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Path Analysis and Correlation of Two Genetic Classes of Maize (*Zea mays* L.)

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Abstract: The objective of this study was to identify the primary and secondary components that are directly or indirectly related to grain yield and this relationship depends on the type of hybrid (single or triple). The maize experiment was conducted in the agricultural year 2011/12, in the State University of Mato Grosso do Sul, with eighteen treatments, consisting of eleven simple hybrids and seven triple hybrids arranged in a randomized block design with four replications. The variables evaluated were plant height and first ear of corn, length and diameter ear, number of rows per ear, number of kernels per row, weight of hundred grains and productivity. The data of simple hybrids and triple hybrids were grouped for comparison by test t at 5% probability. Subsequently, were estimated Pearson correlation coefficients between the parameters evaluated for each genetic class, proceeding the diagnosis of multicollinearity. Then, the correlations between other features and productivity (dependent variable) were split into direct and indirect effects, establishing relations of cause and effect between them. The results show that the relationship between direct and indirect effects on productivity depend on the genetic class. The variable number of grains per row and weight of hundred grains are directly correlated to grain yield and are indirectly influenced through the effects of the length and ear diameter, respectively.

Key words: Relations of cause and effect, simple hybrids, triple hybrids, production components

INTRODUCTION

The generalization of the hybrid is regarded as one of the biggest factors of increased corn yield, today the main raw material of a swine and poultry volume and technological level international (Paterniani and Campos, 2005).

According to CONAB (2013), the domestic production of maize crop in 2011/12 reached a volume of approximately 73 million tons with an average yield of 4.808 kg ha^{-1} and the crop of 2012/13 reached an average yield of 5.058 kg ha^{-1}, with total production of 80,253.4 million tons, representing an increase of almost 10% in the national maize production.

This increase in productivity involves several factors, among which stands out the correct choice of hybrids relevant to different regions of the country, since according to Cruz and Carneiro (2003), the type of hybrid is responsible for 50% of the yield. Parallel to this, the hybrids exhibit superior performance over hybrid triple and double (Emygdio *et al*., 2007; Arnhold *et al*., 2010).

However, yield is a character that genetic inheritance is very complex because of the performance results of several genes of small effect on the phenotype (Cruz and Carneiro, 2003). Concurrently with this, the breeding programs of corn, conducted in research centers, have prioritized the selection of hybrids becoming more productive and adapted to different environments (Lopes *et al*., 2007).

In these programs, it is crucial to understand the correlations between the components of grain yield, especially when, when performing a selection based on a character, resulting changes in other important agronomic characteristics correlated (Santos and Vencovski, 1986). However, these do not determine the relative importance of direct and indirect influences of these characters that make up the grain yield (Furtado *et al*., 2002).

Thus, studies on the unfolding of the correlation coefficient are made by path analysis, which is the study of the direct and indirect effects of characters on one basic variable in that the estimated effects are obtained by means of regression equations where variables are

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previously standardized. Thus, this analysis evaluates the effect of a dependent variable (Y) explanatory variables (X) so that the other explanatory variable (Xi) have no influence on this effect (Cruz and Carneiro, 2003; Lopes *et al*., 2007).

There are several studies of the direct and indirect effects between grain yield and its components in maize (Mohammadi *et al*., 2003; Saidaiah *et al*., 2008; Bello *et al*., 2010; Kumar *et al*., 2011; Pavan *et al*., 2011; Selvaraj and Nagarajan, 2011; Toebe and Filho, 2013). However, these do not consider the behavior of such characters when switching the class genetic evaluated, i.e., the type of hybrid.

In this way the objective of this research was to identify the primary and secondary components that are directly or indirectly related to grain yield and this relationship depends on the type of hybrid (single or triple).

MATERIALS AND METHODS

The experiment was installed in the experimental area of the State University of Mato Grosso do Sul-Unit University Aquidauana (UEMS/UUA), located in the Brazilian Savanna (or Cerrado), located in the municipality of Aquidauana, comprising the following coordinates 20°27'S and 55°40'W with an average elevation of 170 m (Schiavo *et al*., 2010).

The soil was classified as Ultisol sandy loam texture (Embrapa, 2006), with the following layer 0-0.20 m: pH (H_2O) = 6.2; Al exchangeable (cmoL dm^{-3}) = 0.0; Ca+Mg (cmoL$_c$ dm^{-3}) = 4.31; P (mg dm^{-3}) = 41.3; K (cmoL$_c$ dm^{-3}) = 0.2; Organic matter (g dm^{-3}) = 19.7; V (%) = 45.0; m (%) = 0.0; Sum of bases (cmoL$_c$ dm^{-3}) = 2.3; Cation exchange capacity (or CEC) (cmoL$_c$ dm^{-3}) = 5.1. The climate of the region, according to the classification described by Köppen-Geiger is Aw (Savanna Tropical) with cumulative rainfall during the experiment 450 mm and maximum and minimum temperatures of 91.4 and 66.2°F, respectively.

The experimental design was a randomized block with four replications. The area was divided into four blocks with a total of seventy-four plots, each with area 15.75 m^2 (3.15×5.0 m), two meters spacing between blocks. The treatments consisted of eighteen corn hybrids from two genetic classes: single and triple hybrid (Table 1).

In preparation of the experimental area was performed with the herbicide glyphosate for desiccation, in doses of 1 kg ha^{-1}. After drying and complete death of the plant, the furrows were opened using a seeder simple, manually performing seeding under no-tillage, on 02/20/2012, ten days after desiccation, which were distributed six seeds per meter in the rows, spaced 0.45 m. With about

Table 1: Features of eleven hybrids grown in Aquidauana, MS, Brazil (2012)

Commercial Name	Business	Genetic class	Cycle
AG 9010	Agroceres	Single hybrid	Very early
FÓRMULA TL	Syngenta	Single hybrid	Very early
MAXIMUS	Syngenta	Single hybrid	Early
P30F53	Pioneer	Single hybrid	Early
P3340	Pioneer	Single hybrid	Early
STATUS TL	Syngenta	Single hybrid	Early
XB 6010	Semeali	Single hybrid	Very early
XB 6012	Semeali	Single hybrid	Early
XB 7253	Semeali	Triple hybrid	Early
2B433	Dow Agrosciences	Triple hybrid	Very early
2B512	Dow Agrosciences	Triple hybrid	Early
2B655	Dow Agrosciences	Triple hybrid	Early
20A55	Agromen	Triple hybrid	Early
20A78	Agromen	Triple hybrid	Very early
2B587	Dow Agrosciences	Single hybrid	Early
30A30	Agromen	Single hybrid	Hyper early
30A37	Agromen	Single hybrid	Very early
30A95	Agromen	Triple hybrid	Early

fifteen days after emergence of the plants were carried thinning keeping four plants per linear meter for establishment of 88,889 plants ha^{-1}.

The fertilization at sowing time consisted of 300 kg ha^{-1} formulation 4-20-20. In topdressing urea was used as a source of nitrogen, applying 100 kg ha^{-1} on the surface when the plants had five to eight fully expanded leaves, as recommended by Broch (1999).

The control of fall armyworm (*Spodoptera frugiperda* Smith) was made 30 days after planting using the insecticide triflumuron at a rate of 75 mL h^{-1}. For control of weeds pre-emergence, were used 1,125 g ha^{-1} active ingredient atrazine and subsequently weeding.

At harvest time, when the grain had about 18% humidity, measurements were made of plant height and first spike insertion (PH and FSI, respectively), being carried out with a ruler graduated in five plants per plot. In each plot were randomly harvested five sheaves, which were numbered according to the plants evaluated by determining diameter and spike length (SD and SL, respectively) and the number of rows per spike (NRS) and number of grains per row (NGR).

The harvesting and threshing corn cobs were performed manually in three central rows of five meters length, according to the cycle of each hybrid. The Weight of Hundred Grains (WHG) was determined by manual counting, weighing and correction of moisture to 13%. The grain yield (YIE) was estimated by extrapolation of production harvested in the area useful for one hectare, correcting for a 13% wet basis.

Initially, data for single and triple hybrids were grouped so as to obtain the average of each parameter for each genetics class, to be compared by t-test at the 5% probability. We also compared the contrasts between classes using genetic building confidence intervals for differences in averages, at 95% confidence (Oliveira *et al*., 2012). Thereafter, was performed to estimate the Pearson correlation coefficients between the parameters evaluated for each class genetics (Steel *et al*., 1997). On the matrix of correlations among the eight characteristics, proceeded to the diagnosis of multicollinearity (Cruz and Carneiro, 2003). Then, the correlations between the other characteristics and YIE (dependent variable) were split into direct and indirect effects, establishing relations of cause and effect between them, as described in the literature (Cruz and Carneiro, 2003). All procedures were performed using the statistical software Genes (Cruz, 2001).

RESULTS AND DISCUSSION

In Table 2 presents the average values of the parameters evaluated in this study, where no significant difference was identified between the single and triple hybrids ($p<0.05$) for SD, NRS, FSI, PH and WHG. However, for the other variables was found superiority of single hybrids in relation to triple.

Through the analysis of means and confidence intervals for the parameter of the contrast PROD, it was observed that the hybrids were 18.59% higher than those triples. Corroborating this result, Emygdio *et al*. (2007) and Oliveira *et al*. (2012) also found difference between the contrasts analyzed and hybrids were superior in performance in the triple 12.27 and 13.24%, respectively. However, Saleh *et al*. (2002) and Arnhold *et al*. (2010) found no significant difference between these genetic classes for this variable.

The coefficients of the Pearson correlations between the parameters evaluated in this study are shown in Table 3, where there is an emphasis on the positive correlations between PH x FSI, SL x NGR, SD x NRS, NGF x YIE and WHG x YIE were significant ($p<0.05$) for both classes genetic evaluated.

The significant correlations found for both single hybrids and for triple agree with Filho *et al*. (2010) found that the same genetic effects in these classes.

For single hybrids positive correlation between PH x SL, probably because larger plants have higher photosynthetic activity and consequently increased production of photoassimilates resulting increase in variable SL, allied to this, Palhares (2003) attributes this result to greater uniformity these plant hybrids.

The negative correlation between NRS x WHG for the triple hybrids was expected, since according to Almeida *et al*. (1998), some components of yield are negatively correlated, i.e., the increase may cause a decrease in another and concomitantly with this, most of these hybrids of plants unevenness possibly contributes to the significance of this correlation.

The YIE in both genetic classes, is positively correlated with the WHG and NGR, a fact that may result in greater ease in selecting maize genotypes, as these characteristics help identify the characteristics of interest.

However, according to Lopes *et al*. (2007), in breeding programs for increased YIE, it is necessary to

Table 2: Mean values for the length and spike diameter (SL and SD, respectively), number of rows per spike (NRS), number of grains per row (NGR), height and spike height of the plant (FSI and PH, respectively), weight of hundred grains (WHG) and grain yield (YIE) of eleven single hybrids and seven triples. Aquidauana, Mato Grosso do Sul, Brazil (2012)

Parameters	Single hybrids	Triple hybrids	$CI_{0,95}$	CV (%)
SL (cm)	14.76^a	13.97^b	0.79±0,52	1.60
SD (cm)	4.72	4.66	0.06±0,20	1.37
NRS	15.63	16.31	0.68±0,98	2.75
NGR	29.89^a	27.71^b	2.18±1,63	2.51
FSI (m)	1.03	0.98	0.05±0,14	4.38
PH (m)	2.06	2.00	0.06±0.19	5.81
WHG (g)	35.23	32.62	2.61±3.43	4.50
YIE (kg ha^{-1})	8,895.94^a	7,242.10^b	1,653.84±971.15	7.33

Means followed by the same letter in the line do not differ significantly by t-test at 5% significance level. CV: Coefficient of variation, CI: Confidence interval, where the difference is not significant when the interval surpasses the contrast

Table 3: Estimates of the Pearson correlations between length and spike diameter (SL and SD, respectively), number of rows per spike (NRS), number of kernels per row (NGR), height and ear height of the plant (FSI and PH, respectively), weight of hundred grains (WHG) and yield (YIE) of eleven single hybrids (upper diagonal) and seven triples (lower diagonal) maize. Aquidauana, Mato Grosso do Sul, Brazil (2012)

	SL	SD	NRS	NGR	FSI	PH	WHG	YIE
SL	-	0.2627	0.3326	0.9097*	0.4054	0.9737*	0.5559	0.5142
SD	-0.1159	-	0.9857*	0.4523	-0.3111	0.2073	0.2435	0.4330
NRS	-0.0232	0.9457*	-	0.1907	-0.3891	0.2438	-0.5549	0.3382
NGR	0.8911*	0.3375	-0.3506	-	0.4424	-0.0293	0.6538	0.9282*
FSI	-0.1655	0.3319	0.2204	0.0806	-	0.9354*	0.1460	0.7191
PH	-0.0738	0.1598	0.3836	0.0950	0.8813*	-	0.7196	0.6630
WHG	0.2978	0.7940	-0.9606*	0.5916	-0.2205	-0.3525	-	0.9772*
YIE	0.5479	0.3967	-0.5393	0.9596*	-0.1526	-0.1651	0.9521*	-

*Significant by t test at 5% probability of error

Table 4: Estimates of the direct and indirect effects of the length and spike diameter (SL and SD, respectively), number of rows per spike (NRS), number of grains per row (NGR), height and spike height of the plant (FSI and PH, respectively), weight of hundred grains (WHG) and grain yield (YIE) of eleven single hybrids. Aquidauana, Mato Grosso do Sul, Brazil, 2012

Effect	SL	SD	NRS	NGR	FSI	PH	WHG
Direct over YIE	0.0484	0.1390	0.1917	0.6214	-0.1493	-01202.0000	0.5753
Indirect through SL	-	-0.0287	-0.0057	0.2214	-0.0411	-0.0183	0.0739
Indirect through SD	-0.0356	-	-0.2601	0.1038	0.1020	0.0491	0.2442
Indirect through NRS	-0.0044	-0.1621	-	-0.0672	0.0422	0.0735	-0.1841
Indirect through NGR	0.4539	0.2097	-0.2178	-	0.0500	0.0590	0.1676
Indirect through FSI	0.0247	-0.0495	-0.0329	-0.0120	-	0.1465	0.0329
Indirect through PH	0.0088	-0.0192	-0.0461	-0.0114	-0.1179	-	0.0423
Indirect through WHG	0.0521	0.3075	-0.1682	0.1036	-0.0386	-0.0617	-
Total (Pearson)	0.5479	0.3967	-0.5393	0.9596*	-0.1526	-0.1651	0.9521*

Coefficient of determination = 0.9994, *Significant by t test at 5% probability of error

Table 5: Estimates of the direct and indirect effects of the length and spike diameter (SL and SD, respectively), number of rows per spike (NRS), number of grains per row (NGR), height and spike height of the plant (FSI and PH, respectively), weight of hundred grains (WHG) and grain yield (YIE) of seven triple hybrids. Aquidauana, Mato Grosso do Sul, Brazil (2012)

Effect	SL	SD	NRS	NGR	FSI	PH	WHG
Direct over YIE	0.0687	0.1244	0.2803	0.4666	0.6023	0.0634	0.5109
Indirect through SL	-	-0.0706	-0.0893	0.0563	-0.1089	-0.2616	-0.1494
Indirect through SD	0.0810	-	0.3040	0.1086	-0.0959	0.0639	0.0751
Indirect through NRS	0.0932	0.2762	-	0.0534	-0.1090	0.0683	0.0434
Indirect through NGR	0.4186	-0.0313	-0.0169	-	-0.0393	0.0026	-0.0581
Indirect through FSI	0.0442	-0.1874	-0.2343	-0.0889	-	0.3586	0.5096
Indirect through PH	0.0617	0.0131	0.0154	-0.0018	0.0377	-	0.0456
Indirect through WHG	0.0840	0.3084	0.0791	0.3340	0.4322	0.3676	-
Total (Pearson)	0.5142	0.4330	0.3382	0.9282*	0.7191	0.6630	0.9772*

Coefficient of determination = 0.9991, *Significant by t test at 5% probability of error

split the correlation in direct and indirect effects to assess the degree of importance of each of the explanatory variables to the page.

The correlation between grain yield and agronomic traits was split into direct and indirect effects. This analysis showed weak collinearity (NC<100) for both single hybrids (Table 4) and for the triples (Table 5), probably because in both classes only genetic variables NGR and WHG (explanatory) would correlate positively with YIE (main).

Based on the results obtained, regardless of class gene, it was observed that NGR and WHG were the only characters with high direct effect on grain yield.

These data corroborate those reported by Batista *et al.* (2012), verifying that the relationship between agronomic traits and grain yield in maize hybrids, observed that spike weight was the only character that had high direct effect on grain yield. This confirms that the parameters related to the ear weight and grains are the only traits that can be used for indirect selection of more productive genotypes.

When analyzing only the direct effects, there is a general behavior similar in the two genetic classes, where the selection of genotypes that have higher NGR and WHG has a direct effect on the increase in YIE.

The effects of SL and SD on the YIE occur indirectly through NGR and WHG, respectively. In this case, according Fancelli and Dourado-Neto (1999), in maize breeding programs aiming to increase YIE, one must consider the size of the spike (SL and SD), as these act indirectly on this component.

The determination coefficient of the independent variables YIE shows that in 99.94% of the single hybrids is explained by the same, while the triple hybrid this value is 99.91%.

Therefore, both the direct selection of the parameters NGR and WHG as the indirect SL and SD are effective in increasing YIE gene in both classes. Thus, the best strategy is the simultaneous selection of characters for emphasis, also the characters which are more indirect effects (Lopes *et al*., 2007).

CONCLUSION

- The variable number of grains per row and weight of hundred grains are directly correlated with grain yield
- The effects of length and spike diameter on grain yield occur indirectly through the number of grains per row and weight of hundred grains, respectively
- The link between direct and indirect effects on productivity depends on the class genetics

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