Original Article

CORRELATION AND PATH ANALYSIS AS AN INDIRECT SELECTION CRITERION FOR SUNFLOWER ACHENE PRODUCTIVITY

CORRELAÇÃO E ANÁLISE DE TRILHA COMO CRITÉRIO DE SELEÇÃO INDIRETA PARA PRODUTIVIDADE DE AQUÊNIOS DE GIRASSOL

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ABSTRACT: The study was conducted in two different locations in South Brazil, in tillage in the 2009/2010 season on eight sunflower hybrids, aiming to determine the path correlations and coefficients between primary and secondary characters on the main variable of achene productivity. The correlations were similar between environments. The characters of the head diameter and mass of a thousand achenes had a significant influence on sunflower productivity. Based on the magnitude of the direct and indirect effects, we highlighted all primary components on the main variable, beside the good determination coefficient and low residual effect. The secondary component, the number of achenes, despite the significant direct effect on productivity, was indirectly influenced by the primary components, making it an undesirable character for selection.

KEYWORDS: *Helianthus annuus*L.. Components. Yield. Selection.

INTRODUCTION

The cultured sunflower (*Helianthus annuus*) is the fourth most important oilseed crop in the world, with about 37 million tons in the 2011/2012 harvest, an estimated increase in production of 18% over the previous season (USDA, 2011). However, in Brazil, this oilseed operation comprises 60,000 hectares per year, with low average yield. For this harvest, estimates suggest that the Brazilian productivity will be 1.216 kg ha^{-1}, with a negative variation of 3.1% compared with the previous year. Comparing Brazil with Argentina, one can see that the potential is yet to be reached, because this year Argentina cultivated 1.75 million hectares, with an increase of 13.4% compared with the previous harvest, producing 3.7 million tons of sunflower seeds (USDA, 2011).

The complexity of grain yield in crops varies according to various components associated with agronomic productivity and their interactions with the environment (CHIKKADEVAIAH et al., 2002). In addition to variations between populations due to environmental influences on the expression of characteristics, to increase the efficiency of selection, the magnitude of the phenotypic variation and correlations between features are considered essential for success and increased productivity (GOMES et al., 2007).

Although a simple correlation, as well as providing indirect selection, can provide direction and magnitude between two variables, it does not allow the evaluation of the interrelationships between groups of variables by a larger number of traits of agronomic importance, as it does not infer characteristics of cause and effect (CRUZ, 2005).

The analysis proposed by Wright (1921) is the most common tool to establish the exact correlation in terms of cause and effect, and to provide direct relationships, which are the casual effect, and indirect relationships mediated by one or more independent variables. Knowledge of the level of this association allows the determination of variables to be used for an insight into indirect selection for productivity in improvement programs (HOOGERHEIDE et al., 2007; RIGON et al., 2012).

Selecting directly from production is hampered by low heritability of this component. In this case, the indirect selection of other components can increase the seed yield in sunflower crops. In this context, the objective was to determine the primary and secondary components of sunflowers that were most associated with achene yield and their relationships in the selection of the components.

MATERIAL AND METHODS

The experiments were conducted in two different locations with a soil type of Oxisol: one in the experimental area of the Federal University of

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Santa Maria, Frederico Westphalen campus (location 1), and the other in the Missions region, in the city of Guarani das Missões (location 2). Figure 1 shows the meteorological data in the harvest of 2009/2010. Sowing was performed in the first and second 10-day periods of September in locations 1 and 2, respectively, and the weather conditions were classified in the Cfa as humid mesothermal.

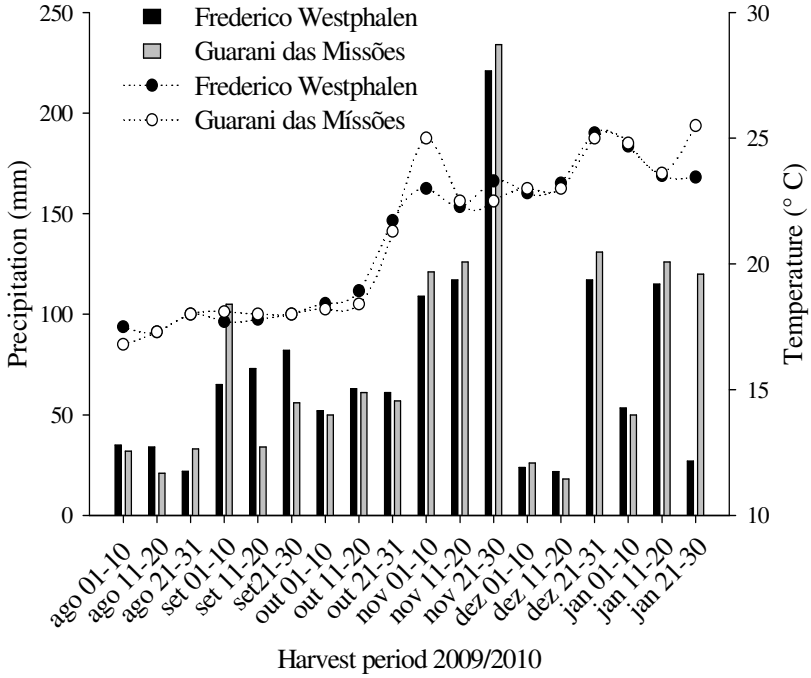

Figure 1. Precipitation (columns) and average temperatures (lines) for 10 days, derived from automatic meteorological stations.

At the first location, the previous culture was ryegrass (*Lolium multiflorum*), with 6.5 Mg ha^{-1} of dry mass. Despite there being no tillage system consolidation. At the time of sowing, soil density was high (1.65 mg m^{-3}). In this case, there was scarification to facilitate the establishment of culture. At the second location, the previous culture was radish (*Raphanus sativus L.*), with 8.2 Mg ha^{-1} of dry mass.

For fertilizer, chemical analysis was performed according to the 0–20 cm soil layer, for expectation of achene yield of 2.6 t ha^{-1}. Locations 1 and 2 were, respectively: 45% and 55% clay, pH: 5.4 and 52; SMP: 5.9 and 6.5; P: 4.0 mg L^{-1} and 4.5 mg L^{-1}; K: 85 mg L^{-1} and 105 mg L^{-1}; OM content: 2.4% and 2.65%; CTC: 15.8 cmol c L^{-1} and 17.54 cmol c L^{-1}; and base saturation: 68.5% and 77.2%. There were two applications of nitrogen, using urea as the source, at a dose of 50 kg ha^{-1} in V4 and V6 in both locations.

The study had a block randomized design with three replications. Treatments consisted of the following cultivars: Olisun 3, Olisun 5 (high oleic), Igrasol 830, Charrua, Aguará 3, Aguará 4, and Aguará 6. The plots were scaled to 5 ft with eight rows of crops, spaced at 0.7 m, aiming for a final population of 45,000 plants ha^{-1} with 20 plants evaluated in each parcel.

Eight characteristics were evaluated: height of insertion of the head (IHEA, in m); head diameter (DHEA, in cm); stem diameter (STDI, in mm); number of achenes per head (NACHE); mass of achenes per head (WACHE, in g); mass of a thousand seeds (P1000, in g); productivity (PROD, in kg ha^{-1}); and oil yield (OILY, in kg ha^{-1}). The diagnosis of multicollinearity was carried out, then single chain track analysis was performed, and the main variable was considered depending on the main components of these primary and secondary components. Genes software was used (CRUZ, 2006).

RESULTS AND DISCUSSION

Estimates of phenotypic correlation (rp) among eight agronomic components varied between the locations, from 0.01 to 0.83 and 0.05 to 0.86, as shown in Table 1. It is important to know the magnitude of association between components because the selection of a character infers the behavior of another.

Table 1. Phenotypic correlation coefficients between the characters[1] IHEA, DHEA, STDI, P1000, NACHE, WACHE, PROD, and OILY in sunflower genotypes at the locations of Frederico (upper) and Guarani das Missões (lower).

	IHEA	DHEA	STDI	P1000	NACHE	WACHE	PROD	OILY
IHEA	1	-0.41	-0.57	0.08	-0.25	-0.13	-0.14	0.01
DHEA	0.07	1	0.43	-0.39	-0.25	-0.36	0.34	-0.05
STDI	-0.11	-0.09	1	-0.31	0.37	0.13	0.18	0.27
P1000	-0.19	0.33	-0.21	1	0.41	0.71*	0.68*	0.65
NACHE	0.08	0.7	0.49	-0.32	1	0.82*	0.73*	0.61
WACHE	-0.05	0.56	0.36	0.36	0.78*	1	0.61*	0.58
PROD	-0.06	0.59*	0.37	0.33	0.65*	0.63*	1	0.83*
OILY	0.31	0.43	0.42	0.32	0.72*	0.61*	0.86*	1

[1] IHEA: height of insertion of the head; STDI: stem diameter; NACHE: number of achenes per head; DHEA: head diameter; WACHE: mass of seeds for each head; P1000: weight of a thousand achenes; OILY: oil yield; and PROD: productivity of achenes.

Although the same cultivars were evaluated at each location, it was observed that the correlations were distinct between the components according to the location. The characters NACHE and WACHE were highly correlated with the main variable and between themselves at both locations, even with different coefficients. However, at Guarani das Missões, the component DHEA also correlated with PROD (0.59), while at Frederico Westphalen, the significant character was P1000 (0.68). The data conform to those of Kholghi et al. (2001), who found that higher phenotypic correlations in sunflower productivity were associated with a mass of 100-seed head diameter and the number of achenes per head. In a study of 14 genotypes, Amorim et al. (2008) also observed a significant correlation between head diameter and grain mass with productivity in the cultivation of sunflowers, with coefficients of 0.63 and 0.55, respectively. In a study of nine sunflower cultivars (FARHATULLAH e KHALIL, 2006), a similar correlation between these two variables and achene productivity was observed. This relationship confirms that diameter head's with good development tend to have higher achene production and with a greater mass (RIGON et al. 2013).

As a study of only the association between characters does now allow conclusions to be drawn about cause and effect relationships, we performed a path analysis, which accorded correlation with data from both locations. Table 2 presents the direct and indirect effects of the primary explanatory variables on grain yield. There was a high coefficient of determination (0.86) coupled with low residual effect (0.32), which implies that these variables explain virtually all of the main variable PROD.

Table 2. Estimates of direct and indirect effects of the primary components[1] DHEA, WACHE, P1000, and OILY on the main variable PROD in eight sunflower genotypes cultivated in two environments in 2010.

FV	Pathways	p	FV	Pathways	p
	Direct effect PROD	0.30		Direct effect PROD	-0.02
	Indirect effect P1000	-0.10		Indirect effect DHEA	-0.03
DHEA	Indirect effect WACHE	0.11	P1000	Indirect effect WACHE	0.21
	Indirect effect OILY	0.23		Indirect effect OILY	0.15
	TOTAL	0.55		TOTAL	0.31
	Direct effect PROD	0.37		Direct effect PROD	0.83
	Indirect effect DHEA	-0.06		Indirect effect DHEA	-0.08
WACHE	Indirect effect P1000	-0.01	OILY	Indirect effect P1000	-0.01
	Indirect effect OILY	0.20		Indirect effect WACHE	0.20
	TOTAL	0.51		TOTAL	0.84
Coefficient of determination: 0.86					
Residual effect: 0.32					

[1] DHEA: head diameter; WACHE: mass of seeds for each head; P1000: weight of a thousand achenes; OILY: oil yield; and PROD: productivity of achenes.

Analyzing the effects of the major components (DHEA, P1000, WACHE, and OILY) on the main variable (Table 2), it was noted that OILY had a more direct effect, while for the other

components, the values were only significant with the indirect effects among themselves, confirming the phenotypic correlation and so totaling a considerable effect on PROD.

The high phenotypic effects on sunflower productivity were justified by the higher influence of the OILY component, which inferred indirectly on the other variables, such as DHEA and WACHE. To improve sunflower yield, the yield per plant, in terms of seed and oil, should be emphasized (CHIKKADEVAIA et al., 2002). Even though WACHE had a greater indirect effect on P1000, a result also reported by Kaya et al. (2008) in a study in two locations with sunflower genotype, it indicates the importance of knowledge in indirect selection in order to achieve gain in the main component, showing the complexity of this character as a result of various interactions. In the path analysis (DARVISHZADEH et al., 2011), it was observed that this variable, along with the number of achenes per head, had a higher positive effect on achene production, while in another study on sunflower genotypes (MACHIKOWA; SAETANG, 2008), it was observed that beside the head diameter, the height of plants was the most influential characteristic on achene yield. Sowmya et al. (2010) observed that only the head diameter had a considerable effect on productivity, with the other variables having little influence on sunflowers.

Table 3 shows the results of the path analysis of the secondary components for each primary component and the total main effect. By analyzing the direct and indirect effects, it appears that, in the secondary components, there was a relationship of direct cause and effect on productivity, particularly through OILY.

Table 3. Estimates of direct and indirect effects of secondary components[1] IHEA, STDI, and NACHE on the primary components[2] DHEA, WACHE, P1000, and OILY and the main variable[3] PROD in eight sunflower genotypes cultivated in two environments in 2010.

Variable	DHEA	P1000	WACHE	OILY	Ef Res.	TOTAL
IHEA						
Direct	0.0135	0.0007	0.0113	0.4371	-0.0018	0.4608
Indirect STDI	0.016	0.004	-0.0251	0.1836	0.0502	0.2144
Indirect NACHE	0.0305	0.0007	-0.1636	-0.219	-0.0038	-0.3552
TOTAL	0.0456	0.0055	-0.1774	0.4017	0.0446	0.32
STDI						
Direct	0.0032	0.008	-0.0502	0.3672	0.1005	0.4288
Indirect IHEA	0.0067	0.0004	0.0057	0.2185	-0.0009	0.2304
Indirect NACHE	0.0128	0.0003	-0.0687	-0.092	-0.0016	-0.1492
TOTAL	0.0228	0.0087	-0.1132	0.4938	0.098	0.51
NACHE						
Direct	-0.0609	-0.0014	0.3273	0.4379	0.0076	0.7105
Indirect IHEA	-0.0067	-0.0004	-0.0057	-0.2185	0.0009	-0.2304
Indirect STDI	-0.0007	-0.0017	0.0105	-0.0771	-0.021	-0.0900
TOTAL	-0.0683	-0.0035	0.3321	0.1423	-0.0126	0.39
R^2	0.21	0.25	0.79	0.65		

[1] IHEA: height of insertion of the head; STDI: stem diameter; NACHE: number of achenes per head; [2] DHEA: head diameter; WACHE: mass of seeds for each head; P1000: weight of a thousand achenes; OILY: oil yield and [3]PROD: productivity of achenes.

There was a high effect of the IHEA component on PROD (0.46), being almost exclusively the contribution of OILY (0.43), while the other primary variables amounted to 0.03, different from the other minor secondary components (STDI with 0.21 and NACHE with -0.35). The results were similar with the component STDI.

Unlike with NACHE, the overall effect was satisfying (0.51), as well as being a high direct estimate of PROD. The indirect effects provided by primary variables would not facilitate the assessment of individuals in the population to be improved, and thus, were considered to be of relatively low magnitude. Göksoy and Turan (2007), during 3 years of path analysis of sunflower culture, observed that the number of achenes per head exerted the most direct influence on productivity (0.79), followed by the mass of 1000 achenes, even though the authors investigated the low ratio of the number of seeds to the diameter (0.2) and the mass of 1000 achenes.

The direct effects of expressive secondary components should also be considered, albeit indirectly. The coefficient is considered to be low to fit with the selection. Thus, the indirect selection of

this variable may result in the reduction of the primary variables, negatively influencing the selection for PROD. The path analysis of primary and secondary components of beans by Cabral et al. (2011) showed similar results, as did the study by Rodrigues et al. (2010).

CONCLUSION

The primary components of sunflowers are good selection criteria for the yield of achenes. Although the number of achenes has a relevant direct effect on productivity, it indirectly suffers from the negative influence of the primary components, making it an undesirable characteristic for selection.

RESUMO: O estudo foi realizado em dois locais no Sul do Brasil na safra 2009/2010, por meio de oito híbridos de girassol, com o objetivo de determinar os coeficientes de correlações e a análise de trilha entre os caracteres primários e secundários sobre a variável principal produtividade de aquênios no girassol. As correlações foram semelhantes entre os ambientes, sendo o diâmetro do capítulo e massa de mil aquênios com maior influência significativa sobre a produtividade do girassol. Com base na magnitude dos efeitos diretos e indiretos, destacamos todos os componentes primários sobre a variável principal, além do coeficiente alto de determinação e efeito residual baixo. O componente secundário, o número de aquênios, apesar do efeito direto na produtividade, é influenciado indiretamente a partir dos componentes principais, tornando-se um carácter indesejável de seleção.

PALAVRAS-CHAVE: *Helianthus annus* L.. Componentes. Rendimento. Seleção.

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