PDMP: percentage of dry mass of the plant, DMYP: dry matter yield in the plant. Ef: efficiency of land.

The maize genotypes performed differently according to the characteristics evaluated for grain production (Table 2). For the variables related to ear, the BRS3046 genotype had the largest diameter and length and the highest number of grain rows and grains per row, followed by the 1Q2383 and 1P2224 genotypes. For the characteristics measured in the grains, these last two genotypes showed higher length and width values. The mass of one hundred grains was not different, with a mean of 20.1 g. The potential maize genotypes for grain yield were 1P2224 (2139.6 kg ha^{-1}) and 1Q2383 (2156.6 kg ha^{-1}), differing only from the BRS1010 (1562.0 kg ha^{-1}) genotype (Table 2).

The graphical visualization in the GT Biplot allowed the first two main components MC1 (62.16%) and MC2 (16.19%) explain 78.35% of the total data variations (Figures 2 and 3). Based on the characteristics evaluated, three groups were formed with the “which-won-where” graph (Figure 2A). The first group included the 1P2224 and 1Q2383 genotypes, comprising 70% of the characteristics (EL, EH, PDMP, PH, NGRE, GSTY, NGE, SD, DMYP, GMY, GY, Ef, GEY, GLMY). In the second group, the KWS9606 and CAPO genotypes showed higher grain thickness (GT) and one hundred seed weight (HSW). In the third group, the BRS3046 genotype gathered the characteristics of ear diameter (ED), the number of leaves (NL), length (GL), and grain width (GW). The BRS 1010 genotype did not represent any group (Figure 2A).

Table 2. Characteristics evaluated at harvest for grains in six maize genotypes, in Dourados-Mato Grosso do Sul, Brazil, 2021.

Genotypes	ED (mm)	EL (cm)	NGRE	NGE	GL (mm)	GW (mm)	GT (mm)	HSW (g)	GY (kg ha^{-1})
1P2224	42.02 bc	15.2 a	14.8 ab	28.0 a	10.29 a	8.60 ab	5.02 ab	18.9	2139 a
1Q2383	45.49 ab	13.6 ab	15.2 ab	23.2 abc	10.36 a	8.55 ab	4.36 b	19.3	2156 a
BRS1010	39.08 cd	11.8 ab	12.8 b	19.0 bc	9.41 ab	8.89 a	4.48 ab	20.7	1562 b
BRS3046	47.72 a	14.8 a	16.8 a	24.6 ab	11.13 a	7.91 ab	4.38 b	19.1	1985 ab
CAPO	37.72 d	9.8 b	14.4 ab	17.6 c	8.04 b	7.19 b	5.17 ab	21.0	1779 ab
KWS9606	40.51 cd	11.2 ab	15.2 ab	18.0 c	7.84 b	8.32 ab	5.36 a	21.4	1937 ab
Mean	42.04	12.73	14.87	21.7	9.51	8.24	4.79	20.1	1926
CV (%)	4.66	15.83	11.63	14.29	10.48	10.05	10.1	6.74	11.91

Means, in the column, followed by the same letter do not differ from each other ($p < 0.05$) by Tukey's test. CV: coefficient of variation. ED: ear diameter; EL: ear lenght; NGRE: number of grain rows per ear; NGE: number of grains per row in ears; GL: grain length; GW: grain width; GT: grain thinckness; HSW: hundred seed weight, GY: grain yield.

Among the genetic materials, the 1P2224 genotype stood out with a performance above the general average among most traits, representing the second most stable genotype after 1Q2383 (Figure 2B).

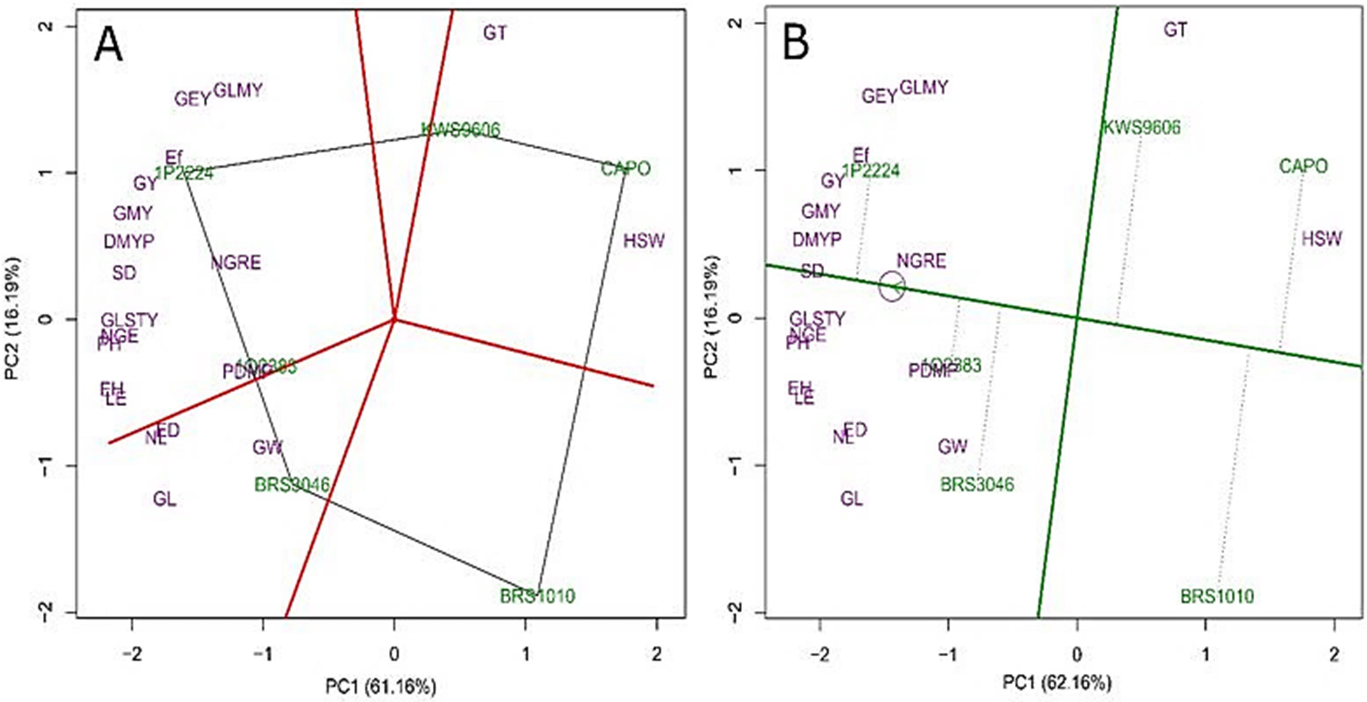

Figure 2. GT Biplot representing the "which-won-where" (A) and "average versus stability" (B) of the six maize genotypes in 20 traits. Dourados, Mato Grosso do Sul, Brazil, 2021.

PH: plant height, EH: ear height, SD: stem diameter, NL: the number of leaves, GMY: green mass yield, GLMY: green leaf mass yield; GSTY: green stem plus tassel yield; GEY: green ears yield, PDMP: percentage of the dry mass of the plant, DMYP: dry matter yield in the plant. Ef: land-use efficiency. ED: ear diameter; EL: ear length; NGRE: the number of grain rows per ear; NGE: the number of grains per row in ears; GL: grain length; GW: grain width; GT: grain thickness; HSW: hundred seed weight, GY: grain yield.

Although there is no genotype in the arrow of the first concentric circle, the 1P2224 is close to ideal (Figure 3A). The "Discriminant vs. Representative" graph (Figure 3B) showed that all characteristics were discriminating, except for NGRE, GW, and PDMP, which have smaller vectors. The most representative characteristics observed were SD, GSTY, and DMYP, and less suitable for GLMY, GW, GT, and HSW due to higher angles.

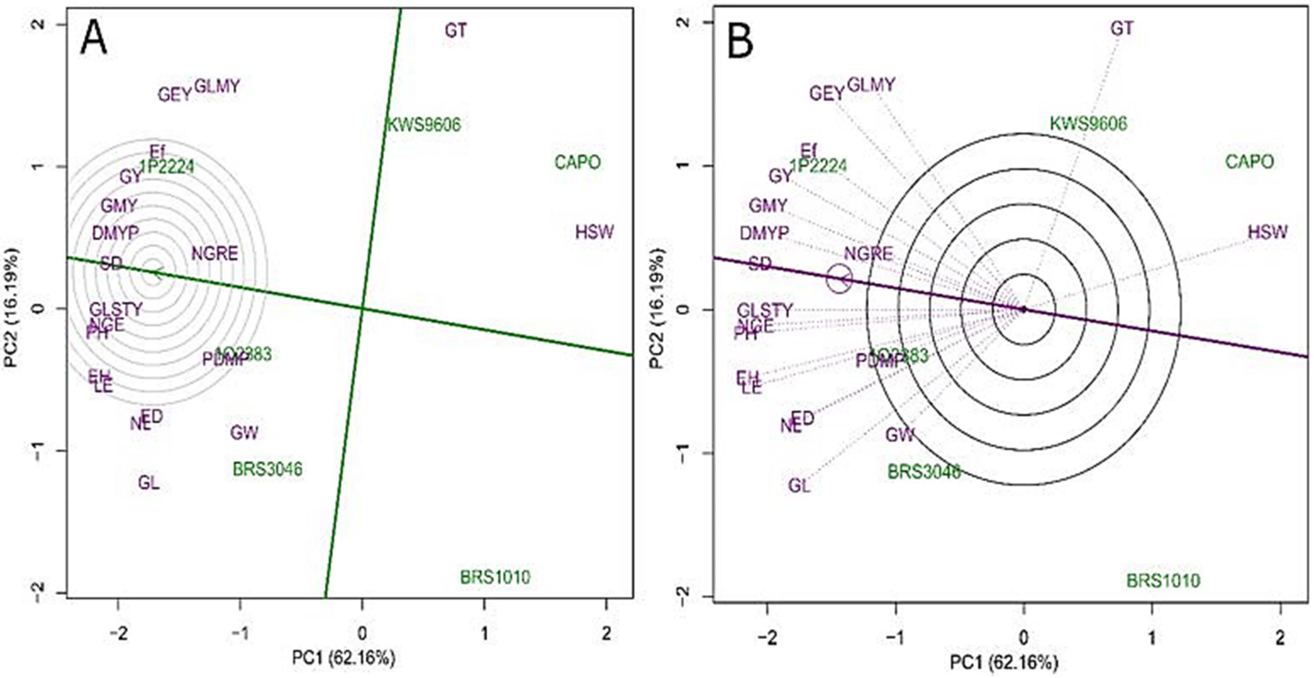

Figure 3. GT Biplot representing Ranking Genotypes (A) and Discriminant *vs.* Representative (B) of the six maize genotypes in 20 traits. Dourados, Mato Grosso do Sul, Brazil, 2021.
PH: plant height, EH: ear height, SD: stem diameter, NL: the number of leaves, GMY: green mass yield, GLMY: green leaf mass yield; GSTY: green stem plus tassel yield; GEY: green ears yield, PDMP: percentage of the dry mass of the plant, DMYP: dry matter yield in the plant. Ef: land-use efficiency. ED: ear diameter; EL: ear length; NGRE: the number of grain rows per ear; NGE: the number of grains per row in ears; GL: grain length; GW: grain width; GT: grain thickness; HSW: hundred seed weight, GY: grain yield.

4. Discussion

The recommendation of a maize cultivar for silage can be supported by its biomass, including larger sizes, which result in a higher production of green and dry mass forage that is nutritionally richer, digestible, and with a lower fiber content (Duarte et al. 2014; Crevelari et al. 2018; Pereira et al. 2018b). The taller plants of the 1P2224 and 1Q2383 maize genotypes may represent a higher green and dry mass production.

The plant dry matter agrees with values close to the 33 to 37% recommended (Magalhães & Durães, 2006). Lower values may cause the development of clostridia due to excess moisture in the material, which leads to undesirable fermentations with nutrient loss by leaching and losses through effluents and gases (Duarte et al. 2014; Negrão et al. 2016). Animals may reject a higher DM content because it hinders crushing and compaction and favors the development of aerobic fungi and yeasts that heat the mass and degrade the silage due to excess air inside the silo (Duarte et al. 2014). The KWS9606, CAPO, BRS3046, and 1Q2383 genotypes were within the recommended range, and the others were near the limit.

As for the proportion of maize plant fractions, Duarte et al. (2014) mention that an equivalent composition of 20% leaves, 28% stem, and 52% ears would be ideal to obtain high-quality silage. The present study showed mean values close to 17.07% leaves, 39.67% stem plus tassel, and 43.35% ear (Table 1). These characteristics are influenced by seasons, crop sites, and maize genetic material.

The results of the present study for green and dry mass yields in the plant were lower than those found in the literature, probably because of the prolonged drought during the study, the growing season (cropping season or off-season), different maize genotypes, management, and edaphoclimatic conditions (Pereira et al. 2020). Maize crops require an average of 250 to 350 mm of water for forage maize and around 500 to 600 mm for grain production (Cruz et al. 2008). The CAPO genotype was harvested 84 days after sowing, with a precipitation accumulation of only 80.3 mm. The other genotypes were harvested 104 days after sowing, totaling 243.1 mm (Figure 1), which may have contributed to smaller plants with lower green and dry mass yields. A study by Pereira et al. (2018b) with AS 1551 PRO maize under irrigated cultivation (386.7 mm), in Santa Maria, RS, Brazil, obtained higher yields than the present study, with 35316.0 kg ha^{-1} of green mass and 13461.0 kg ha^{-1} of dry matter.

Farmers must know the dry matter of maize plants because dry matter intake determines the food value related to the nutritional value (nutrient content), which corresponds to a good performance potential for animals (Medeiros and Marino 2015). Thus, the 1P2224, 1Q2383, and BRS3046 experimental genotypes showed higher dry mass yields (Table 1).

This efficiency, calculated from sowing to harvesting, predicts that these genotypes will show a better use of dry matter, even considering the water stress during the experiment. Water stress affects grain production under floral initiation and inflorescence development (when the potential number of grains is determined) and grain wadding (when the dry matter deposition increases). The lack of water would cause lower carbohydrate production and dry matter volume in the grains, consequently reducing starch production (Magalhães and Durães 2006).

The average yield of off-season maize in the present study (1926.0 kg ha^{-1}) was below the August 2020/2021 estimate for Mato Grosso do Sul (3029.0 kg ha^{-1}), the midwest region (4843.0 kg ha^{-1}), and Brazil (4056.0 kg ha^{-1}) (Conab 2021a). There was also a decrease in grain production in Mato Grosso do Sul for off-season maize, from 9374.0 thousand tons in 2018/2019 to an estimated 6403.0 thousand tons in 2020/2021 (Conab 2021a). This lower production was due to water stress at the initial crop establishment in March 2021 and the cold air masses in the final weeks of June that caused frost, affecting plant development, grain wadding, and maturation (Conab 2021b). In the present study, the grains were harvested with a rainfall accumulation of 244.6 mm, well below the ideal for grain production (average 500 mm) (Cruz et al. 2008).

The GT biplot tool can be used to simplify the results of various characteristics and gather and group them according to the most targeted genotypes for maize silage and grain (Figures 2 and 3). The first two main components explained 78.35% of the total data variations, that is, the GT Biplot graphs presented most of the existing variability, allowing the safe interpretation of the studied characteristics and genotypes. The major advantage of the genotype by trait biplot is the easy graphical visualization in a dataset (Sharifi and Ebadi 2018).

The three formed groups aimed to gather the variables with perpendicular lines that characterize the genotypes, forming a polygon (Yan and Tinker 2006; Oliveira et al. 2018; Sharifi and Ebadi 2018). Variables such as plant height and green mass yield are extremely important in silage production (Crevelari et al. 2018), and characteristics related to the grain, such as ear length, the number of grain rows, the number of grains per row, and grain yield, are essential for selecting genotypes (Pereira et al. 2018a). Thus, the 1P2224 and 1Q2383 genotypes encompass these characteristics for cultivation in the region (Figure 2A). These two genotypes are materials under improvement at Embrapa Maize and Sorghum that have not been registered in MAPA and may contain alleles favorable to gene expression under midwestern conditions. Hence, the BRS 1010 genotype is unfavorable to the groups of characteristics evaluated and can be discarded from the study regarding the dual purpose of grain and silage.

The superior potential to other genotypes can be identified with the arrowhead in the circle and stability along the perpendicular line because the smaller the genotype vector around the ordinate, the higher the stability (Yan et al. 2007). There is evidence for using 1P2224 and 1Q2383 genotypes for cultivation or as parents in an improvement program in the midwest region of Brazil, with the dual purpose of silage and grain. The other genotypes are less stable, as they were more distant from the origin of the graph, resulting in higher performance variability and less stability in both directions. Thus, they must be studied for each growing region.

The type of maize grain and its proportion in the silage can increase grain quality, as it is more digestible than the leaves and stems of the plant (Cruz et al. 2021). Thus, dent maize is softer or farinaceous and more digestible than hard maize, as it presents higher starch degradation in the rumen of animals (Correa et al. 2002). The BRS3046 genotype is classified as dent maize and suitable for silage and grain, but it was not superior and showed medium stability in the study region (Figure 2B). The BRS1010 genotype is classified as semi-hard and suitable for grains, but it showed a low grain yield (1562.0 kg ha^{-1}) (Table 2) for the off-season maize in this study. The KWS9606 VIP3 genotype is also classified as semi-hard, with evidence for dual purpose, but not superior for desirable characteristics for silage and grain (Tables 1 and 2).

Plant breeders look for genotypes closest to the ideal, which can be visualized with the nearest representation by the arrow in the center of the concentric circles (Kaplan et al. 2017; Yan and Frégeau-Reid 2018) on the "Ranking Genotypes" graph (Figure 3A). Hence, the 1P2224 is the genotype closest to the ideal. The other genotypes placed in the other concentric circles or outside them help visualize the distance between each genotype and the ideal one. The GT biplot analyses have been used to identify genotypes or groups of genotypes that are particularly good in certain aspects and, therefore, potential candidates for the best genotypes (Sharifi and Ebadi 2018).

An ideal variable should discriminate genotypes and represent other characteristics. In the "Discriminant *vs.* Representative" graph (Figure 3B), the ability to discriminate the genotype is visualized with the vector size, in which the larger the vector, the more discriminating the characteristic (Yan et al. 2007; Kaplan et al. 2017). The most representative variables form smaller angles with the line presenting the circle formed with the arrow, that is, with the medium (Yan and Tinker 2006). Therefore, the characteristics that could be discriminating and represent maize genotypes the most were SD, GSTP, and DMPP (Figure 3B), and the variables that were exceptions for discrimination or representativeness (NGRE, GW, PDMP, GLMY, GT, and HSW) were not very useful for genotype selection in the present study. These considerations are important to verify the relevant and influential traits for selecting superior genotypes. The literature has reported that GT biplots are excellent tools for visualizing genotype-by-trait data and revealing interrelationships among traits (Oliveira et al. 2018; Sharifi and Ebadi 2018).

5. Conclusions

The 1P2224 and 1Q2383 maize genotype tests have the potential for silage production and grain yield. The GT Biplot tool can graphically display interrelationships between traits and maize genotypes. The 1P2224 maize genotype was superior according to the GT Biplot tool, with indications for cultivation or as a parent in an improvement program in the midwest region of Brazil for silage and grain evaluations of one off-season, under limited water and frost.

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References

CONAB - Companhia Nacional de Abastecimento. *Série histórica das safras: Milho 1º Safra, Milho 2º Safra*. 2021a. Available from: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=20

CONAB - Companhia Nacional de Abastecimento. *Acompanhamento da safra brasileira de grãos: safra 2020/2021- 11º Levantamento*. 2021b. Available from: https://www.conab.gov.br/info-agro/safras

CORREA, C.E.S., et al. Relationship Between Corn Vitreousness and Ruminal In Situ Starch Degradability. *Journal of Dairy Science*. 2002, **85**(11), 3008–3012. https://doi.org/10.3168/jds.S0022-0302(02)74386-5

CREVELARI, J.A.A., et al. Correlations between agronomic traits and path analysis for silage production in maize hybrids. *Bragantia*. 2018, **77**(2), 1-10, 2018. https://doi.org/10.1590/1678-4499.2016512

CRUZ, J.C., et al. *A cultura do milho*. Sete Lagoas: Embrapa Maize e Sorghum, 2008.

CRUZ, C.D. Genes Software-extended and integrated with the R, Matlab and Selegen. *Acta Scientiarum Agronomy*. 2016, **38**(4), 547-552. https://doi.org/10.4025/actasciagron.v38i4.32629

DOLATABAD, S.S., et al. Multienvironment analysis of traits relation and hybrids comparison of maize based on the genotype by trait Biplot. *American Journal of Agricultural and Biological Sciences*. 2010, **5**(1), 107-113.

DUARTE, A.P., SAWAZAKI, E. and PAZIANI, S.F. 2014. Milho para Silagem. In: A.T. AGUIAR, et al. eds. Instruções agrícolas para as principais culturas econômicas. Campinas: Instituto Agronômico, pp. 276-279.

FIETZ, R.C., et al. *O clima da região de Dourados*, MS. Dourados: Embrapa Western Agriculture, 2017 Available from: https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1079733/1/DOC2017138FIETZ.pdf

GUIA CLIMA. *Boletem Agrometeorológico.* 2020. Available from: https://clima.cpao.embrapa.br/?lc=site/boletins/boletins

GUIA CLIMA. *Dados Meterológicos de Dourados*. 2021. Available from: https://clima.cpao.embrapa.br/?lc=site/banco-dados/base_dados

KAPLAN, M., et al. GT biplot analysis for silage potential, nutritive value, gas and methane production of stay-green grain sorghum shoots. *Ciencia e investigación agraria: revista latinoamericana de ciencias de la agricultura*. 2017, **44**(3), 230-238. http://dx.doi.org/10.7764/rcia.v44i3.1802

MAGALHÃES, P.C. and DURÃES, F.O. Fisiologia da produção de milho. Sete Lagoas: Embrapa Maize and Sorghum, 2006. Available from: https://www.infoteca.cnptia.embrapa.br/bitstream/doc/490408/1/Circ76.pdf

MEDEIROS, S.R. and MARINO, C.T. 2015. Valor nutricional dos alimentos na nutrição de ruminantes e sua determinação. In: S.R. MEDEIROS, R.C. GOMES and D. J. BUNGENSTAB, eds. Nutrição de bovinos de corte: fundamentos e aplicações. Campo Grande: Embrapa Beef Cattle, pp. 1-6.

MOHAMMADI, R. and AMRI, A. Genotype × environment interaction and genetic improvement for yield and yield stability of rainfed durum wheat in Iran. *Euphytica.* 2013, **192**(2), 227-249. https://doi.org/10.1007/s10681-012-0839-1

NEGRÃO, F.M., et al. Perdas, perfil fermentativo e composição química das silagens de capim Brachiaria decumbens com inclusão de farelo de arroz. *Revista Brasileira de Saúde e Produção Animal*. 2016, **17**(1), 13-25. https://doi.org/10.1590/S1519-99402016000100002

NEUMANN, M., et al. Aditivos químicos utilizados em silagens. *Pesquisa Aplicada & Agrotecnologia*. 2010, **3**(2), 187-195. ISSN 1984-7548

OLIVEIRA, T.R.A., et al. The GT biplot analysis of green bean traits. *Ciência Rural*. 2018, **48**(6), 1-6. https://doi.org/10.1590/0103-8478cr20170757

PEREIRA, V.R.F., et al. Critical variables for estimating productivity in maize as a function of plant population and spacing. *African Journal of Agricultural Research*. 2018a, **13**(35), 1828-1836. https://doi.org/10.5897/AJAR2018.13273

PEREIRA, L.B., et al. Características agronômicas da planta e produtividade da silagem de milho submetido a diferentes arranjos populacionais. *Magistra.* 2018b, **29**(1), 18-27. ISSN 2236-4420.

PEREIRA, M.G., et al. UENF MSV2210 and UENF MS2208: Silage and green maize hybrids for Rio de Janeiro State, Brazil. *Crop Breeding and Applied Biotechnology*. 2020, **20**(3), e309320310. https://doi.org/10.1590/1984-70332020v20n3c44

R CORE TEAM. 2020. *R:* A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from: https://www.r-project.org/

SABAGHNIA, N. and JANMOHAMMADI, M. Interrelationships among some morphological traits of wheat (*Triticum aestivum* L.) cultivars using biplot. *Botanica Lithuanica*. 2014, **20**(1), 19-26. https://doi.org/10.2478/botlit-2014-0003

SABAGHNIA, N., et al. Graphic analysis of trait relations of spinach (*Spinacia oleracea* L.) landraces using the biplot method. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis.* 2015, **63**(4), 1187-1194. https://doi.org/10.11118/actaun201563041187

SANTOS, H.G., et al. *Sistema Brasileiro de Classificação de Solos*. Rio de Janeiro: Embrapa, 2018. Available from: https://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1094003

SHARIFI, P. and EBADI, A.A. Relationships of rice yield and quality based on genotype by trait (GT) biplot. *Anais da Academia Brasileira de Ciências*. 2018, **90**(1), 343-356. https://doi.org/10.1590/0001-3765201820150852

YAN, W. and TINKER, N.A. Biplot analysis of multi-environment trial data: Principles and applications. *Canadian Journal of Plant Science*. 2006, **86**(3), 623-645. https://doi.org/10.4141/P05-169

YAN, W., et al. GGE biplot vs, AMMI Analysis of Genotype-by-Environment Data. *Crop Science.* 2007, **47**(2), 643-653. https://doi.org/10.2135/cropsci2006.06.0374

YAN, W. and FRÉGEAU-REID, J. Genotype by yield* trait (GYT) biplot: a novel approach for genotype selection based on multiple traits. Scientific *Reports.* 2018, **8**(1), 1-10. https://doi.org/10.1038/s41598-018-26688-8

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