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Spatial arrangement and its implications in the yield of maize cultivars

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ABSTRACT. There is a lack of information regarding variables that regulate the expression of the yield potential of maize. We studied yield components of maize under different arrangements on field, in the southwest region of the state of Goiás, Brazil. The soil of the experimental area is classified as Typic Orthotic. The experimental design was randomized blocks, in a 9x2 factorial scheme, with nine maize hybrids [30F53, 30F35, P3630, P3898, P3779, AG7098, DKB 310, CD 3612 and SHS 7990] and two spatial arrangements (single rows (45x45 cm) and twin rows (45x90x45 cm), with four replicates. The seeding was made with a one row sowing machine, and soil fertilizing carried out according to technical recommendations. Pest and weed control was employed when required, using an integrated management. The results were submitted to variance analysis, using a means comparison by Scott-Knot test and by multivariate models. The results of the interactions of maize hybrids and spatial arrangements were significant for all the variables with exception of the foliar area index. There were differences in correlations between the variables, with distinct canonical correlations and cultivar groupings. The maize hybrids DKB310 and P3839 stood out, showing satisfactory yield in both spatial arrangements. The modeling of spatial arrangements influenced the behavior of maize hybrids, especially DKB310 and P3898, which showed satisfactory yields in both spatial arrangements.

Key words: *Zea mays*; Density; Spacing; Population

INTRODUCTION

Currently maize has a great importance in human nutrition, and methods to increase production have evolved both in technology and genetic breeding. Several methodologies are being disseminated in the field, and plant spacing used has demonstrated importance.

Maize is, probably, the most sensitive grass to variation in the spatial arrangement of plants. Consequently, it is recognized as one of the cultural practices with greatest influence on grain yield. The reduction of line spacing and the increase in distance between plants in the line optimizes the use of factors of production such as water, light and nutrients (Demétrio, 2008; Balem, 2013).

Recently, the combination of the spacing between the sowing lines and the number of plants per meter has been frequently discussed, due to the greater or lesser adaptation of the crop to the environment, due to the morphological and genetic variations presented by the current hybrids (Demétrio, 2008). The association between the evolution of the plant arrangement and the yield increase of maize grains has been reported in the literature (Marchão et al., 2005; Sangoi, 2005; Demétrio, 2008; Brachtvogel et al., 2012; Balem, 2013).

It is understood that the best arrangement is the one that provides uniform distribution of plants per area, which means, equidistance between plants, allowing obtaining a better light, water and nutrient utilization (Brachtvogel et al., 2012). According to Brachtvogel et al. (2012), the maize plants architecture should preferably obtain greater efficiency in the mechanical harvesting and prevent breakage problems and bedding. Generally, small plants tolerate larger populations, maintaining the uniformity of the ears (Brachtvogel et al., 2012). The increase in plant density is a strategy employed to increase the interception of radiation incident on maize (Sangoi et al., 2005), constituting one of the management practices that is most important to increase grain yield (Marchão et al., 2005).

Understanding the mechanisms that interfere in the definition of the number of grains produced per area is important to maximize this yield component and, consequently, the productivity of corn genotypes in high competitive intraspecific environments (Sangoi et al., 2005). However, these practices should be studied locally before being adopted, as they may require high investments in machinery and inputs (Balem, 2013).

Some works elucidate the logistic of distribution of corn plants in the field, such as Marchão et al. (2005) when verifying that the grains yield is significantly influenced by plant density, where the highest yields of the evaluated hybrids were found in high density. The same being found by Demetrius et al. (2008), which concluded that maize productivity increases with the reduction in line spacing for evaluated hybrids; Brachtvogel et al. (2012) found that equidistant spatial arrangement between plants, for the hybrid evaluated, is not effective in intraspecific competition, since it did not influence most of the morphological characteristics they evaluated.

In view of this scenario, there is a lack of information about the variables that control the expression of productive potential of maize, as it is affected by planting arrangement. Therefore, research that can improve production and increase the yield of maize, from a better understanding of the plants response to intraspecific competition and its relation to the productive environment, is necessary. Thus, our objective was to study the yield components of maize cultivars in different arrangements of plants in the field, under the ecological conditions of the Southwest region of the state of Goiás, Brazil.

MATERIAL AND METHODS

The study was carried out at the Luiz Eduardo de Oliveira Sales Experimental Farm in the municipality of Mineiros-GO, located in the geographic coordinates of 17°34'10"S latitude and 52°33'04"W longitude, with average altitude of 760 m. During the realization of the experiment the temperature averages were 23.48°C, relative humidity of 55.29%, dew point of 10.51°C, atmospheric pressure of 940.57 hPa, wind speed of 1.74 ms^{-1}, radiation of 842.55 kJ m^{-2} and rainfall of 567.60 mm, occurring mainly in spring and summer. The experimental area was classified as Aw type (hot to dry).

The soil of the experimental area is classified as Typic Orthotic, with medium texture, smoothly wavy topography and good drainage (EMBRAPA, 2013). It presented the following chemical characteristics during the implantation of the experiment in the 0-20 cm layer: pH in $CaCl_2$ 0.01 mol L^{-1} 5.7; calcium 3, magnesium 0.8, aluminum 0.2, hydrogen + aluminum 2, cation exchange capacity 5.9, in $cmol_c$ dm^{-3} ; potassium 53, phosphorus in Mehlich 59, sulfur 1.7, boron 0.2, copper 1.4, iron 51, manganese 23, zinc 8.3, sodium 1.5, in mg dm^{-3} ; clay 223, silt 50, sand 728, organic matter 20 and organic carbon 12, in mg dm^{-3}. The analyzes were carried out at the UNIFIMES Soil Chemistry and Fertility Laboratory, according to the methodology of EMBRAPA (2009).

The experimental design was in randomized blocks, arranged in a factorial scheme 9x2, corresponding to nine maize hybrids with potential for the region (30F53, 30F35, P3630, P3898, P3779, AG70 98, DKB 310, CD 3612 and SHS 7990) and two spatial arrangements of plants [simple lines (45x45 cm) and twin lines (45x90x45 cm)] in 4 replicates. The experimental unit was composed of four lines of five meters in length, accounting for a population of 60,000 plants per hectare.

The sowing was realized with one-line planter coupled to micro tractor and fertilization according to Sousa and Lobato (2004). The cultural practices pertinent to the control of weeds and pests were carried out whenever necessary, using good practices of integrated pest management (Valicente, 2015). The variables were analyzed after harvest, on April 25, 2018. Therefore, we determined plant height (ALT) in cm (Rodrigues et al 2012.); diameter of stalk (DC) in mm (Rodrigues et al., 2012); leaf area index (IAF) in cm^2 (Pereira, 1987); number of row in ear (NFE) on unit (Rodrigues et al., 2012); number of grains per row (NGF) in unit (DURES et al., 1995); number of grains per ear (NGE) in unit (Rodrigues et al., 2012); grain yield (GY) in t ha^{-1} (Hanisch et al., 2012); and mass of one thousand grains (MTG) in g (Brasil, 2009).

The data obtained were submitted to the assumptions of the statistical model, verifying the normality and homogeneity of the residual variances, as well as the additivity of the model. Afterwards, it was run the variance analysis in order to identify the interaction between maize hybrids x spatial arrangements of plants. When significant interaction was found, simple effects were examined by means of the grouping Scott-Knott test, at 5% of probability. Subsequently, the variables were submitted to a linear correlation in order to understand the association trend, and their significance was based on a 5% probability by the t test. Subsequently, the genetic dissimilarity was determined by the Mahalanobis algorithm, where the residue matrix was weighted, being the dendrogram of the distance constructed through the UPGMA grouping. In addition, the canonical biplot method was used, where it was possible to visualize the general variability of the experiment and the multivariate tendencies. The analyses were performed at the interface Rbio and R (Bhering, 2017).

RESULTS AND DISCUSSION

The results of the interaction of maize hybrids and spatial arrangements were not significant in any of the analyzed variables. Significance was observed only among the cultivar factor for ALT, DC, NFE, NGF, NGE, GY and MTG ($P < 0.01$); and the row factor in IAF, NGF, NGE and PMG ($P < 0.05$) (Table 1). Differences were also observed in the correlations between the variables, distinct canonical contributions and groupings of the cultivars. A similar approach is reported in Kopper et al. (2017), when observing that the plant population factor influenced all the response variables analyzed.

Table 1. Summary of variance analysis (F calculated and CV (%)) for maize plant height (ALT), stem diameter (DC), leaf area index (IAF), number of rows per ear (NFE), number of kernels per row (NGF), number of grains per ear (NGE), grain yield (GY) and thousand grain mass (MTG). Mineiros -GO, UNIFIMES, Brazil, 2020.

Factors	ALT	DC	IAF	NFE	NGF	NGE	GY	MTG
Cultivar	6.96 **	5.07 **	01.62 ^{ns}	31.42 **	8.27 **	16.19 **	18.85 **	15.02 **
Row	0.23 ^{ns}	1.71 ^{ns}	06.30 *	01.05 ^{ns}	4.28 *	7.21 **	00.20 ^{ns}	04.61 *
C x F	0.47 ^{ns}	0.73 ^{ns}	00.42 ^{ns}	00.24 ^{ns}	0.71 ^{ns}	0.88ns	01.19 ^{ns}	01.10 ^{ns}
CV (%)	4.92	6.38	11.38	04.48	5.03	5.76	07.31	07.04

* * significant at 1 % probability by F test; * significant at 5% probability by F test; ^{ns} not significant at 5% probability by the F test.

For ALT, in simple line arrangement, the DKB310 and P3898 hybrids stood out by presenting larger plants with an average of 2.91 m, whereas the arrangement of the twin lines, the maize DKB310 obtained greater height with 2.96 m. There was no variation among cultivars for the two proposed arrangements (Figure 1A). Demétrio et al. (2008) did not find alterations in the ALT with the reduction of the spacing between lines of maize hybrids. Balem (2013) also obtained similar results, noting that the spacing used did not influence the parameter used in the proposed work. However, Marchão et al. (2005) and Brachtvogel et al. (2012), in different experiments, have shown that ALT and ear insertion varied in relation to sowing density.

The hybrids AG7098, DKB310, P3630 and P3779 expressed higher DC with an average of 27.48 mm in the arrangement of single lines, not differing the hybrids in the arrangement of twin lines, as well as the arrangements among the hybrids (Figure 1B). Demétrio et al. (2008) observed that the reduction of line spacing did not affect the DC of the maize plants, however, this variable presented significant differences regarding the hybrid and the population density. Balem (2013) had significant results with an increase of 4.3% in the DC when the USER u twin line arrangement in comparison to the simple lines and Brachtvogel et al. (2012) recorded a decrease in DC as the plant population increased.

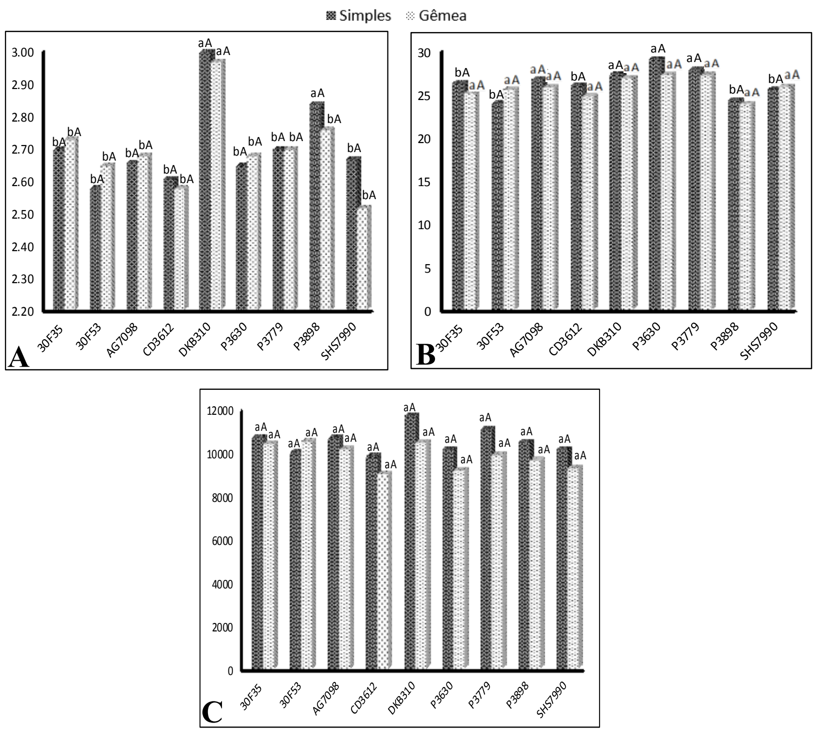

Figure 1. Plant height (ALT) in cm (A), stem diameter (DC) mm (B) and leaf area index (IAF) in cm2 (C) of maize hybrids with simple lines and twin lines spacing. Mineiros -GO, UNIFIMES, Brazil, 2020. Means followed by the same lowercase letter among hybrids and upper case within the hybrid and between the arrangements do not differ by Scott- Knott's test at 5% probability.

The IAF did not differ in any of the proposed conditions (Figure 1C). Procópio et al. (2014) observed that in the soybean crop the highest plant density decreased the IAF, regardless of the spacing used. Schmitt (2014) noted that IAF, at silking, increased linearly with the increase in the plant density in the spacing between plant lines. Sangoi et al. (2007) suggests that slower leaf senescence during grains filling can be positive to increase productivity of corn at high densities populations. It should be noted that the higher the photosynthetic balance, the greater the accumulation of biomass. Like this, in order to obtain high REND values, it is suggested that the interception of solar radiation should be maximized, through the appropriate choice of plant arrangement (Brachtvogel et al., 2012).

Among the characters evaluated in the ears, only NFE did not vary in spite of plant density (Figure 2). The explanation may be related to the fact that the production potential is defined in the first stage of development, when the onset of the floral differentiation process and the formation of the ear, there being not a significant influence of plant competition in the environment (Marchão et al., 2005).

The NFE, in both arrangements, was higher in the hybrids P3630 and P3898 (Figure 2). Balem (2013) observed that the different line spacings significantly influenced NFE, being the largest value found in the twin lines spacing. Modolo et al. (2010) observed that were found no significant difference for different hybrids and no interaction between hybrids and spacings.

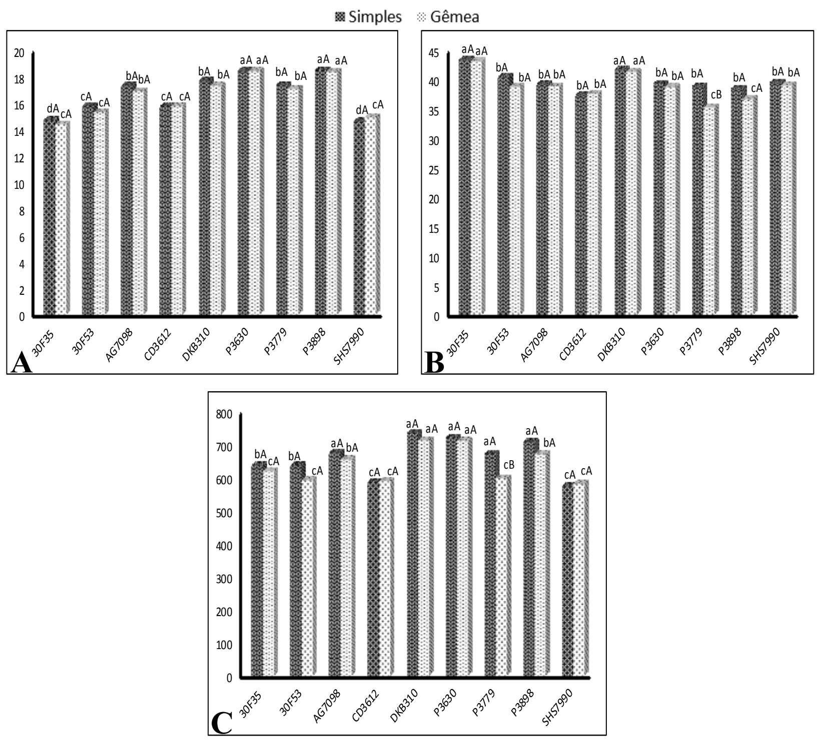

Figure 2. Number of row per ear (NFE) in unid (A), number of grains per row (NGF) in unit (B) and number of grains per ear (NGE) in unid (C) of maize hybrids in spacing with single lines and twins. Mineiros - GO, UNIFIMES, Brazil, 2020. Means followed by the same lowercase letter within hybrids and upper case within the hybrid and between the arrangements do not differ by Scott-Knott's test at 5% probability.

In relation to NGF, the 30F35 and DKB310 hybrids stood out, obtaining an average of 42.37 and 42.08 grains, respectively, when carried out in two spatial arrangements (Figure 2b). Modolo et al. (2010) noticed that there was no interaction between corn hybrids and spacings, however, when applying the spacing of 0.90 m it resulted in a higher NGF when compared to the others. Durval Dourado et al. (2003) observed that reducing the spacing between the lines did not influence the NGF in corn hybrids.

The highest averages for the NGE, in the arrangement of single line, were found in the AG7098, DKB310, P3630, P3779 and P3898, with a mean of 699.38 grains ear^{-1}, whereas, with the twin lines, DKB310 and P3630 stood out, with a mean of 709.56 grains eat^{-1}. The only hybrid that presented difference among the arrangements was P3779 with the highest NGE in single lines (Figure 2C). Influence on the NGE was observed by Balem (2013) in the sowing system of twin lines, comparing to the conventional system, and in

Demétrio et al. (2008), observing interactions between densities and spacing and between population density and hybrids. According to Sangoi et al. (2010), the modifications in the NGE may occur due to the ether equidistant distribution incidence over the plants in the area, which maximizes the post-anthesis photosynthetic activity. Brachtvogel et al. (2009) in their work with relation to the spacing x density noticed that there were no changes in the NGE when analyzing spacing, only in the density of plants.

The hybrid DKB310 performed better GY in simple line, presenting 267.5 sc ha^{-1}. With twin lines in addition to DKB310, the variety P3898 obtained similar GY with average of 251 sc ha^{-1} (Figure 3). Brachtvogel et al. (2012) states that, of the existing forms of spatial arrangement management, the plant population is the one that has greater interference in the GY of maize kernels. Balem (2013) obtained positive results with twin lines, and explains that the increase in GY in this spacing can be attributed to the greater efficiency in the interception of radiation and the decrease of competition for light, water and nutrients among the plants in the line, due to their more equidistant distribution. Demétrio (2008) had the GY of the beans influenced positively with the reduction in the spacing between the lines, and explains that this component was also dependent on the interaction between population densities and hybrids. Balem et al. (2014) observed a tendency to obtain higher yields with larger populations using double line spacing than with conventional spacing. Strieder et al. (2008) observed small increases in grain yield with reduced spacing between rows.

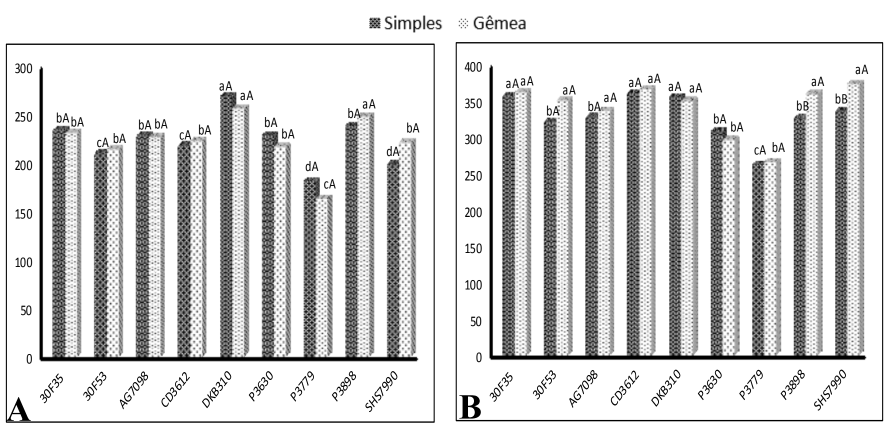

Figure 3. Yield - GY in t ha^{-1} (A) and weight of a thousand grains - MTG in g (B) of corn hybrids in spacing with single and twin lines. Mineiros -GO, UNIFIMES, Brazil, 2020. Means followed by the same lowercase letter of the hybrids and upper case within the hybrid and between the arrangements do not differ by Scott-Knott's test at 5% of probability.

In the single-line arrangement, MTG was highest in the 30F35, CD3612 and DKB310 (356.15 g) and with twin lines, the hybrids 30F35, 30F53, AG7098, CD3612, DKB310, P3898 and SHS7990 (355.45 g). The arrangements differed only in the hybrids P3898 and SHS7990 demonstrating higher MTG in the arrangement with twin lines (Figure 3B). Balem (2013) observed that the different spacings between rows significantly influenced the ear mass, with a 7.8% increase in twin lines compared to single spacing. However, Demétrio (2008) did not observe variances for these arrangements in maize hybrids. The formation of grains in corn is related to the translocation of sugars and nitrogen from vegetative organs, especially leaves, to grains (DEMÉTRIO, 2008).

The pairs of attributes whose correlations were high (0.6-1), medium (0.31-0.59) and low (0.1-0.3) presented positive and negative correlations, indicating increasing and decreasing function among variables. Thus, scientific consistency was noted for the following positive correlation pairs: (single line: NGE x ALT, NGE x NFE and MTG x GY; twin line: IAF x ALT, GY x ALT and NGE x NFE) and only one negative correlation pair (single line: x DC). For Vian et al. (2016), obtaining high maize grain yields is conditioned by the final population of plants, with uniform spatial distribution of plants, where the component that is best correlated with maize crop productivity, with adequate spatial uniformity was the number of ears per area. In the spacing with single and twin lines the NGF and ALT were the variables with the highest correlation with GY, respectively (Table 2). For Kuneski et al. (2017) the NGE was the component that presented the highest correlation with GY.

Table 2. Matrix of linear correlation of maize hybrids in single line and twin line spacing . Mineiros -GO, UNIFIMES, Brazil, 2019.

Variables	ALT	A.D	IAF	NFE	NGF	NGE	GY	MTG
ALT	1	0.24879 ^{ns}	0.57574 ^{ns}	0.45217 ^{ns}	0.32348 ^{ns}	0.72781 *	0.41846 ^{ns}	-0.1404 ^{ns}
A.D	0.12504 ^{ns}	1	0.07629 ^{ns}	0.24057 ^{ns}	0.00244 ^{ns}	0.29027 ^{ns}	-0.447 ^{ns}	-0.7179 *
IAF	0.80025 **	0.36885 ^{ns}	1	-0.2175 ^{ns}	0.4756 ^{ns}	0.10442 ^{ns}	0.1521 ^{ns}	0.03813 ^{ns}
NFE	0.45893 ^{ns}	0.37935 ^{ns}	0.34802 ^{ns}	1	-0.4627 ^{ns}	0.7561 *	0.08258 ^{ns}	-0.5086 ^{ns}
NGF	0.3073 ^{ns}	0.0437 ^{ns}	0.46896 ^{ns}	-0.3283 ^{ns}	1	0.22763 ^{ns}	0.56959 ^{ns}	0.4784 ^{ns}
NGE	0.64815 ^{ns}	0.42263 ^{ns}	0.60955 ^{ns}	0.87917 **	0.15986 ^{ns}	1	0.51621 ^{ns}	-0.1988 ^{ns}
GY	0.69992 *	0.06485 ^{ns}	0.42256 ^{ns}	0.34687 ^{ns}	0.41265 ^{ns}	0.57997 ^{ns}	1	0.73374 *
MTG	0.19652 ^{ns}	-0.3048 ^{ns}	-0.0955 ^{ns}	-0.4149 ^{ns}	0.32736 ^{ns}	-0.2585 ^{ns}	0.63615 ^{ns}	1

Significance: * 5% probability; ** 0.01 probability; ^{ns}: not significant. Variables: plant height - ALT; stem diameter - DC; leaf area index - IAF; row number per ear - NFE; number of grains per row - NGF; number of grains per ear - NGE; yield - GY and weight of thousand grains - MTG.

Positive correlation was observed in GY and MTG in both spatial arrangements (Figure 4 A and B), as well as between ALT and NGE, in the arrangement of single lines, which also presented positive correlation (Figure 4A). The other correlations did not present significance (Figure 4 A and B). According to Miotto Junior (2014), the NFE, ear length, GY and MTG are significantly linked to the population factor, being influenced by density. Belem (2013), in its results, achieved higher GY planting in twin lines, which he attributed to higher incidence of light and less competitiveness by water and nutrients. Marchão et al. (2005) found that the GY was significantly influenced by the density of plants, and by the interaction between hybrids and densities. In Kopper et al. (2017), the was affected directly only by height of ear insertion, showing that plants with ears inserted in higher height tend to produce more. With the increase in population density, plant and first insertion heights increased, while stem diameter, number of rows per ear, 1,000-kernel weight and crop yield decreased (Modolo et al. 2014).

Based on the results obtained by the technique of canonical variables (CAN), the respective eigenvalues and percentages of the variance explained by each are presented (Figure 5 A and B). The first two CANs, in the single line arrangement, accounted for 69.4% of the total data variation, where the variables with the highest factor load were NFE and GY, respectively. The variables of NGF and MTG presented similar and positive contributions to the CAN1, in addition to both contrast with the CD. A close proximity was also observed between the NFE, ALT and NGE characteristics, the latter characteristic being more attributed to the hybrid P3898 (Figure 5A).

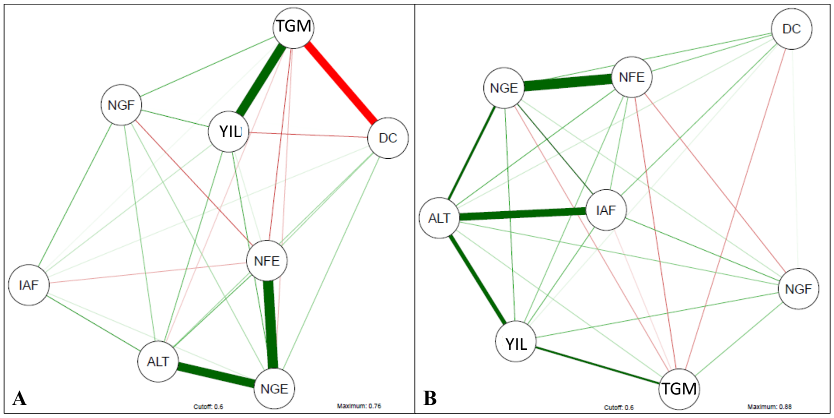

Figure 4. Network of phenotypic correlations of maize characteristics. The red lines represent negative correlations and the green ones represent positive corrections. The line thickness is proportional to the magnitude of the correlation. The highlighted lines represent correlation in a module greater than 0.6. Variables of adult plants: plant height - ALT ; stem diameter - DC ; leaf area index - IAF ; number of row per ear - NFE; number of grains per row - NGF ; number of grains per ear - NGE ; yield - GY and mass of thousand grains - MTG. Figure (A) represents single lines and Figure (B) represents twin lines. Mineiros-GO, UNIFIMES, Brazil, 2019.

In the arrangement of twin lines, the first two CANs responded with 75.3% of the data variation. The hybrids 30F35 with high MTG and DKB310 for the IAF and ALT stood out among others. Positive correlation was observed between NFE, NGE, DC, IAF, ALT and GY characteristics with higher weight factor for the first two in CAN1. The AG7098 hybrid was not very expressive for the data variation (Figure 5B). According to Durval Dourado (2010), the DC and NGF increased when submitted to low population densities, consequently, with high densities occurred the increase of ALT. Merchão (2010) observed that the increase in plants density improved GY.

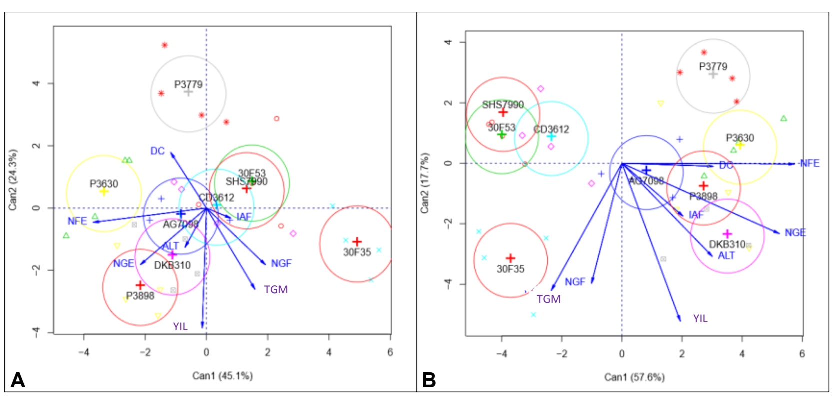

Figure 5. Analysis of canonical variables of averages of components of maize hybrids yield, GY: total productivity; PRODC: commercial productivity; plant height - ALT; stem diameter - DC ; leaf area index - IAF ; n humerus row by cob - NFE; number of grains per row - NGF ; number of grains per spike - NGE; yield GY and weight of thousand grains - MTG, where Figure (A) represents single line and Figure (B) represents twin lines. Mineiros-GO, UNIFIMES, Brazil, 2020.

The analysis of dissimilarity grouping between maize cultivars revealed the formation of two groups for each spatial arrangement describing the formation of the smallest groups for the arrangement of single lines (30F53, 30F35 , AG7098 and DKB 310) and only the DKB 310 in the arrangement of twin lines (Figure 6). Silva et al. (2017), observed the formation of groups between yield and final plant stand. According to Brachtvogel et al. (2012), high plants populations cause various physiological and morphological changes in maize, with different responses for each cultivar, that is, for each production system there is a population that optimizes the use of available resources, or optimum density, maximizing the productivity of the crops in that environment.

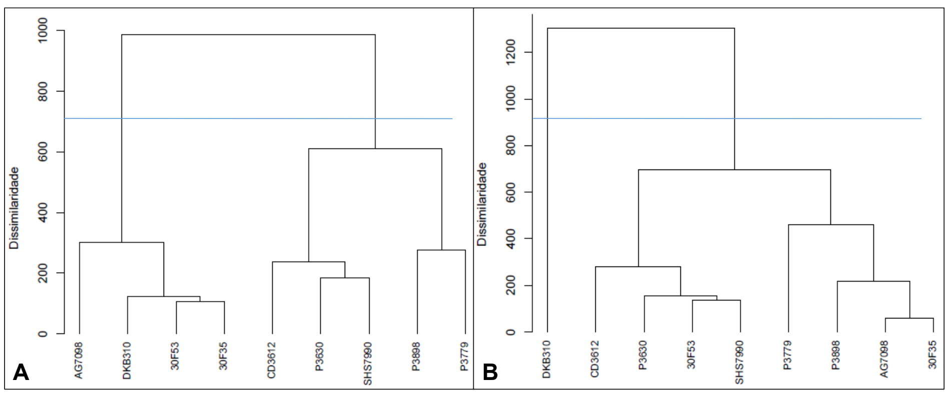

Figure 6. Dendrogram representative of dissimilarity among maize cultivars, obtained by the nearest neighbor technique, based on Euclidean distance. Figure (A) represents single line and Figure (B) represents twin lines. Mineiros-GO, UNIFIMES, Brazil, 2020.

The yield of grains can be increased maximizing the photosynthetic efficiency of the community, mainly for the improvement of interception of photosynthetically active radiation, by more efficient conversion of radiation intercepted in dry matter and by the partition of photoassimilates in the reproductive organs (Marchão et al., 2005). The spatial variability or the heterogeneity of grain yield may be associated with a number of factors that interact in a complex way and condition the expression of culture (Vian et al., 2016).

CONCLUSIONS

The modeling of spatial arrangements influenced the behavior of maize hybrids, especially DKB310 and P3898, which showed satisfactory yields in both spatial arrangements. In deciding on the best distribution of maize hybrids in the field, aspects such as availability of natural resources, purposes and objectives of the producer should be taken into account, as well as the genotypic adaptability of the same.

The multivariate techniques in association with the univariate ones collaborated to better elucidate the phenomena present in the interaction of the corn hybrids x spatial arrangements in single and twin lines. The arrangement of corn hybrids in twin lines has presented good results when compared to simple lines, making the thematic promising for future research.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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