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CROP PRODUCTION

Genetic variability and linear relationships between plant architecture and maize grain yield

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ABSTRACT: *The objectives of this study were to analyze whether there is genetic variability and assess the linear relationships between plant architecture and maize grain yield. Three experiments were carried out in a complete randomized block design. A group of 51 cultivars was assessed in relation to 22 traits: number of leaves, plant height, ear height, leaf angle, leaf length, leaf width, leaf area, and grain yield. Individual analyses of variance were performed, the assumptions of normality of errors and homogeneity of residual variances were tested, and means were grouped by the Scott-Knott test. The phenotypic correlation matrix was constructed using the 22 traits of the 51 cultivars. Results showed that there is genetic variability among cultivars for number of leaves, plant height, ear height, leaf angle, leaf length, leaf width, leaf area, and grain yield. Leaves close to the ear have smaller leaf angle and larger length, width, and area of the leaves. Leaf angle gradually increases towards the lower and upper ends of the plant. Length, width, and area gradually decreases in leaves towards the lower and upper ends of the plant. Cultivars with higher number of leaves and larger leaf area are associated with higher grain yield.*
Key words: *Zea mays L., number of leaves, leaf angle, leaf area.*

Variabilidade genética e relações lineares entre a arquitetura de planta e a produtividade de grãos de milho

RESUMO: *Os objetivos deste trabalho foram verificar se há variabilidade genética e avaliar as relações lineares entre a arquitetura de planta e a produtividade de grãos de milho. Foram conduzidos três experimentos no delineamento blocos completos ao acaso. Em 51 cultivares, foram avaliados caracteres relacionados ao número de folhas, às alturas de planta e de espiga, ao ângulo foliar, ao comprimento da folha, a largura da folha, a área foliar e a produtividade de grãos, totalizando 22 caracteres. Foram realizadas análises de variância individuais, verificados os pressupostos de normalidade dos erros e homogeneidade de variâncias residuais e agrupadas as médias de cultivares pelo teste de Scott-Knott. Foi determinada a matriz de correlação fenotípica entre os 22 caracteres das 51 cultivares. Há variabilidade genética entre as cultivares em relação ao número de folhas, alturas de planta e de espiga, ângulo foliar, comprimento da folha, largura da folha, área foliar e produtividade de grãos. Folhas localizadas próximas a espiga apresentam menor ângulo foliar e maiores comprimento da folha, largura da folha e área foliar. O ângulo foliar aumenta gradativamente em direção as folhas da extremidade inferior e superior da planta. O comprimento da folha, a largura da folha e a área foliar diminuem gradativamente em direção as folhas da extremidade inferior e superior da planta. Cultivares com maior número de folhas e maior área foliar estão associadas a plantas com maior produtividade de grãos.*
Palavras-chave: *Zea mays L., número de folhas, ângulo foliar, área foliar.*

INTRODUCTION

Because of the great importance of maize (*Zea mays* L.), plant breeding programs have developed new genotypes seeking to improve plant architecture and enhance grain yield. Therefore, it is necessary to evaluate the genotypes regarding plant architecture traits such as leaf number, plant height, ear height, leaf angle, leaf length, leaf width, leaf area, and grain yield to distinguish the genotypes in the crop environment.

Traits related to plant architecture in maize are important to define population and spatial distribution of plants in the area. Adequate spatial distribution and population can increase the interception of solar radiation and its use efficiency, as well as increase grain yield due to the influence on leaf area index, leaf angle, and leaf distribution in the canopy (ARGENTA et al., 2001). To achieve high grain yields, it is important to understand the morphological, physiological, phenological, and allometric characteristics that contribute to better adaptation of maize to high plant densities (SANGOI et al., 2002).

One of the objectives of maize breeding programs is to select plants with high grain yield. For

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a direct selection of plants with higher grain yield, it is necessary to harvest the ears to obtain grain weight, destroying the plant. Plant architecture traits, such as leaf number, plant height, ear height, leaf angle, leaf length, leaf width, and leaf area can be measured in a non-destructive way. An indirect selection, without destroying the plant, is possible when there are linear relationships between the mentioned traits and grain yield. The Pearson linear correlation coefficient (r), which varies between -1 (perfect negative linear relationship) and 1 (perfect positive linear relationship), is able to measure the strength of association between two variables and can be used to indicate the traits for indirect plant selection.

Studies have been carried out to characterize maize genotypes regarding plant architecture and grain yield (VIEIRA JUNIOR et al., 2005; VIEIRA JUNIOR et al., 2006; BELLO et al., 2010; KU et al., 2010; TIAN et al., 2011; HANASHIRO et al., 2013; WASSOM, 2013; BEKELE & RAO, 2014; ZHANG et al., 2014; NARDINO et al., 2016; HUANG et al., 2017; BORELLA et al., 2019) and the linear relationships between those traits (BELLO et al., 2010; KU et al., 2010; TIAN et al., 2011; BEKELE & RAO, 2014; OGUNNIYAN & OLAKOJO, 2014; NARDINO et al., 2016). In general, these studies have shown a wide genetic variability and the possibility of using plant architecture traits for indirect selection considering grain yield. Plant architecture traits, grain yield, and the relationship between them, should; therefore, be constantly assessed in the new genotypes developed in plant breeding programs.

It is believed that maize cultivars have varied plant architecture and grain yield, and that it is possible to find linear relationships between these traits. Thus, the objective of this research was to verify the existence of genetic variability and to evaluate the linear relationships between plant architecture and maize grain yield.

MATERIALS AND METHODS

Three experiments with maize (*Zea mays* L.) were carried out in the experimental area of the Department of Agricultural Sciences at the Federal University of Santa Maria, *Santa Maria*, state of *Rio Grande do Sul* (29º42'S; 53º49'W; 95 m above sea level). According to the Köppen classification, the climate is humid subtropical (Cfa), with hot summers and no dry season (ALVARES et al., 2013). The soil is classified as dystrophic Red Argisol (SANTOS et al., 2018) with the following physical and chemical (0 - 20 cm depth) characteristics: pH_{H2O} 1:1: 5.8; Ca: 5.7 $cmol_c$ dm^{-3}; Mg: 2.4 $cmol_c$ dm^{-3}; Al: 0.0 $cmol_c$ dm^{-3}; H+Al: 3.5 $cmol_c$ dm^{-3}; SMP index: 6.2; organic matter: 2.4%; clay content: 29.0%; S: 13.3 mg dm^{-3}; P (Mehlich): 25.7 mg dm^{-3}; K: 0.696 $cmol_c$ dm^{-3}; CTC_{pH7}: 12.4 $cmol_c$ dm^{-3}; Cu: 1.28 mg dm^{-3}; Zn: 0.753 mg dm^{-3}; and B: 0.1 mg dm^{-3}.

Experiment 1 consisted of 26 maize cultivars from the maize cultivar trial network of *Rio Grande do Sul*, which is coordinated by the State Agricultural Research Foundation (FEPAGRO). Experiments 2 and 3 refer to the national maize cultivar trial network coordinated by the Brazilian Agricultural Research Corporation (EMBRAPA). Experiment 2 included 13 cultivars of early cycle maize from the national trial in the south and experiment 3 included 12 super-early maize cultivars from the national trial (Table 1).

The experiments were carried out in a complete randomized block design, with three replicates in experiment 1 and two replicates in experiments 2 and 3. Plots in all three experiments consisted of two 5-m-rows, 0.80 m apart, and plants in a 0.20 m in-row spacing. Cultivars were sowed by hand on November 19, 2016, using basal fertilization (20 kg ha^{-1} of N, 80 kg ha^{-1} of P_2O_5, and 80 kg ha^{-1} of K_2O).

After crop emergence and establishment, plant thinning was carried out by hand, and plant density was adjusted to 62,500 plants per hectare. Topdressing fertilization was divided into two applications: on the 4th and 19th of December 2016, when the plants had four and eight expanded leaves, respectively. Each application consisted of 90 kg ha^{-1} of N, totalizing 180 kg ha^{-1} of N topdressed.

At flowering (50% stamens with pollen-releasing anthers), one plant in each plot was labeled, and the leaves were numbered in ascending order from the plant base (the leaf closest to the soil was numbered as 1). In each plant, the number of leaves (NL), the number of leaves below the ear (NLBE) and the number of leaves above the ear (NLAE) were counted. Plant height (PH, in cm) and ear insertion height (EIH, in cm) were measured. Leaf angle (AG, in degrees) was measured on each leaf of each plant. The leaf insertion angle represents the inclination between the central rib of the leaf blade and the stem and was measured using a "Clinometer® "+ bubble level®"). Leaf length (LL, in cm) and maximum leaf width (LW, in cm) were measured. The leaf area (LA, in cm^2) was estimated for each leaf using the equation: LA = LL×LW×0.75 (ELINGS, 2000).

Following, each plant was divided into portions (lower, middle and upper), according to the

Table 1 - Cultivar, company, genetic basis, cycle, and grain texture of the maize cultivars assessed in the three experiments.

Cultivar	Company	Genetic basis	Cycle	Grain texture
----------Experiment 1 - trial of maize cultivars from *Rio Grande do Sul*----------				
20A55	Morgan Seeds	Triple hybrid	Early	Semi-hard
30A68	Morgan Seeds	Simple hybrid	Super-early	Semi-hard
30F53	Pioneer	Simple hybrid	Early	Semi dentade
AG8780	Agroceres Seeds	Simple hybrid	Early	Semi dentade
AG9025	Agroceres Seeds	Simple hybrid	Super-early	Semi dentade
AM9724	Melhoramento Agropastoril	Simple hybrid	Super-early	Dentade
AS1666	Agroeste	Simple hybrid	Super-early	Semi dentade
AS1677	Agroeste	Simple hybrid	Super-early	Semi dentade
BM3066	Biomatrix	Simple hybrid	Early	Semi dentade
CD324	Coodetec	Simple hybrid	Early	Semi-hard
CD384	Coodetec	Triple hybrid	Early	Semi-hard
CD393	Coodetec	Simple hybrid	Early	Hard
CD397	Coodetec	Triple hybrid	Early	Semi dentade
Celeron	Syngenta Seeds	Simple hybrid	Super-early	Hard
DKB230	Dekalb	Simple hybrid	Super-early	Semi dentade
DKB290	Dekalb	Simple hybrid	Early	Semi dentade
MS2010	Melhoramento Agropastoril	Simple hybrid	Early	Semi dentade
MS2013	Melhoramento Agropastoril	Simple hybrid	Early	Semi-hard
MS3022	Melhoramento Agropastoril	Triple hybrid	Early	Hard
P1630	Pioneer	Simple hybrid	Super-early	Semi dentade
P2530	Pioneer	Simple hybrid	Super-early	Semi-hard
SHS7915	Santa Helena Seeds	Simple hybrid	Super-early	Semi dentade
StatusVIP3	Syngenta Seeds	Simple hybrid	Early	Hard
StatusVIP	Syngenta Seeds	Simple hybrid	Early	Hard
SX7331	Syngenta Seeds	Simple hybrid	Early	Hard
XB6012	Semeali	Simple hybrid	Early	Semi-hard
----------Experiment 2 - national trial of early cycle south maize cultivars----------				
AL2015	DSMM/CATI	Variety	Early	Semi-hard
ALPiratininga	DSMM/CATI	Variety	Early	Dentade/Soft
Embrapa1M1642	Embrapa	Simple hybrid	Early	Semi-hard
XB61493	Semeali	Simple hybrid	Early	Semi-hard
70XB01	Semeali	Simple hybrid	Early	Semi-hard
Balu383VIP3	Balu Seeds	Simple hybrid	Early	-
Balu388VIP3	Balu Seeds	Simple hybrid	Early	-
Exp929791	Balu Seeds	Simple hybrid	Early	-
EXP937891	Balu Seeds	Simple hybrid	Early	-
Exp918391	Balu Seeds	Simple hybrid	Early	-
Balu280PRO	Balu Seeds	Simple hybrid	Early	-
Balu188	Balu Seeds	Triple hybrid	Early	-
Balu761	Balu Seeds	Double hybrid	Early	-
----------Experiment 3 - national trial of super-early cycle south maize cultivars----------				
Cr122	Criagene SK	Triple hybrid	Super-early	Dentade
98CV02	DSMM/CATI	Variety	Super-early	Semi-hard
70XB03	Semeali	Simple hybrid modified	Super-early	-
Exp917694	Balu Seeds	Simple hybrid	Super-early	-
Exp93294	Balu Seeds	Simple hybrid	Super-early	-
EXP942491	Balu Seeds	Simple hybrid	Super-early	-
EXP942494	Balu Seeds	Simple hybrid	Super-early	-
EXP978791	Balu Seeds	Simple hybrid	Super-early	-
EXP978894	Balu Seeds	Simple hybrid	Super-early	-
Balu280PRO	Balu Seeds	Simple hybrid	Super-early	-
Balu188	Balu Seeds	Triple hybrid	Super-early	-
Balu761	Balu Seeds	Double hybrid	Super-early	-

Source: The information about the cultivars in Experiment 1 was provided by the maize cultivar experiment network in Rio Grande do Sul coordinated by the State Agricultural Research Foundation (FEPAGRO). The cultivars in Experiments 2 and 3 were provided by the national maize cultivar experiment network coordinated by the Brazilian Agricultural Research Corporation (Embrapa), at <https://www.embrapa.br/milho-e-sorgo/solucoes-tecnologicas/ensaionacional>.

number of leaves. Plants with 12, 15 and 18 leaves were divided into portions with 4, 5 and 6 leaves each, respectively. The plants with number of leaves not multiple of three had the canopy divided as follows: plants with 13 leaves (5 leaves in the lower portion, 4 leaves in the middle portion, and 4 leaves in the upper portion); plants with 14 leaves (5 leaves in the lower portion, 5 leaves in the middle portion, and 4 leaves in the upper portion); plants with 16 leaves (6 leaves in the lower portion, 5 leaves in the middle portion,and 5 leaves in the upper portion); and plants with 17 leaves (6 leaves in the lower portion, 6 leaves in the middle portion,and 5 leaves in the upper portion).

Measurements AG, LL, LW, and LA of each leaf were used to calculate the following traits: plant leaf angle (AGP, in degrees; average AG of plant leaves); leaf angle of the lower portion (AGL, in degrees; average AG of the lower portion leaves); leaf angle of the middle portion (AGM, in degrees; average AG of the middle portion leaves); leaf angle of the upper portion (AGU, in degrees; average AG of the upper portion leaves); plant leaf length (LLP, in cm; average LL of plant leaves); leaf length of the lower portion (LLL, in cm; average LL of the lower portion leaves); leaf length of the middle portion (LLM, in cm; average LL of middle portion leaves); leaf length of the upper portion (LLU, in cm; average LL of the upper portion leaves); plant leaf width (LWP, in cm; average LW of plant leaves); leaf width of the lower portion (LWL, in cm; average LW of the lower portion leaves); leaf width of the middle portion (LWM, in cm; average LW of the middle portion leaves); leaf width of the upper portion (LWU, in cm, average LW of the upper portion leaves); plant leaf area (LAP, in cm^2; LA of the plant leaves); leaf area of the lower portion (LAL, in cm^2; LA of the lower portion leaves); leaf area of the middle portion (LAM, in cm^2; LA of the middle portion leaves); and leaf area of the upper portion (LAU, in cm^2; LA of upper portion leaves).

At physiological maturity, when 50% of the kernels have formed black layers at the point of attachment of the kernel to the cob, the corn ears were harvested and threshed. The grain was weighed using a digital scale and the moisture content was determined using an electronic moisture meter. Grain mass was corrected to 13% moisture and grain yield was calculated (GY, in g $plant^{-1}$).

In all three experiments, analysis of variance was carried out for each of the 22 traits (NL, NLBE, NLAE, PH, EIH, AGP, AGL, AGM, AGU, LLP, LLL, LLM, LLU, LWP, LWL, LWM, LWU, LAP, LAL, LAM, LAU, and GY), using the following mathematical model: $Y_{ij}=\mu+C_i+B_j+\varepsilon_{ij}$, where Y_{ij} represents the value of the variable Y of the i^{th} cultivar (i = 1, 2,...,n) in the j^{th} repetition (block) (j = 1, 2, ..., r); μ is the overall mean; C_i is the effect of the i^{th} cultivar (i = 1, 2, ..., n) (fixed effect); B_j is the effect of the j^{th} repetition (block) (j = 1, 2, ..., r); and ε_{ij} is the effect of the experimental error referring to the observation Y_{ij}, supposedly normal, independent and distributed with zero mean and common variance σ^2 (STORCK et al., 2016). The following statistics were recorded: F test for cultivar (F), mean, and coefficient of variation (CV). The p-value of the Kolmogorov-Smirnov test was determined for error normality and the p-value of the Bartlett test was determined for residual variance homogeneity. The selective accuracy was estimated using the equation $SA = (1-1/F)^{0.5}$ (RESENDE & DUARTE, 2007). The cultivar means were grouped using the Scott-Knott test, at 5% significance.

The Pearson correlation coefficient matrix (r, phenotypic correlation) between the 22 traits was constructed using the means of the repetitions. The Student t test at 5% significance was used to verify the coefficient significance, with n-2 = 49 degrees of freedom, where n = 51 maize cultivars. Statistical analyzes were performed using Microsoft Office Excel application and the Genes program (CRUZ, 2016).

RESULTS AND DISCUSSION

In the 66 experimental cases (22 traits × three experiments), the p-value of the Kolmogorov-Smirnov tests ranged between 0.106 and 0.999 and the Bartlett test between 0.020 and 0.999 (Table 2). For both tests, the greater the p-value the greater the evidence of error normality and residual variance homogeneity. Therefore, at a 2% significance level, it can be affirmed that the assumptions were met in 100% of the cases and the results of the analysis of variance and Scott-Knott test were statistically valid (STORCK et al., 2016).

The F test of the analysis of variance showed significant effect ($p \leq 0.05$) of cultivars in 22 traits (100%) in experiment 1 (maize cultivars from *Rio Grande do Sul*); 4 traits (18.2%) in experiment 2 (early cycle south maize cultivars from the national experiment); and 5 traits (22.7%) in experiment 3 (super-early maize cultivar from the national trial in the Southern Region) (Table 2). Results indicated that it is possible to select superior genotypes from the genetic variability existing in the germplasm, especially among the 26 cultivars in experiment 1. The experiments 2 and 3 had a lower number of replications and cultivars than experiment 1. This

Table 2 - Values of the F test for: cultivar (F), mean, coefficient of variation (CV), selective accuracy (SA), p-value of the Kolmogorov-Smirnov test (KS) for error normality and p-value of the Bartlett test for homogeneity of residual variances for 22 maize traits assessed in three experiments.

Statistics	NL	NLBE	NLAE	PH	EIH	AGP	AGL	AGM	AGU	LLP	LLL
----------Experiment 1 - trial with maize cultivars from *Rio Grande do Sul*----------											
F	7.02*	4.51*	2.51*	3.38*	4.53*	5.85*	5.31*	6.00*	5.54*	8.32*	4.65*
Mean	14.87	7.95	6.92	231.23	120.14	23.97	27.75	22.15	21.55	80.39	77.13
CV(%)	5.32	9.56	11.65	4.91	7.83	10.13	10.70	12.76	15.54	4.33	7.67
SA	0.93	0.88	0.78	0.84	0.88	0.91	0.90	0.91	0.91	0.94	0.89
KS	0.624	0.501	0.106	0.988	0.485	0.738	0.768	0.996	0.939	0.988	0.999
Bartlett	0.642	0.407	0.063	0.468	0.020	0.071	0.576	0.585	0.407	0.856	0.322
----------Experiment 2 - national trail with early cycle south maize cultivars----------											
F	0.77ns	0.38ns	1.22ns	2.87*	1.03ns	4.21*	1.62ns	2.53ns	2.57ns	3.30*	2.12ns
Mean	15.19	8.50	6.69	242.78	129.34	23.36	27.07	20.68	22.12	84.46	79.74
CV(%)	6.71	10.98	12.08	4.98	8.79	9.52	15.63	11.58	17.37	5.61	9.86
SA	-	-	0.42	0.81	0.16	0.87	0.62	0.78	0.78	0.83	0.73
KS	0.436	0.771	0.522	0.967	0.844	0.995	0.623	0.951	0.999	0.984	0.996
Bartlett	0.060	0.205	0.734	0.522	0.857	0.834	0.993	0.434	0.664	0.389	0.194
----------Experiment 3 - national trail with super-early cycle south maize cultivars----------											
F	0.98ns	0.41ns	1.55ns	4.27*	1.63ns	7.11*	2.76ns	3.90*	4.33*	2.73ns	4.87*
Mean	14.92	8.21	6.71	234.36	123.69	23.59	28.46	20.50	21.39	81.66	75.13
CV(%)	6.70	13.48	10.50	4.72	7.79	10.27	12.72	15.52	21.11	5.15	7.30
SA	-	-	0.60	0.88	0.62	0.93	0.80	0.86	0.88	0.80	0.89
KS	0.518	0.709	0.526	0.965	0.999	0.999	0.974	0.985	0.978	0.994	0.977
Bartlett	0.943	0.524	0.899	0.220	0.278	0.469	0.220	0.603	0.640	0.754	0.091

	LLM	LLU	LWP	LWL	LWM	LWU	LAP	LAL	LAM	LAU	GY
----------Experiment 1 - trial with maize cultivars from *Rio Grande do Sul*----------											
F	8.33*	5.01*	3.19*	3.05*	3.70*	2.58*	5.96*	3.46*	5.30*	2.90*	2.35*
Mean	96.46	67.14	8.96	8.00	10.39	8.55	8301.07	2518.03	3684.36	2098.67	182.07
CV(%)	3.71	6.86	6.62	8.41	6.22	9.19	9.58	14.63	9.86	16.09	16.94
SA	0.94	0.89	0.83	0.82	0.85	0.78	0.91	0.84	0.90	0.81	0.76
KS	0.985	0.896	0.999	0.639	0.999	0.944	0.543	0.754	0.864	0.993	0.704
Bartlett	0.501	0.197	0.609	0.517	0.375	0.733	0.994	0.618	0.252	0.796	0.691
----------Experiment 2 - national trail with early cycle south maize cultivars----------											
F	4.10*	2.13ns	1.55ns	1.88ns	2.42ns	0.95ns	1.06ns	1.87ns	1.02ns	0.82ns	0.74ns
Mean	101.44	71.66	9.05	8.07	10.43	8.68	9008.41	2663.00	4002.95	2342.46	171.76
CV(%)	4.84	8.17	6.78	7.58	5.62	11.57	14.87	19.63	13.02	22.44	19.76
SA	0.87	0.73	0.59	0.68	0.77	-	0.25	0.68	0.13	-	-
KS	0.986	0.999	0.988	0.375	0.981	0.971	0.944	0.757	0.739	0.901	0.888
Bartlett	0.792	0.248	0.272	0.998	0.358	0.478	0.259	0.823	0.115	0.038	0.906
----------Experiment 3 - national trail with super-early cycle south maize cultivars----------											
F	1.78ns	0.69ns	1.06ns	0.97ns	1.22ns	1.05ns	1.42ns	1.87ns	2.20ns	0.74ns	0.78ns
Mean	98.90	70.69	8.81	7.86	10.29	8.30	8345.78	2429.15	3748.13	2168.50	178.98
CV(%)	4.40	13.38	6.05	8.40	5.67	10.44	9.56	15.68	7.02	24.72	17.85
SA	0.66	-	0.24	-	0.43	0.21	0.54	0.68	0.74	-	-
KS	0.969	0.999	0.996	0.999	0.997	0.912	0.800	0.989	0.999	0.983	0.940
Bartlett	0.805	0.311	0.133	0.549	0.553	0.934	0.175	0.770	0.311	0.139	0.846

Traits: NL: number of leaves; NLBE: number of leaves below the ear; NLAE: number of leaves above the ear; PH: plant height, in cm; EIH: ear insertion height, in cm; AGP: leaf angle of the plant, in degrees; AGL: leaf angle of the lower portion, in degrees; AGM: leaf angle of the middle portion, in degrees; AGU: leaf angle of the upper portion, in degrees; LLP: leaf length of the plant, in cm; LLL: leaf length of the lower portion, in cm; LLM: leaf length of the middle portion, in cm; LLU: leaf length of the upper portion, in cm; LWP: leaf width of the plant, in cm; LWL: leaf width of the lower portion, in cm; LWM: leaf width of the middle portion, in cm; LWU: leaf width of the upper portion, in cm; LAP: leaf area of the plant, in cm^2; LAL: leaf area of the lower portion, in cm^2; LAM: leaf area of the middle portion, in cm^2; LAU: leaf area of the upper portion, in cm^2; and GY: grain yield, in g $plant^{-1}$. * Significant effect by the F test at 5% significance; ns non-significant.

may have contributed to the lack of differences among cultivars in 18 traits in experiment 2 and in 17 traits in experiment 3. A higher number of replications is important to increase cultivar discrimination, and six replications is recommended for experiments with maize cultivars (CARGNELUTTI FILHO et al., 2018).

Coefficient of variation (CV) for the 22 traits ranged between 3.71% and 16.94% in experiment 1; 4.84% and 22.44% in experiment 2; and 4.40% and 24.72% in experiment 3 (Table 2). CV is a statistical tool widely used to measure the experimental precision. PIMENTEL-GOMES (2009) ranked the CVs in agricultural experiments as follows: low (below 10%); medium (between 10 and 20%); high (between 20 and 30%); and very high (above 30%). Thus, it can be inferred that for 14, 11, and 11 traits in experiments 1, 2, and 3, respectively, the experimental precision was high (CV under 10%); for 8, 10, and 9 traits in experiments 1, 2 and 3, respectively, the experimental precision was medium (CV between 10 and 20%); and for 1 and 2 traits, in experiments 2 and 3, respectively, the experimental precision was low (CV between 20 and 30%).

Selective accuracy (SA), a statistics of experimental precision proposed by RESENDE & DUARTE (2007), varied between 0.76 and 0.94, in experiment 1, between 0.13 and 0.87, in experiment 2, and between 0.21 and 0.93, in experiment 3. Experiments 2 and 3 reached the lowest SA and, because F was below 1, it was not possible to calculate SA for 5 and 6 traits, respectively (Table 2). Experiment 1 had the highest experimental accuracy compared with experiments 2 and 3, which is in agreement with the findings of CARGNELUTTI FILHO et al. (2018) regarding the need of a higher number of repetitions. Thus, the cases with no significant differences among cultivars identified by the F test are related to lower experimental precision.

For the 22 traits, using the Scott-Knott test, at 5% significance, the groups of cultivars varied between 1 and 4, in experiment 1 and between 1 and 2, in experiments 2 and 3 (Tables 3 and 4). Therefore, the highest number of groups confirmed the greatest variability among cultivars in experiment 1. This can be explained by the highest experimental precision (lower values of CV and higher values of AS), highest number of repetitions, and highest number of cultivars. For all three experiments, genetic variability was reported among cultivars for number of leaves, plant height, ear height, leaf angle, leaf length, leaf width, leaf area, and grain yield. Variability of traits in maize genotypes was also observed by VIEIRA JUNIOR et al. (2005), VIEIRA JUNIOR et al. (2006), HANASHIRO et al. (2013), WASSOM (2013), and BORELLA et al. (2019).

Considering the 51 cultivars (26, 13 and 12 cultivars in experiments 1, 2 and 3, respectively), the number of leaves varied between 12.7 and 17.3, with an average of 15.0 leaves. Similar variations were reported in other studies, between 12 and 16 leaves per plant in 20 maize genotypes (VIEIRA JUNIOR et al., 2005) and between 9 and 14 leaves per plant in 44 maize genotypes (VIEIRA JUNIOR et al., 2006). SANGOI et al. (2002) assessed three genotypes and reported a variation in the average number of leaves between 18.4 and 23.2 leaves. The average number of leaves below the ear (8.2 leaves) was higher in relation to the number of leaves above the ear (6.8 leaves) (Table 3). HANASHIRO et al. (2013) also obtained variation between 6 and 7 leaves above the ear.

Among the 51 cultivars, EIH varied between 103.8 and 150.4 cm and PH between 204.4 and 261.0 cm. The average of the 51 cultivars for the relative position of the ears, as calculated by the ratio between EIH (123.3 cm) and PH (234.9 cm), was 0.52 cm. This may explain the higher number of leaves below the ear (Table 3). HANASHIRO et al. (2013) described similar results for 45 maize genotypes, with EIH varying between 109 and 155 cm, and average of 133 cm. Lower averages for EIH, between 69.12 and 86.19 cm were reported by KU et al. (2010) and BEKELE & RAO (2014), respectively. HANASHIRO et al. (2013) reported values between 190 and 257 for PH, with an average of 233 cm. KU et al. (2010) and BEKELE & RAO (2014) found lower averages for this trait, 201.04 and 188.99 cm, respectively. WASSOM (2013) found a close value for PH, 223.13 cm. Higher averages for plant height (between 251 and 302 cm) were recorded by SANGOI et al. (2002). Therefore, there is a wide genetic variability of EIH and PH in maize. The development of less tall hybrids and ears closer to the ground reduced the number of lodged and broken plants (SANGOI et al., 2002).

Plant leaf angle (AGP) among the 51 cultivars ranged between 14.8º and 34.1º, with an average of 23.7º. Leaf angle averages in the lower, middle and upper portions were 27.7º, 21.4º, and 21.7º, respectively. This showed a greater inclination of the leaves at the base of the plant in relation to the middle and upper portions (Table 3). The leaf angle gradually decreased from the basal leaves towards the upper leaves. Similar results were reported by VIEIRA JUNIOR et al. (2005) in a study to estimate the population and spatial arrangement of maize according to the canopy architecture and

Table 3 - Means for nine traits of the maize cultivars assessed in three experiments and number of groups formed by the Scott-Knott test.

Genotype	NL	NLBE	NLAE	PH	EIH	AGP	AGL	AGM	AGU
----------Experiment 1 - trial of maize cultivars from *Rio Grande do Sul*----------									
20A55	15.3 b	7.7 b	7.7 a	234.5 a	110.2 b	23.0 c	28.0 b	19.5 b	20.9 b
30A68	17.3 a	9.0 a	8.3 a	235.0 a	117.2 b	22.8 c	27.7 b	20.5 b	19.8 b
30F53	15.0 b	8.0 a	7.0 a	232.7 a	127.2 a	20.6 c	20.8 c	17.1 b	23.9 a
AG8780	15.7 b	9.0 a	6.7 a	245.3 a	127.8 a	24.1 b	32.5 a	19.9 b	19.0 b
AG9025	13.7 d	8.3 a	5.3 a	215.8 b	112.0 b	20.6 c	24.2 c	19.1 b	17.8 b
AM9724	14.7 c	8.0 a	6.7 a	221.9 b	119.0 b	29.1 a	34.7 a	28.3 a	24.0 a
AS1666	12.7 d	7.0 b	5.7 a	228.0 b	113.7 b	24.5 b	23.4 c	24.7 a	25.8 a
AS1677	15.0 b	8.0 a	7.0 a	219.9 b	105.9 b	21.1 c	26.8 c	19.5 b	16.3 b
BM3066	17.3 a	9.3 a	8.0 a	252.8 a	150.4 a	29.9 a	34.1 a	26.9 a	28.5 a
CD324	14.3 c	7.7 b	6.7 a	228.3 b	116.8 b	19.9 c	23.8 c	17.8 b	17.3 b
CD384	13.7 d	6.7 b	7.0 a	228.9 b	112.2 b	20.7 c	22.5 c	19.5 b	19.8 b
CD393	14.0 c	7.3 b	6.7 a	242.3 a	123.2 a	23.7 b	27.7 b	23.6 a	19.1 b
CD397	15.0 b	8.3 a	6.7 a	233.0 a	127.9 a	27.6 a	28.7 b	23.8 a	30.4 a
Celeron	14.0 c	7.0 b	7.0 a	216.1 b	107.8 b	27.3 a	33.2 a	28.5 a	19.3 b
DKB230	13.7 d	7.7 b	6.0 a	215.5 b	103.8 b	25.9 b	29.5 b	25.1 a	22.2 a
DKB290	15.7 b	8.7 a	7.0 a	239.2 a	121.9 b	15.7 c	22.2 c	14.5 b	10.2 b
MS2010	14.7 c	7.7 b	7.0 a	253.2 a	129.8 a	26.5 b	29.4 b	27.4 a	22.5 a
MS2013	16.0 b	9.0 a	7.0 a	237.6 a	121.3 b	25.7 b	33.0 a	24.7 a	17.9 b
MS3022	15.7 b	7.3 b	8.3 a	211.9 b	109.8 b	28.7 a	32.9 a	28.5 a	23.8 a
P1630	12.7 d	5.0 c	7.7 a	219.4 b	113.3 b	27.6 a	28.0 b	26.5 a	28.4 a
P2530	13.3 d	7.7 b	5.7 a	227.7 b	103.9 b	24.3 b	24.1 c	22.9 a	26.2 a
SHS7915	15.7 b	8.3 a	7.3 a	215.5 b	113.1 b	23.0 c	25.2 c	19.1 b	24.4 a
StatusVIP3	16.0 b	9.0 a	7.0 a	236.8 a	133.6 a	24.7 b	28.3 b	21.1 b	23.8 a
StatusVIP	15.7 b	9.0 a	6.7 a	241.7 a	135.9 a	24.5 b	28.4 b	20.5 b	24.0 a
SX7331	15.3 b	8.0 a	7.3 a	250.0 a	130.9 a	21.5 c	24.3 c	20.1 b	19.8 b
XB6012	14.7 c	8.0 a	6.7 a	229.1 b	135.0 a	20.1 c	27.9 b	17.1 b	15.3 b
Number of groups	4	3	1	2	2	3	3	2	2
----------Experiment 2 - national trail with early cycle south maize cultivars----------									
AL2015	15.5 a	8.5 a	7.0 a	230.8 b	118.3 a	22.7 a	26.3 a	18.7 a	22.6 a
ALPiratininga	15.5 a	8.0 a	7.5 a	256.5 a	130.0 a	26.3 a	30.9 a	23.2 a	24.7 a
Embrapa1M1642	16.5 a	9.0 a	7.5 a	228.3 b	117.9 a	26.2 a	30.6 a	23.4 a	23.7 a
XB61493	15.5 a	9.0 a	6.5 a	243.8 a	131.8 a	25.0 a	28.3 a	24.6 a	21.3 a
70XB01	16.0 a	8.5 a	7.5 a	256.7 a	135.6 a	22.7 a	21.6 a	21.2 a	25.6 a
Balu383VIP3	15.0 a	8.0 a	7.0 a	256.6 a	131.5 a	25.8 a	31.3 a	21.0 a	25.2 a
Balu388VIP3	15.0 a	8.0 a	7.0 a	251.1 a	132.4 a	26.5 a	29.5 a	22.9 a	26.6 a
Exp929791	15.0 a	8.5 a	6.5 a	252.3 a	133.5 a	17.9 a	21.6 a	17.3 a	14.8 a
EXP937891	15.0 a	8.5 a	6.5 a	220.8 b	114.1 a	21.6 a	28.6 a	18.0 a	18.3 a
Exp918391	14.5 a	9.0 a	5.5 a	259.8 a	140.5 a	26.9 a	30.9 a	21.3 a	28.6 a
Balu280PRO	15.0 a	8.5 a	6.5 a	249.3 a	137.6 a	16.9 a	20.9 a	15.5 a	14.3 a
Balu188	14.0 a	8.0 a	6.0 a	223.8 b	124.7 a	22.9 a	24.7 a	22.0 a	21.9 a
Balu761	15.0 a	9.0 a	6.0 a	226.8 b	133.9 a	22.3 a	26.6 a	19.7 a	20.0 a
Number of groups	1	1	1	2	1	1	1	1	1
----------Experiment 3 - national trail with super-early cycle south maize cultivars----------									
Cr122	15.0 a	8.0 a	7.0 a	211.0 a	117.6 a	22.2 a	32.6 a	19.0 a	15.1 a
98CV02	14.0 a	7.5 a	6.5 a	261.0 a	135.0 a	27.6 a	33.9 a	21.7 a	27.3 a
70XB03	15.0 a	8.0 a	7.0 a	238.1 a	122.6 a	23.8 a	27.6 a	21.5 a	22.4 a
Exp917694	14.5 a	8.0 a	6.5 a	237.0 a	126.7 a	34.1 a	35.7 a	31.9 a	35.4 a
Exp93294	16.0 a	8.0 a	8.0 a	228.9 a	108.6 a	26.5 a	29.3 a	21.2 a	28.5 a
EXP942491	15.0 a	9.0 a	6.0 a	222.5 a	131.9 a	14.8 a	19.9 a	13.1 a	10.5 a
EXP942494	15.5 a	9.0 a	6.5 a	253.6 a	136.9 a	22.3 a	26.3 a	20.8 a	19.3 a
EXP978791	15.5 a	8.5 a	7.0 a	244.7 a	119.3 a	22.4 a	30.4 a	17.4 a	18.4 a
EXP978894	14.5 a	7.5 a	7.0 a	238.3 a	123.0 a	21.6 a	26.2 a	21.7 a	15.9 a
Balu280PRO	15.0 a	8.5 a	6.5 a	232.8 a	124.8 a	21.3 a	25.8 a	17.4 a	20.4 a
Balu188	13.5 a	8.0 a	5.5 a	204.4 a	111.3 a	23.8 a	27.0 a	21.8 a	22.5 a
Balu761	15.5 a	8.5 a	7.0 a	240.3 a	126.9 a	22.5 a	27.0 a	18.4 a	21.2 a
Number of groups	1	1	1	1	1	1	1	1	1

Traits: NL: number of leaves; NLBE: number of leaves below the ear; NLAE: number of leaves above the ear; PH: plant height, in cm; EIH: ear insertion height, in cm; AGP: leaf angle of the plant, in degrees; AGL: leaf angle of the lower portion, in degrees; AGM: leaf angle of the middle portion, in degrees; AGU: leaf angle of the upper portion, in degrees. Means in the column not followed by the same letter are significantly different by the Scott-Knott test, at 5% significance.

Table 4 - Means for 13 traits of the maize cultivars assessed in three experiments; number of groups formed by the Scott-Knott test.

Cultivar	LLP	LLL	LLM	LLU	LWP	LWL	LWM	LWU	LAP	LAL	LAM	LAU	GY
----------Experiment 1 - trial of maize cultivars from *Rio Grande do Sul*----------													
20A55	85.9 b	82.6 a	104.0 b	71.5 b	9.6 a	8.7 a	11.1 a	9.2 a	9887 a	2959 a	4331 a	2597 a	180 a
30A68	84.1 b	79.7 a	99.8 c	71.2 b	8.4 b	7.7 b	9.5 b	7.8 b	9405 a	2803 a	4289 a	2313 a	185 a
30F53	76.3 d	71.6 b	94.9 d	62.2 c	9.0 a	7.9 a	10.3 b	8.7 a	8007 c	2175 b	3668 b	2164 a	189 a
AG8780	80.1 c	76.7 b	96.7 c	67.2 c	8.8 b	7.7 b	10.0 b	8.7 a	8486 b	2572 a	3638 b	2276 a	203 a
AG9025	78.7 c	69.2 b	96.6 c	70.0 b	7.7 b	6.8 b	9.1 b	7.2 b	6467 d	1806 b	3086 c	1575 b	189 a
AM9724	85.1 b	80.6 a	103.2 b	70.1 b	8.7 b	7.8 a	10.0 b	8.3 a	8423 b	2416 b	3856 a	2151 a	219 a
AS1666	76.7 d	78.4 a	90.4 d	60.9 c	8.6 b	8.0 a	10.2 b	7.6 b	6453 d	2220 b	2765 c	1468 b	148 b
AS1677	76.0 d	73.9 b	93.1 d	59.6 c	8.4 b	7.9 a	9.5 b	7.7 b	7523 c	2435 b	3337 b	1752 b	147 b
BM3066	80.8 c	78.0 a	97.1 c	65.6 c	9.2 a	8.8 a	10.4 b	8.4 a	10000 a	3132 a	4520 a	2348 a	215 a
CD324	97.8 a	94.5 a	111.0 a	87.8 a	9.9 a	8.7 a	11.6 a	9.4 a	10632 a	3357 a	4510 a	2765 a	180 a
CD384	85.8 b	85.3 a	100.5 c	71.6 b	9.8 a	8.9 a	11.3 a	9.2 a	8675 b	2913 a	3550 b	2212 a	161 b
CD393	88.8 b	86.3 a	105.7 b	73.5 b	9.3 a	8.2 a	10.9 a	8.8 a	8861 b	2709 a	3995 a	2157 a	183 a
CD397	84.1 b	87.2 a	97.7 c	66.0 c	8.4 b	8.2 a	9.9 b	7.0 b	8186 c	2864 a	3604 b	1718 b	211 a
Celeron	79.2 c	75.5 b	92.2 d	69.7 b	8.6 b	7.3 b	10.2 b	8.4 a	7419 c	2139 b	3289 b	1990 b	119 b
DKB230	73.0 d	72.5 b	87.0 d	57.4 c	8.8 b	7.1 b	10.4 b	9.2 a	6817 d	1987 b	3158 c	1672 b	142 b
DKB290	82.6 b	79.5 a	98.8 c	68.6 b	9.3 a	8.2 a	10.4 b	9.4 a	9236 b	2656 a	4104 a	2476 a	226 a
MS2010	85.3 b	85.4 a	102.6 b	66.6 c	9.0 a	7.4 b	10.3 b	9.3 a	8586 b	2415 b	3939 a	2232 a	182 a
MS2013	77.8 c	67.9 b	100.4 c	67.1 c	7.9 b	6.5 b	9.4 b	8.0 b	7731 c	2059 b	3562 b	2110 a	190 a
MS3022	73.8 d	67.0 b	90.1 d	63.7 c	8.2 b	7.1 b	10.0 b	7.6 b	7500 c	2104 b	3591 b	1805 b	182 a
P1630	71.3 d	67.2 b	85.7 d	61.4 c	9.1 a	8.0 a	10.3 b	9.2 a	6343 d	1956 b	2644 c	1743 b	150 b
P2530	75.6 d	72.3 b	91.5 d	62.5 c	10.1 a	8.8 a	12.1 a	9.5 a	7892 c	2474 b	3560 b	1858 b	214 a
SHS7915	81.6 c	77.3 b	97.7 c	70.6 b	9.8 a	8.4 a	11.6 a	9.6 a	9714 a	2854 a	4237 a	2622 a	221 a
StatusVIP3	75.9 d	68.0 b	92.7 d	68.4 b	9.1 a	8.3 a	10.5 b	8.6 a	8528 b	2590 a	3636 b	2302 a	172 b
StatusVIP	74.2 d	67.5 b	91.7 d	64.2 c	8.7 b	8.0 a	10.0 b	8.4 a	7879 c	2342 b	3438 b	2100 a	173 b
SX7331	79.4 c	76.6 b	95.3 d	66.8 c	9.0 a	8.3 a	10.3 b	8.4 a	8443 b	2570 a	3679 b	2194 a	189 a
XB6012	80.0 c	85.0 a	91.7 d	61.7 c	9.6 a	9.2 a	11.1 a	8.5 a	8736 b	2961 a	3807 a	1968 b	162 b
Number of groups	4	2	4	3	2	2	2	2	4	2	3	2	2
----------Experiment 2 - national trail with early cycle south maize cultivars----------													
AL2015	79.9 b	79.0 a	95.3 b	65.0 a	9.7 a	8.5 a	11.7 a	9.1 a	9468 a	2936 a	4151 a	2381 a	201 a
ALPiratininga	91.4 a	93.6 a	103.7 a	73.5 a	8.7 a	7.8 a	10.0 a	7.9 a	9419 a	3058 a	4301 a	2060 a	145 a
Embrapa1M1642	80.7 b	76.3 a	98.6 b	66.3 a	8.3 a	7.5 a	9.6 a	8.0 a	8676 a	2632 a	3924 a	2120 a	191 a
XB61493	91.7 a	84.0 a	113.0 a	79.0 a	9.6 a	8.7 a	10.8 a	9.5 a	10517 a	3070 a	4552 a	2895 a	153 a
70XB01	90.4 a	92.4 a	109.0 a	69.4 a	9.7 a	8.8 a	11.1 a	9.4 a	10808 a	3738 a	4529 a	2541 a	167 a
Balu383VIP3	80.3 b	74.4 a	98.3 b	68.3 a	9.0 a	8.2 a	10.4 a	8.3 a	8388 a	2336 a	3828 a	2224 a	177 a
Balu388VIP3	81.7 b	82.3 a	95.4 b	65.6 a	9.4 a	9.1 a	10.9 a	8.2 a	8933 a	3158 a	3910 a	1866 a	192 a
Exp929791	81.1 b	71.5 a	98.6 b	73.1 a	8.6 a	7.8 a	9.9 a	8.0 a	8042 a	2133 a	3649 a	2259 a	154 a
EXP937891	78.1 b	68.6 a	92.2 b	73.5 a	9.4 a	7.7 a	11.0 a	9.5 a	8533 a	2031 a	3815 a	2687 a	163 a
Exp918391	90.9 a	82.2 a	109.7 a	79.6 a	9.5 a	8.3 a	10.7 a	9.4 a	9648 a	2636 a	4390 a	2623 a	162 a
Balu280PRO	93.9 a	86.9 a	111.5 a	83.5 a	8.6 a	7.6 a	9.6 a	8.5 a	9270 a	2510 a	4026 a	2733 a	181 a
Balu188	80.6 b	75.9 a	96.7 b	69.5 a	8.9 a	7.8 a	9.9 a	9.2 a	7822 a	2272 a	3295 a	2255 a	204 a
Balu761	77.3 b	69.5 a	96.8 b	65.3 a	8.3 a	7.1 a	10.1 a	7.7 a	7585 a	2109 a	3669 a	1807 a	143 a
Number of groups	2	1	2	1	1	1	1	1	1	1	1	1	1
----------Experiment 3 - national trail with super-early cycle south maize cultivars----------													
Cr122	74.0 a	60.2 b	91.4 a	70.5 a	8.7 a	7.5 a	10.0 a	8.5 a	7522 a	1750 a	3436 a	2336 a	166 a
98CV02	87.1 a	90.5 a	101.1 a	65.3 a	8.8 a	8.3 a	10.5 a	7.3 a	8327 a	2858 a	3979 a	1491 a	158 a
70XB03	74.9 a	70.0 b	92.4 a	62.4 a	8.8 a	7.7 a	10.2 a	8.5 a	7682 a	2058 a	3503 a	2121 a	163 a
Exp917694	83.6 a	72.9 b	100.0 a	76.6 a	9.4 a	8.7 a	10.7 a	8.7 a	8806 a	2442 a	4007 a	2357 a	173 a
Exp93294	81.8 a	72.7 b	101.3 a	73.3 a	8.7 a	7.8 a	10.1 a	8.3 a	8843 a	2621 a	3840 a	2381 a	227 a
EXP942491	80.9 a	72.4 b	99.1 a	70.7 a	8.4 a	7.2 a	9.9 a	8.3 a	8012 a	2195 a	3680 a	2137 a	163 a
EXP942494	79.2 a	69.2 b	98.9 a	70.3 a	9.2 a	7.8 a	10.6 a	9.3 a	8762 a	2295 a	3930 a	2536 a	196 a
EXP978791	83.2 a	74.3 b	102.6 a	73.5 a	8.4 a	7.4 a	10.0 a	7.9 a	8513 a	2339 a	3833 a	2342 a	186 a
EXP978894	85.6 a	76.6 b	103.8 a	78.4 a	9.5 a	8.4 a	11.1 a	9.4 a	9138 a	2735 a	3870 a	2533 a	199 a
Balu280PRO	90.8 a	91.4 a	103.6 a	75.6 a	8.8 a	8.1 a	10.1 a	8.1 a	9202 a	3085 a	3905 a	2212 a	169 a
Balu188	81.6 a	76.1 b	96.7 a	71.4 a	8.3 a	7.4 a	9.5 a	7.9 a	7041 a	2203 a	3083 a	1755 a	169 a
Balu761	77.1 a	75.2 b	95.9 a	60.4 a	8.8 a	8.1 a	10.9 a	7.6 a	8302 a	2570 a	3910 a	1822 a	179 a
Number of groups	1	2	1	1	1	1	1	1	1	1	1	1	1

Traits: LLP: leaf length of the plant, in cm; LLL: leaf length of the lower portion, in cm; LLM: leaf length of the middle portion, in cm; LLU: leaf length of the upper portion, in cm; LWP: leaf width of the plant, in cm; LWL: leaf width of the lower portion, in cm; LWM: leaf width of the middle portion, in cm; LWU: leaf width of the upper portion, in cm; LAP: leaf area of the plant, in cm^2; LAL: leaf area of the lower portion, in cm^2; LAM: leaf area of the middle portion, in cm^2; LAU: leaf area of the upper portion, in cm^2; and GY: grain yield, in g $plant^{-1}$. Means in the column not followed by the same letter are significantly different by the Scott-Knott test, at 5% significance.

crop location. They found that the average leaf angle varied between 16º and 37º. These values are also in agreement with the results obtained by KU et al. (2010), WASSOM (2013), and ZHANG et al. (2014), of 27.5º, 26.0º, and 23.9º, respectively, for the average leaf angle. However, VIEIRA JUNIOR et al. (2006) recorded greater angles for three open pollinated varieties, eight double hybrids, eight triple hybrids, ten simple hybrids, and 15 lines, with average value of 38.67º, varying between 19º and 43º.

Grain yield is increased in plants with more upright leaves, with smaller leaf angles, which allow plant density to be increased, and favor light capture for photosynthesis (TIAN et al., 2011; ZHANG et al., 2014; HUANG et al., 2017). An ideotype of a compact plant, having shorter plants with fewer and more erect leaves, improves the quality of light within the canopy and reduces the dominance of the tassel (apical) over the ears (SANGOI et al., 2002). In this sense, the selection of plants with smaller leaf insertion angle, larger stem diameter, and higher thousand-grain mass may increase grain yield (NARDINO et al., 2016).

Plant leaf length (LLP) varied between 71.3 and 97.8 cm, with average of 81.7 cm (Table 4). Similar leaf lengths were recorded in other studies; for instance, between 64 and 108 cm (VIEIRA JUNIOR et al., 2005), between 52 and 106 cm (VIEIRA JUNIOR et al., 2006), average of 85.90 cm (KU et al., 2010), and average of 76.46 cm (WASSOM, 2013). In the lower, middle and upper portions, the average leaf length was of 77.3, 98.3, and 69.1 cm, respectively. This showed that the leaves were shorter at the base and top of the plant, and longer in the central part of the plant. The increases in the base and top towards the middle part of the plant were gradual.

A similar pattern was observed in relation to leaf width (LWP), which varied between 7.7 and 10.1 cm, with average of 8.9 cm (Table 4). Higher values were found by VIEIRA JUNIOR et al. (2005): between 21 and 27 cm. Similar values were found by VIEIRA JUNIOR et al., 2006: between 4.5 and 14.5 cm. The average leaf width in this study (8.9 cm) was similar to the results reported by KU et al. (2010) (8.89 cm) and WASSOM (2013) (9.1 cm). Leaf width gradually increased from the lower portion (average= 8.0 cm) and the upper portion (average= 8.5 cm) towards the middle portion (average = 10.4 cm) of the plant.

Plant leaf area (LAP) varied between 6,343 and 10,808 cm^2, with average of 8,492 cm^2. The patterns for leaf length and leaf width can explain the gradual increase of the leaf area in the lower portion (average=2,534 cm^2) and the upper portion (average= 2,177 cm^2) towards the middle portion (average = 3,781 cm^2). Similar leaf area, between 1,177.67 and 9,244.24 cm^2, was estimated by VIEIRA JUNIOR et al. (2006). Conversely, HANASHIRO et al. (2013) assessed maize cultivars and found two groups in relation to the leaf area of the leaf above and opposite to the first ear: the first group varied between 796 and 883 cm^2 and the second group between 668 and 783 cm^2, which was lower than the results of this study. Cultivars with high leaf areas and leaves with greater insertion angle demand more space between the rows and lower plant density per area, in order to minimize competition for water, light, and nutrients, which results in lower yield.

Results showed that the leaves close to the ear (middle portion) had smaller leaf angle and greater leaf length, leaf width, and leaf area. There was a gradual increase of leaf angle towards the leaves at the lower end of the plant, while a gradual decrease of leaf length, leaf width, and leaf area occurred towards the leaves at the lower and upper end of the plant. Therefore, in relation to the basal leaves, the leaves close to the ear were more erect, longer, wider, and had greater leaf area.

Grain yield (GY) ranged between 119 and 227 g $plant^{-1}$, with an average of 179 g $plant^{-1}$ (Table 4). Similar results were described by HANASHIRO et al. (2013), who found grain yield ranging from 5,926 to 14,419 kg ha^{-1} in a population of 60,000 plants ha^{-1}, resulting in 98.77 and 240.32 g $plant^{-1}$, respectively. In the 2008/2009 harvest year, TOEBE et al. (2014) reported the following values for grain yield per plant: 131.44, 153.25 and 144.85 g $plant^{-1}$, for single, triple, and double hybrids, respectively. In the 2009/2010 harvest year, the numbers were recorded as follows: 115.68, 116.62, and 86.37 g $plant^{-1}$ for single, triple, and double hybrids, respectively, which were values below those found in the present study.

The Pearson's correlation coefficient (r) showed a positive linear association between the traits NL and NLBE ($r = 0.72$) and NL and NLAE ($r = 0.63$). Plants with greater height are associated with higher ear insertion height ($r = 0.75$). The traits related to leaf angle (AGP, AGL, AGM, and AGU) had a positive linear correlation ($0.45 \leq r \leq 0.90$). A positive linear relationship was reported between the traits related to leaf length (LLP, LLL, LLM, and LLU; $0.38 \leq r \leq 0.93$), leaf width (LWP, LWL, LWM, and LWU; $0.40 \leq r \leq 0.93$), and leaf area (LAP, LAL, LAM, and LAU; $0.36 \leq r \leq 0.95$) (Table 5).

Grain yield showed no linear correlation with the groups of traits related to plant height (PH and EIH; $0.03 \leq r \leq 0.07$), leaf angle (AGP, AGL, AGM, and AGU; $-0.07 \leq r \leq 0.10$), leaf length (LLP, LLL, LLM, and LLU; $0.00 \leq r \leq 0.15$), and leaf width

Table 5 - Pearson's correlation coefficient matrix (phenotypic correlation) based on the means for 22 traits of 51 maize cultivars.

	NL	NLBE	NLAE	PH	EIH	AGP	AGL	AGM	AGU	LLP	LLL
NL	-										
NLBE	0.72*	-									
NLAE	0.63*	-0.09 ns	-								
PH	0.33*	0.30*	0.13 ns	-							
EIH	0.37*	0.50*	-0.02 ns	0.75*	-						
AGP	0.00ns	-0.19 ns	0.21 ns	0.07 ns	-0.01 ns	-					
AGL	0.18 ns	0.01 ns	0.25 ns	0.05 ns	0.02 ns	0.81*	-				
AGM	-0.15 ns	-0.33*	0.16 ns	-0.05 ns	-0.12 ns	0.90*	0.66*	-			
AGU	-0.06 ns	-0.18 ns	0.12 ns	0.16 ns	0.07 ns	0.84*	0.45*	0.65*	-		
LLP	0.09 ns	0.13 ns	-0.03 ns	0.44*	0.30*	-0.11 ns	-0.11 ns	-0.12 ns	-0.04 ns	-	
LLL	-0.02 ns	-0.05 ns	0.03 ns	0.42*	0.24 ns	-0.04 ns	-0.13 ns	-0.05 ns	0.08 ns	0.85*	-
	NL	NLBE	NLAE	PH	EIH	AGP	AGL	AGM	AGU	LLP	LLL
LLM	0.22 ns	0.29*	-0.01 ns	0.49*	0.35*	-0.13 ns	-0.11 ns	-0.14 ns	-0.08 ns	0.93*	0.66*
LLU	0.07 ns	0.17 ns	-0.09 ns	0.19 ns	0.16 ns	-0.18 ns	-0.09 ns	-0.17 ns	-0.18 ns	0.79*	0.38*
LWP	-0.09 ns	-0.17 ns	0.06 ns	0.21 ns	0.09 ns	-0.02 ns	-0.18 ns	-0.05 ns	0.15 ns	0.29*	0.34*
LWL	-0.01 ns	-0.13 ns	0.13 ns	0.34*	0.25 ns	0.07 ns	-0.12 ns	-0.03 ns	0.30*	0.35*	0.49*
LWM	-0.14 ns	-0.20 ns	0.02 ns	0.12 ns	-0.04 ns	-0.02 ns	-0.16 ns	-0.06 ns	0.15 ns	0.20 ns	0.28*
LWU	-0.08 ns	-0.11 ns	0.00 ns	0.06 ns	-0.03 ns	-0.13 ns	-0.22 ns	-0.04 ns	-0.07 ns	0.18 ns	0.08 ns
LAP	0.54*	0.39*	0.35*	0.51*	0.40*	-0.07 ns	-0.05 ns	-0.17 ns	0.02 ns	0.75*	0.63*
LAL	0.34*	0.16 ns	0.31*	0.45*	0.32*	0.02 ns	-0.09 ns	-0.08 ns	0.19 ns	0.69*	0.81*
LAM	0.61*	0.48*	0.34*	0.55*	0.44*	-0.01 ns	0.07 ns	-0.13 ns	0.04 ns	0.70*	0.56*
LAU	0.44*	0.37*	0.23 ns	0.29*	0.25 ns	-0.23 ns	-0.13 ns	-0.25 ns	-0.21 ns	0.51*	0.18 ns
GY	0.36*	0.28*	0.21 ns	0.07 ns	0.03 ns	0.01 ns	-0.02 ns	-0.07 ns	0.10 ns	0.06 ns	0.00 ns
	LLM	LLU	LWP	LWL	LWM	LWU	LAP	LAL	LAM	LAU	GY
LLM	-										
LLU	0.79*	-									
LWP	0.20 ns	0.20 ns	-								
LWL	0.21 ns	0.12 ns	0.84*	-							
LWM	0.11 ns	0.11 ns	0.93*	0.74*	-						
LWU	0.19 ns	0.29*	0.80*	0.40*	0.66*	-					
LAP	0.74*	0.58*	0.60*	0.59*	0.49*	0.44*	-				
LAL	0.57*	0.30*	0.56*	0.73*	0.49*	0.21 ns	0.84*	-			
LAM	0.72*	0.51*	0.47*	0.46*	0.41*	0.31*	0.95*	0.74*	-		
LAU	0.61*	0.71*	0.51*	0.29*	0.34*	0.67*	0.77*	0.36*	0.69*	-	
GY	0.15 ns	0.07 ns	0.16 ns	0.16 ns	0.13 ns	0.15 ns	0.30*	0.21 ns	0.29*	0.27 ns	-

Traits: NL: number of leaves; NLBE: number of leaves below the ear; NLAE: number of leaves above the ear; PH: plant height, in cm; EIH: ear insertion height, in cm; AGP: leaf angle of the plant, in degrees; AGL: leaf angle of the lower portion, in degrees; AGM: leaf angle of the middle portion, in degrees; AGU: leaf angle of the upper portion, in degrees; LLP: leaf length of the plant, in cm; LLL: leaf length of the lower portion, in cm; LLM: leaf length of the middle portion, in cm; LLU: leaf length of the upper portion, in cm; LWP: leaf width of the plant, in cm; LWL: leaf width of the lower portion, in cm; LWM: leaf width of the middle portion, in cm; LWU: leaf width of the upper portion, in cm; LAP: leaf area of the plant, in cm^2; LAL: leaf area of the lower portion, in cm^2; LAM: leaf area of the middle portion, in cm^2; LAU: leaf area of the upper portion, in cm^2; and GY: grain yield, in g $plant^{-1}$.* Significant by the Student's t test at 5% significance, with 49 degrees of freedom; ^{ns} non-significant.

(LWP, LWL, LWM, and LWU; $0.13 \leq r \leq 0.16$) (Table 5). Differently from this study, BELLO et al. (2010) assessed maize hybrids grown in Nigeria and found a positive correlation between plant height (r = 0.56) and ear insertion height (r = 0.45) with grain yield. Conversely, NARDINO et al. (2016) also reported that there was no linear correlation between leaf angle and grain yield (r =-0.004), which agrees with

our results. Therefore, the selection of plants using plant height, ear height, number of seeds per row, and hundred seed weight improves maize grain yield (BEKELE & RAO, 2014).

The groups of traits related to the number of leaves (NL, NLBE, and NLAE; $0.21 \leq r \leq 0.36$) and leaf area (LAP, LAL, LAM, and LAU; $0.21 \leq r \leq 0.30$) had a positive linear association with GY, but of small magnitude (Table 5). A positive correlation between NLAE and GY ($r = 0.21$) is important because the physiologically active leaf area above the ear is characterized as the most efficient in grain yield (ALVIM et al., 2010). Therefore, cultivars with higher number of leaves ($r = 0.36$) or higher leaf area ($r = 0.30$) are linearly associated with plants with higher grain yield. These results indicated that plants with more leaves and higher leaf area are more productive. NARDINO et al. (2016) also described a positive phenotypic correlation between leaf area and grain yield ($r = 0.284$). The results of this research are consistent with those of OGUNNIYAN & OLAKOJO (2014), who reported positive phenotypic correlation between number of leaves per plant ($r = 0.83$) and leaf area ($r = 0.37$) with grain yield.

Considering the 51 cultivars (3 varieties, 2 double hybrids, 7 triple hybrids, and 39 simple hybrids), the average of NL, PH (cm), EIH (cm), AGP (degrees), LLP (cm), LWP (cm), LAP (cm^2), and GY (g $plant^{-1}$) was 15.0, 249.4, 127.8, 25.5, 86.1, 9.1, 9,072, and 168 for the varieties; 15.3, 233.6, 130.4, 22.4, 77.2, 8.6, 7,944, and 161 for the double hybrids; 14.6, 221.1, 116.2, 24.1, 80.8, 8.8, 8,091, and 182 for triple hybrids; and 15.0, 236.4, 123.9, 23.6, 81.8, 9.0, 8,547, and 180 for the simple hybrids, respectively. Comparisons between genetic bases must be considered with caution due to the low representation the varieties, double hybrids, and triple hybrids had in this data set.

The averages for the traits NL, PH (cm), EIH (cm), AGP (degrees), LLP (cm), LWP (cm), LAP (cm^2), and GY (g $plant^{-1}$) were: 15.2, 239.8, 127.4, 23.5, 83.0, 9.0, 8,844, and 180 for the 29 early-cycle cultivars and 14.6, 228.5, 117.9, 24.1, 80.1, 8.8, 8,028, and 176 for the 22 super-early cycle cultivars, respectively. These results indicated that early-cycle cultivars are taller plants, with more leaves and with higher ear insertion height. The leaves are more erect, longer and wider, with larger leaf area, and are more productive than super-early cycle cultivars.

Regarding the regions of adaptation (state and national levels), the averages for the traits NL, PH (cm), EIH (cm), AGP (degrees), LLP (cm), LWP (cm), LAP (cm^2), and GY (g $plant^{-1}$) were: 14.9, 231.2, 120.1, 24.0, 80.4, 9.0, 8,301, and 182 for the 26 cultivars of the state trial (experiment 1) and 15.1, 238.7, 126.6, 23.5, 83.1, 8.9, 8,690, and 175 for the 25 cultivars of national trials (experiments 2 and 3), respectively. Results indicated that the cultivars from experiment 1 are shorter plants, with fewer leaves, shorter ear insertion height. Their leaves are less erect, shorter and wider, with smaller leaf area and are more productive than the cultivars from experiments 2 and 3.

The data on the average pattern of plant architecture and the grain yield among the genetic bases, cycles, and regions of adaptation were presented as complementary information, considering it was not the focus of this study. Further studies, using statistical criteria, need to be carried out to detail the comparisons among genetic bases, among cycles, and among regions of adaptation. They also need to include a larger number of cultivars, locations and years (environments), in order to achieve a higher level of representation in the data set.

CONCLUSION

Genetic variability was reported among cultivars for number of leaves, plant height, ear height, leaf angle, leaf length, leaf width, leaf area, and grain yield.

Leaves closer to the ear have smaller leaf angle, greater leaf length, greater leaf width, and greater leaf area. The leaf angle gradually increases towards the leaves at the lower and upper ends of the plant. Leaf length, leaf width, and leaf area gradually decreases towards the leaves of the lower and upper ends of the plant.

Cultivars with a greater number of leaves and a larger leaf area are associated with plants with higher grain yield.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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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