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Association of secondary traits with yield in maize F_1's

Associação de caracteres secundários com o rendimento em F_1's de milho

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ABSTRACT

The objective was to identify phenotypic and genotypic associations, and cause-and-effect relations of secondary components on primary components to establish criteria in the indirect selection process for maize. Partial diallel crosses were conducted in Clevelândia. F1's were evaluated in five environments. For the purpose of increasing the yield of corn grain, breeders should seek to reduce the characters distance from the last node to the first branch of the tassel, tassel length and number of branches. The indirect selection for distance from the last node to the first branch of the tassel would be effective to increase the grain yield. The selection for smaller leaf angle, larger stem diameter and thousand grain weight are favorable for increasing grain yield in maize.

Key words: *direct and indirect effects,* ***Zea mays*** *L., Tassel characters.*

RESUMO

O objetivo deste trabalho foi identificar associações fenotípicas, genotípicas e relações de causa e efeito de componentes secundários sobre componentes primários para se estabelecer critérios nos processos de seleção indireta para milho. Os cruzamentos do dialelo parcial foram conduzidos em Clevelândia. Os F1's foram avaliados em cinco ambientes. Para fins de aumento do rendimento de grãos de milho, os melhoristas devem buscar a redução dos caracteres distância do último nó até primeira ramificação do pendão, comprimento do pendão e número de ramificações. A seleção indireta para menor distância do último nó até a primeira ramificação do pendão seria eficiente para o aumento do rendimento de grãos. A seleção para menor ângulo de folha, maior diâmetro de colmo e massa de mil grãos mostram-se favoráveis para o aumento do rendimento de grãos em milho.

Palavras-chave: *efeitos diretos e indiretos,* ***Zea mays*** *L., Caracteres de pendão.*

INTRODUCTION

The classical breeding can be performed in a direct manner by the selection of superior plants, or by indirect means, by knowledge of associations between characters, but the environment and the interaction provide changes in the phenotype, mostly to characters that have low penetrance and expressivity (HALLAUER et al., 2010; RAMALHO et al., 2012). It is up to the breeder to assess the magnitude of the significance and quantify the effects of the interaction and thus determine the techniques and strategies in the adoption of the selection procedures. Understanding the associations between characters is important for genetic gains and selection of the best parents, whose breeding objective is the development of high performance hybrids (HALLAUER, 2007; 2010; BERNINI & PATERNIANI, 2012).

Indirect selection is recommended for the character that has low heritability, difficult measurement, or when the selection is made early by the breeder. In this sense, the path analysis developed by WRIGHT (1923) is an important tool, since it is decomposed the linear correlation of the other characters with the character of interest in direct and indirect effects (CRUZ & CARNEIRO, 2006), assisting the breeder with the understanding of the existing relations and enabling more rapid progresses in comparison with the direct selection.

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VENCOVSKY & BARRIGA (1992) reported that the correlation between characters that one can directly view is of phenotypic nature, caused by genetic and environmental factors, pointing out that the breeding should worry about genetic associations (HALLAUER et al., 2010). Notwithstanding, the genetic, phenotypic and environmental correlations are indicators of the association and/or the relationship between variables, yet not always their magnitudes show cause-and-effect relations (FALCONER & MACKAY, 1996).

For most of the yield components, associations are elucidated. The literature presents some studies on the relationship between characters of agronomic importance to the corn crop, via path analysis (LOPES et al., 2007; ANDRADE & MIRANDA FILHO, 2008; BARROS et al., 2010; TOEBE & CARGNELUTTI FILHO, 2013). For secondary morphological characters, there are few studies linking them with the yield of corn grain. In this context, attention is drawn from breeding programs to observations also for strains morphology. Thus, the objective of this study was to identify the phenotypic and genotypic associations, and cause-and-effect relations of secondary (morphological) components on primary (yield) components to establish criteria in the indirect selection processes for grain yield in maize.

MATERIALS AND METHODS

The research with the crossings between homozygous lines was conducted in the municipality of Clevelândia - PR in the agricultural year 2010/2011. The inbred lines (nine generations of selfing) were grouped into two heterotic groups and come from the breeding program of the company KSP Sementes Ltda. The crossings were conducted in partial diallel scheme (cross between individuals of two heterotic groups) with a heterotic group of 15 female parents from simple hybrids and the other heterotic group of eight male parents from triple hybrids. The following crosses were performed: 1x1', 1x4', 2x3', 3x1', 3x4', 4x3', 4x7', 4,8', 5x3', 5x4', 6x3', 6x4', 7x4', 8x4', 9x4', 10x5', 11x3', 12x3', 13x3', 13x4', 14x4', 15x3', 15x5', 15x8' and 15x2', which resulted in 25 hybrids. The hybrid seeds were collected manually, dried and prepared for the sowing of the trials.

Sowing was conducted in 2011/2012 harvest in five environments of the three states of southern Brazil. In Rio Grande do Sul the test was conducted in the city of FredericoWestphalen, in Santa Catarina it took place in Itapiranga, and in Paraná, in PatoBranco, Ampére and Clevelândia.

F1's (hybrids) were evaluated according to the experimental design of randomized complete block with three replications per location. The experimental units were composed of two rows of five meters in length, spaced 0.70 meters. The hybrid seeds were sown manually. After emergence and crop establishment, it was held the manual adjustment of the population of the plots to 42 plants, the equivalent of 60 thousand plants ha^{-1}.

The characters analyzed were stem diameter (SD), measured with a digital caliper between the second and third internode in millimeters; leaf angle (LA), measured on the leaf with the cob with protractor of the type rule in degree; tassel length (TL), measured in centimeters from the last node of the stem to the tip of the tassel; distance from the last node (DLN), measured in cm from the last node to the first branch of the tassel; distance from the flag leaf to the first branch of the tassel (DFL), measured in the stem at the height of the collar of the flag leaf to the insertion of the first branch in centimeters; number of primary branches of the tassel (NPB), inserted into the main stem of the tassel; number of secondary branches of the tassel, inserted from the primary branches (NSB), total leaf area (TLA), measured by the length and width of all plant leaves, corrected by the factor of 0.75; thousand grain weight (TGW), measured by weighing eight repetitions of 100 grains; and grain yield (GY), obtained by manual harvest of grain of all plants in each plot, adjusted to 13% moisture and transformed into kg ha^{-1}.

The collected data were submitted to individual variance analysis. For each variable, in each test it was carried out the diagnosis of univariate normality of the residue (TOEBE & CARGNELUTTI FILHO, 2013), using the Shapiro-Wilk test (SHAPIRO & WILK, 1965) and homogeneity of variance by Bartlett test (STEEL et al., 1997). Selective accuracy was estimated according to RESENDE & DUARTE (2007). Then the phenotypic and genotypic linear correlation coefficients were calculated among the ten pairs of traits assessed (CRUZ & REGAZZI, 1997). The coefficients were carried out based on the joint analysis of data. The significance was tested at 5% and 1% error probability according to the t test (STEEL et al., 1997).

Diagnosis of multicollinearity was held at the matrices of phenotypic and genotypic correlation (TOEBE & CARGNELUTTI FILHO, 2013) through the variance inflation factor (VIF) and condition number (CN). The VIF <10 and CN <100 criteria were used for the maintenance of variables in the analysis. Estimating path coefficients was performed using the method presented by CRUZ & CARNEIRO (2006). Statistical analyzes were prepared with the aid of Microsoft Office Excel and Genes software (CRUZ, 2013).

RESULTS AND DISCUSSION

Variance analysis revealed significant effects for genotype x environment interaction for all traits assessed. Estimates of selective accuracy (SA), used as a measure of experimental precision, were SD (0.62), LA (0.64), DFL (0.66), DLN (0.71), TL (0.69), NPB (0.90), NSB (0.89), TGW (0.79), TLA (0.65) and GY (0.70), respectively. Thus, the accuracy estimates revealed adequate experimental precision, with estimates classified from moderate (0.5<SA<0.70) to very high (SA> 0.90) (RESENDE & DUARTE 2007). Selective accuracy has the property to report on the effectiveness of inference about the genotypic value of the cultivar, and such parameter does not depend only on the magnitude of the residual variation, but also on the ratio of the changes of genetic and residual nature associated with the character being evaluated (RESENDE & DUARTE, 2007; CARGNELUTTI FILHO & STORCK, 2007; CARGNELUTTI FILHO & STORCK, 2009).

The phenotypic correlations presented 22 pairs, and the genotypic presented 28 pairs of correlation with significance (Table 1). In the analysis of the correlation pairs, the magnitude of genotypic relations is superior to the phenotypic correlations, indicating that genotypic components have greater magnitude in the total correlation (FALCONER & MACKAY 1996). The genetic correlation is important because it represents the heritable fraction of the parent characters to progeny, usually caused by effects of pleiotropic or linked genes, being one important attribute in breeding programs (COIMBRA et al., 2005; LOPES et al., 2007; ANDRADE & MIRANDA FILHO, 2008; HALLAUER et al., 2010; TOEBE & CARGNELUTTI FILHO, 2013).

With respect to phenotypic correlations, attention is drawn to the pairs DFL x TGW (-0.241), DLN x TGW (-0.228) and NPB x TGW (-0.244), characters related to tassel size, revealing that phenotypes with larger tassel have likelihood of reduction of TGW. These effects are not desired by breeders, in view of the strong association with grain yield (NASTASIC et al., 2010). However, many estimates were low possibly due to the absence of pleiotropy and linear connection between the characters (VENCOVSKY & BARRIGA, 1992).

In the phenotypic correlations with grain yield are highlighted the negative effects of tassel characters DLN, TL and NPB (Table 1). Notwithstanding, the phenotypic correlations, for indirect selection purposes, should be observed with caution, as this is caused by two factors, both genetic and environmental. Environmental variations, in a number of plants, can cause correlations between characters, whether positive or negative, of strictly environmental nature. For indirect selection purposes in the breeding, it is not enough to know the phenotypic correlation, as it is usually masked by environmental effects, ie, environmental correlation. This way, attention should be focused on the genetic fraction,

Table 1 - Coefficients of phenotypic (superior diagonal) and genotypic (lower) correlation of ten agronomic characters evaluated at five environments, FredericoWestphalen, 2015.

G/P	SD[1]	LA	DFL	DLN	TL	NPB	NSB	TGW	TLA	GY
[1]SD	--	0.346*	-0.015	0.484*	0.168	0.399*	0.396*	-0.101	-0.143	0.032
LA	0.438*	--	-0.482*	0.149	0.177	0.240*	0.401*	0.216	-0.490*	-0.004
DFL	-0.026	-0.566*	--	0.042	0.018	0.087	-0.126	-0.241*	0.706*	0.008
DLN	0.603*	0.230*	-0.023	--	0.416*	0.579*	0.203	-0.228*	-0.326*	-0.548*
TL	0.178	0.279*	-0.057	0.443*	--	0.117	-0.168	-0.108	-0.248*	-0.324*
NPB	0.440*	0.300*	0.099	0.734*	0.136	--	0.362*	-0.244*	-0.187	-0.344*
NSB	0.454*	0.497*	-0.154	0.255*	-0.214	0.378*	--	-0.003	-0.153	-0.022
TGW	-0.160	0.296*	-0.297*	-0.321*	-0.155	-0.293*	-0.005	--	0.099	0.581*
TLA	-0.238*	-0.610*	0.789*	-0.378*	-0.329*	-0.241*	-0.193	0.097	--	0.284*
GY	0.036	-0.016	0.026	-0.678*	-0.363*	-0.390*	-0.027	0.680*	0.311*	--

[1]SD: stem diameter (mm); LA: leaf angle; DFL: distance from the flag leaf to the first branch (cm); DLN: distancefrom the last node to the insertion of the tassel branch (cm); TL: tassel length (cm); NPB: number of primary branches; NSB: number of secondary branches; TLA: total leaf area; TGW: thousand grain weight (g); GY: grain yield (kg ha^{-1}).

*Significant by t test at 5% error probability.

or on the genetic correlation between characters, as this represents the inheritable fraction and can be used in the guidance for indirect selection of the breeding program (VENCOVSKY & BARRIGA, 1992; FALCONER & MACKAY, 1996).

For number of branches, which already has search results that corroborate this research according to SANGOI et al. (2002), HALLAUER et al. (2010) and EDWARDS (2011), the branches present in the tassel negatively influence the grain yield due to increased demand for energy and the hormonal balance in the plant (SANGOI et al., 2002; EDWARDS, 2011); nonetheless the other characters evaluated in this study are still poorly researched.

Regarding the genotype correlations, it is important to highlight the significant correlations of LA x TGW (0.296), DFL x TGW (-0.297), DLN x TGW (-0.321), NPB x TGW (-0.293). It is assumed that selection for reducing these characters will benefit the GY, due to the presence of negative linear associations. To FALCONER & MACKAY (1996), an auxiliary character can sometimes be more appropriate to improve the main character than the actual selection of the main character.

For linear associations with yield, the negative effects of tassel characters are highlighted, where the reduction in size and number of branches would positively influence the GY. The magnitude of the correlations DLN x GY (-0.678), TL x GY (-0.363) and NPB x GY (-0.39) assumes that the selection should be made considering these three characters, because its estimates are negative and with significant magnitudes compared to the GY. Genetic associations between characters are caused by pleitropism or connection between loci. Pleiotropism is the property by which a gene participates in the control of two or more characters simultaneously, so that if the gene is segregating, it will cause simultaneous variation in the characteristics that it affects (FALCONER & MACKAY 1996).

The characters DLN, TL, NPB and NSB have positive and significant genetic correlations with LA, it is assumed that there can be gain with selection for smaller leaf angle. Similarly, the selection for higher TLA would decrease the characters DLN, TL and NPB, which relate negatively with grain yield. But such inferences can be taken in haste, by the fact that there may be relationships with other characters that can not be seen, not justifying making concrete decisions on the type of association that governs the pair of X/Y characters (COIMBRA et al., 2005).

Path analysis separates the associations of characters in direct and indirect effects. The adoption strategy of the path analysis enables to prioritize the most relevant characters for gains via indirect selection (COIMBRA et al., 2005; CRUZ & CARNEIRO, 2006).

Regarding character stem diameter (SD), phenotypic and genotypic direct effects were high (0.448 and 0.637), GY (Table 2). The total effects are much lower than the direct, because the DLN (-0.295 and -0.553) indirectly affects, negatively, the SD, reducing the overall magnitude. SANGOI et al. (2001) report that hybrids with higher stem diameter have the potential to be more productive hybrids, by remobilizing stem reserves to the cob in cases of damage in the leaves, in particular in the reproductive phase.

For the assessment of the effects of leaf angle (LA) on GY, the total phenotypic and genotypic correlations are lower than the direct magnitudes, especially the genotypic estimates (Table 2). The direct effects are negative (-0.121 and -0.362), revealing that the higher leaf angle negatively affects grain yield, the character DLN via indirect effects negatively affects LA, assuming that such characters could be selected jointly. Studies on the leaf angle and morphology of the tassel have gained attention from breeders who seek to make efficient the practice of plant saturation. This practice limits the incidence of solar radiation on the leaves;
therefore the sought for cultivars with smaller leaf angle, an upright tassel architecture, with few ramifications (KU et al., 2010).

Regarding the distance from the flag leaf to the insertion of the first branch (DFL), direct and total phenotypic and genotypic effects show up, of low magnitude on GY (Table 2).

The character distance from the last node to the first branch of the tassel (DLN) reveals high negative direct effects on GY, among all the traits evaluated, DLN is what reveals the greatest effects with grain yield for the phenotypic estimates (-0.612) and especially for the genotypic effects (-0.918) (Table 2). These results are of great importance for the genetic improvement of maize, and there may be gains in yield via selection for reducing the DLN. Thus, the attention of the breeders is once again requested for the secondary (morphological) characters, as DLN, having associations with grain yield.

The DLN character, measured from the extension of the last node to the first branch of the tassel, reveals causal action with grain yield. It is the morphological character of this research, which shows the greatest impact on grain yield. The high results for the coefficient of determination presented

Table 2 - Results of the phenotypic and genotypic path analysis of nine independent characters on grain yield (dependent character). Frederico Westphalen. 2015.

		----Direct Effect----	------Indirect Effect------									
Character		GY	SD	LA	DFL	DLN	TL	NPB	NSB	TGW	TLA	Total
SD	r_G	0.637	--	-0.158	-0.002	-0.553	0.008	0.094	0.006	-0.103	0.040	0.036
	r_P	0.448	--	-0.042	-0.003	-0.295	-0.018	-0.012	-0.010	-0.057	0.025	0.032
LA	r_G	-0.362	0.278	--	-0.065	-0.210	0.013	0.064	0.006	0.191	0.105	-0.016
	r_P	-0.121	0.155	--	-0.117	-0.090	-0.019	-0.007	-0.011	0.122	0.086	-0.004
DFL	r_G	0.115	-0.016	0.205	--	0.021	-0.002	0.021	-0.002	-0.192	-0.135	0.025
	r_P	0.243	-0.006	0.058	--	-0.025	-0.002	-0.002	0.003	-0.136	-0.124	0.008
DLN	r_G	-0.918	0.383	-0.083	-0.002	--	0.022	0.157	0.003	-0.208	0.065	-0.677
	r_P	-0.612	0.216	-0.018	0.010	--	-0.046	-0.018	-0.005	-0.129	0.057	-0.545
TL	r_G	0.049	0.113	-0.101	-0.006	-0.406	--	0.029	-0.002	-0.100	0.056	-0.363
	r_P	-0.110	0.075	-0.021	0.004	-0.254	--	-0.003	0.004	-0.061	0.043	-0.324
NPB	r_G	0.215	0.280	-0.108	0.011	-0.674	0.006	--	0.005	-0.189	0.041	-0.389
	r_P	-0.032	0.178	-0.029	0.021	-0.354	-0.012	--	-0.010	-0.138	0.032	-0.344
NSB	r_G	0.014	0.289	-0.180	-0.017	-0.234	-0.010	0.081	--	-0.002	0.033	-0.026
	r_P	-0.027	0.177	-0.048	-0.030	-0.124	0.018	-0.011	--	-0.011	0.001	-0.021
TGW	r_G	0.648	-0.101	-0.107	-0.034	0.295	-0.007	-0.062	0.000	--	-0.016	0.680
	r_P	0.568	-0.045	-0.026	-0.058	0.139	0.011	0.007	0.000	--	-0.017	0.580
TLA	r_G	-0.172	-0.151	0.221	0.091	0.347	-0.016	-0.051	-0.002	0.063	--	0.311
	r_P	-0.176	-0.064	0.059	0.172	0.199	0.027	0.006	0.004	0.055	--	0.283
Determination Coefficient						r_G				0.940		
						r_P				0.679		
Effect of the residual variable						r_G				0.244		
						r_P				0.567		

SD: stem diameter (mm); LA: leaf angle; DFL: distance from the flag leaf to the first branch (cm); DLN: distance from the last node to the insertionof the tassel branch (cm); TL: tassel length (cm); NPB: number ofprimary branches; NSB: number of secondary branches; TLA: total leaf area; TGW: Thousand grain weight (g); GY: Grain yield (kg ha^{-1}).

at the end of the tables, especially for genotypic estimates (0.94), indicated that the data adjustment to the model were adequate.

With regard to direct effects, of the total length of the tassel (TL) on the grain yield, the phenotypic and genotypic direct estimates have low magnitude (Table 2). Tassel features, as tassel size, were being reduced in commercial hybrids (DUVICK et al., 2010). The main factor contributing to breeding programs selecting to a smaller size tassel is justified by HALLAUER et al. (2010), where the mass is directly related to the tassel size, negatively affecting grain production, by the competition for nutrients with the cob.

Among the measured tassel structures, it is evident that even with the tassel size negatively affecting grain yield, its magnitude is lower than the DLN character. PARVEZ (2007), investigating the genetic effects of tassel characters on mass and length of the cob, reports negative significant effects of 0.38, between the length of the tassel and cob mass. These results are similar to those obtained in this research, with phenotypic and genotypic estimates of -0.324 and -0.363, respectively. In addition, the same author, along with MICKELSON et al. (2002), concluded that the selection of the length and mass of the tassel are negatively correlated with cob length. Breeders should select for shorter and light tassels, results that corroborate this research, where the same magnitude was revealed about the thousand grain weight and grain yield.

The number of branches on the main stem of the tassel (NPB) is a character investigated by many researchers. Some authors mentioned the character's relationship with the tolerance to conditions of water stress and high plant densities. Estimates show that NPB has negative linear relationship with GY (-0.344 phenotypic and -0.389 genotypic). With the decomposition of estimates via path analysis, direct magnitudes on grain yield are lower, with the linear relationshipbeing superior because of DLN that indirectly influence the NPB (Table 2). The number of branches has high heritability; therefore, the selection would become very efficient in reducing the number of branches (ANDRADE & MIRANDA FILHO, 2008). GERALDI et al. (1985), noting the size and mass of tassel, reported that hybrids with more ramifications are not desirable by the breeding for increasing the shading on the flag leaf of the plant, reducing the photosynthetic rate.

Regarding the number of secondary branches in the tassel (NSB), there was a low magnitude of phenotypic and genotypic estimates (Table 2). However, as previously mentioned, the number of branches has effects on tassel mass according to PARVEZ (2007), in studies with tassel characters in different plant densities and with practice of detasseling, concluding that the total removal of the tassel increases the grain yield, especially in high densities of plants, because of the greater intraespecific competition of the reproductive organs of the plant, notwithstanding the hybrids that were selected for fewer secondary branches did not differ from hybrids with more secondary branches in productivity, when detasseled.

Considering that the removal of the tassel is a practice that requires high labor and is costly, it has become unviable, thus the selection of lines with fewer secondary branches would be effective for obtaining increased corn kernels yield (ANDRADE & MIRANDA FILHO, 2008).

Conversely, hybrids under high stress conditions, with small tassel and few branches, would not enable adequate pollination, so the parents should be selected for larger tassel due to the pollen production being drastically reduced under high stress conditions. Nonetheless, a way to get around this would be the selection of strains with branches in vertical positions in the tassel; according to MICKELSON et al. (2002), it would reduce the angle of light energy interception by branches and also would not compromise the fertilization of plants in high stress conditions, facilitating this process because, as mentioned, the character presents high heritability.

TGW estimates on the yield reveal high direct phenotypic (0.568) and genotypic effects (0.648) (Table 2), being the total estimates of 0.58 and 0.68, indicating causal relation, so the selection may be performed indirectly to increase the grain mass. Similar estimates were observed by NASTASIC et al. (2010).

The TLA character has low direct effects with GY, but total estimates have positive magnitudes, higher than the direct effects, mainly due to the indirect effects of LA and DLN with TLA.

With respect to the residual values, one can infer that were lower for genotypic effects (0.244), and median for phenotypic (0.567) (Table 2). The revealed determination coefficients can be considered as high, especially for the genotypic - (0.940), indicating good adjustment of the data to the model used in this research - and phenotypic (0.679) effects. The statistics of the determination coefficient has favorable properties for the classification of the quality of the experiment, along with statistics such as selective accuracy, of the relationship between the coefficients of genetic and experimental variation, heritability (CARGNELUTTI FILHO & STORCK, 2007), where even greater magnitudes of the statistics heritability and coefficient of determination are associated with lower residual variances (CARGNELUTTI FILHO & STORCK, 2009).

CONCLUSION

The indirect selection for lower distance from the last node to the first branch of the tassel is effective to increase the grain yield. Selection for smaller leaf angle, larger stem diameter and thousand grain weight shown to be favorable for increasing the yield of maize grain.

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