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Correlations and Path Analysis in Sunflower Grown at Lower Elevations

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Abstract

Sunflower cultivation has great importance in Brazil, mainly for production of oil and animal feed. Studies on sunflower cultivar selection are important for crop expansion, contributing to better cultivar adaptation to different environments. Thus, the objective of this study was to evaluate the linear relations among sunflower (*Helianthus annuus* L.) morphological traits in a subtropical region with lower elevations and to identify traits that may assist in cultivar selection based on agronomic performance and path analysis. The experiment was performed during the 2017/2018 agricultural year in Santa Maria (latitude 29º71′ S, longitude 53º70′ W and 90 m altitude), southern Brazil. The experimental design was a randomized block with four replicates and eight cultivars: Syn 045, BRS 323, BRS G58, BRS G59, BRS G60, BRS G61, Multissol 02 and Catissol 03. Assessed traits were plant height, stem diameter, head diameter, thousand achenes weight, yield of achenes per head and number of achenes per head. Hereafter, associations between morphological traits and achene yield were verified by means of linear relations and path analysis. Thousand achenes weight and number of achenes per head exhibited linear relations and direct effects on achene yield in subtropical region at lower elevations. Head diameter does not present direct effect on achenes yield but it has direct effect on the number of achenes per head, indicating cause-effect relation and becoming an important alternative for indirect selection of sunflower cultivars.

Keywords: *Helianthus annuus* L., linear relations, indirect selection

1. Introduction

In Brazil, sunflower (*Helianthus annuus* L.) is grown for the production of oil and animal feed. The main sunflower producers are the states of Mato Grosso, Goiás, Minas Gerais e Rio Grande do Sul. The Brazilian production in the 2017/2018 agricultural season reached 120.4 thousand tons with a growing area of 76,400 hectares (CONAB, 2018).

Modern sunflower cultivars are considered photoperiod-insensitive, enabling cultivars recommended for cultivation in the central-west region to be grown in southern Brazil. In this sense, the main variables interfering in sunflower cultivar development and the quality of the produced oil are the air temperature and the intercepted solar radiation (Echarte et al., 2010).

A study conducted in Turkey by Turhan et al. (2010) emphasizes the importance of the sunflower growing site as a determining factor to meet the expectations of oil quality, being the growing site altitude and air temperature the main factors interfering in the fatty acids composition of achenes. Moreover, locations with higher elevation presented lower minimum night temperature associated with yield and quality of fatty acids (Grunvald et al., 2013), mainly at the initial stage of grain filling (Izquierdo et al., 2002).

The study of linear relations in agricultural crops contributes to the comprehension of interrelations between traits, assisting the decision making regarding the use of indirect selection and sunflower cultivar positioning based on the best ideotype for a certain growing site. Furthermore, path analysis allows unfolding the correlation coefficient into direct and indirect effects (Wright, 1921).

The path analysis methodology is widely applied in crops such as sunflower, where studies have been developed in different growing environments in Brazil (Amorim et al., 2008; Rigon et al., 2014; Chambó et al., 2017), India (Chikkadevaiah et al., 2002; Anandhan et al., 2010; Yasin & Singh, 2010; Rani et al., 2017), Turkey (Göksoy & Turan, 2007), Iran (Darvishzadeh et al., 2011), Pakistan (Hassan et al., 2013) and Serbia (Radic et al., 2013). These studies demonstrated the importance of path analysis in the indirect selection for cropping positioning and releasing new cultivars and sunflower. Recent studies also investigated linear relations and path analysis for other crops, such as soybean (Teodoro et al., 2015; Follmann et al., 2017) and maize (Crevelari et al., 2018).

Studies of linear relations and path analysis among traits in sunflower grown at a lower elevation region in subtropical climate were not found in the literature. We assumed that these linear relations exist and they can be used for growing recommendations and indirect selection of high-yielding cultivars. Thus, the objective of this study was to evaluate the linear relations among sunflower (*Helianthus annuus* L.) morphological traits in a subtropical region with lower elevations and to identify traits that may assist in cultivar selection based on agronomic performance and path analysis.

2. Material and Methods

The experiment was performed at the Federal University of Santa Maria (UFSM) in Santa Maria (latitude 29º71′ S, longitude 53º70′ W and 90 m altitude), Rio Grande do Sul state, southern Brazil. According to the Peel et al. (2007) climate classification, the climate is Cfa, subtropical humid, with hot summers and without dry season defined. The soil of the experimental area is classified as sandy loam typic Paleudalf (Embrapa, 2013), presenting proper drainage in a coxilha-knoll site. According to the chemical and physical analysis, the soil presented the following contents: clay = 19%, organic matter = 1.9%, base saturation = 40.5%, pH = 4.8, P = 22.6 mg/dm^3, K = 72.0 mg/dm^3 and B = 0.4 mg/dm^3.

Treaments were composed of eight sunflower cultivars: Syn 045, BRS 323, BRS G58, BRS G59, BRS G60, BRS G61, Multissol 02 and Catissol 03. The study integrates the First Year Final Trial of the 2017/2018 agricultural year (National Sunflower Trial), coordinated by the Brazilian Agricultural Research Corporation (EMBRAPA). The plot area was 21.6 m² (6 × 3.6 m), with an useful area of 9 m² (5 × 1.8 m), totaling 32 experimental plots.

Seeding was carried out on September, 2017 in a no-tillage system, with rows spaced at 0.9 m and plant density of 45,000 plants ha^{-1}. At sowing time, 20 kg ha^{-1} of N, 80 kg ha^{-1} of P_2O_5 and 80 kg ha^{-1} of K_2O (400 kg ha^{-1} of the NPK commercial formula 05-20-20) were applied for basic fertilization. Topdressing fertilization was carried out 25 days after emergence using 31.5 kg ha^{-1} of nitrogen in the form of urea (45% nitrogen) and 2 kg ha^{-1} of boron in the form of borax (11.3% boron). Weed control was performed with manual weeding and other cultural practices were performed according to crop technical indications (Leite et al., 2007). During the conduction of the experiment, mean temperature and precipitation were considered within normality, *i.e.*, a characteristic year of the experimental site (Figure 1).

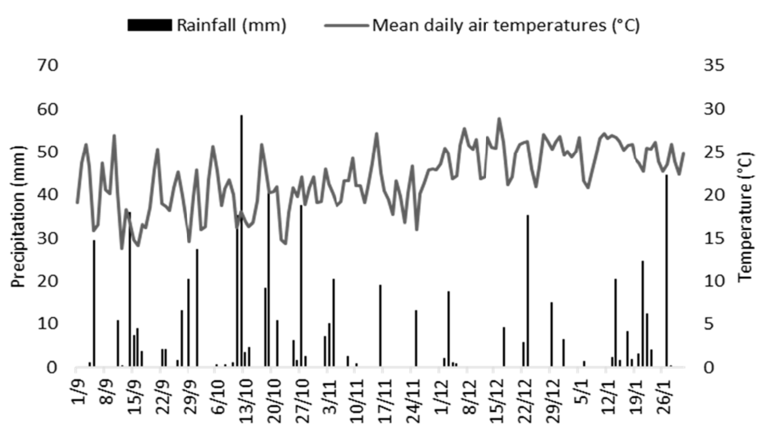

Figure 1. Mean daily air temperatures (°C) and mean rainfall (mm) for the 2017/2018 agricultural year

In the crop physiological maturation period, eight plants were labeled in the useful area of each plot and plant height (PH, in m) and stem diameter (SD, in mm) were measured. The flower heads corresponding to the plot area were protected with TNT fabric, forming a physical barrier in order to prevent bird attack.The protection was utilized after sunflower physiological maturity in order to avoid damage to grain filling, which follows the recommendations of the National Sunflower Trials. Flower head harvesting of labeled plants was carried out on January, 2018, maintaining the same identification of the individual plants for subsequent evaluation in the Laboratory of the Research Group in Ecophysiology and Management of Annual Crops (GEMCA-UFSM). In the laboratory, head diameter (HD, in cm), thousand achenes weight (TAW, in g) and yield of achenes per head (YAH, in g) were measured and the weight was corrected to 13% moisture. The number of achenes per head (NAH) was estimated by means of the expression NAH = YAH × 1000/TAW.

The experimental design was a randomized block with four replicates (blocks) and eight cultivars. For the traits PH, SD, HD, TAW, NAH and YAH, analysis of variance and F-tests were performed for block and cultivar effects at 5% error probability. The estimates of mean square of cultivar (MSC) and mean squared error (MSE) were recorded and the overall mean of the experiment (m) and the coefficient of variation (CV) were calculated.

For the study of linear relations, the phenotypic (r_f) and partial (r_p) correlation matrices among the traits PH, SD, HD, TAW, NAH and YAH were estimated. Afterwards, the significance of r_f and r_p was verified by means of the Student's t-test ($p \leq 0.05$).

Multicollinearity diagnosis (Cruz, 2016) was performed in the matrix of phenotypic correlation coefficients (r_f) among PH, SD, HD, TAW and NAH and the relation among the traits was expressed by Pearson's linear correlation and partial correlation. For the interpretation of the multicollinearity diagnosis, the condition index (CI) was used and multicollinearity was considered low when CI < 100, moderate to severe when 100 ≤ CI ≤ 1,000 and severe when CI > 1,000, according to the criterion of Montgomery and Peck (1982).

In each experiment, path analysis of the main variable (YAH) in function of the explanatory variables (PH, SD, HD, TAW and NAH) was performed. Statistical analyzes were performed using the Microsoft Office Excel® application and the Genes software (Cruz, 2016).

3. Results and Discussion

Climatic conditions regarding temperature and precipitation are within the normal climate of the region during the study (Figure 1). Greater reliability in the study results is observed because reduced environmental differences play into the observed result, conditioning high applicability.

According to the analysis of variance, there was significance ($p \leq 0.05$) for the mean square of cultivars for the traits PH, SD, HD, TAW and YAH (Table1). Coefficients of variation (CV) of 4.03% for PH, 4.32% for SD, 4.04% for HD, 11.71% for TAW, 11.41% for NAH and 9.60% for YAH denote good experimental accuracy, proper experimental planning, conduction and quality control at all stages of the experimental plan. The frequency histograms of six traits in eight sunflower cultivars (Figure 2) indicate that the measured traits adhered to the normal distribution, demonstrating adequate data representativeness.

Table 1. Analysis of variance and significance of mean squares of the sources of variation, coefficient of variation (CV), lower mean, higher mean and overall mean in traits of eight sunflower cultivars

Source of variation	PH	SD	HD	TAW	NAH	YAH
Block (DF = 3)	0.451*	57.161*	5.913^{ns}	5.062^{ns}	167,258.374^{ns}	661.082^{ns}
Cultivar (DF = 7)	0.189*	67.352*	14.452*	2,232.249*	319,639.423^{ns}	3,275.875*
Experimental error (DF = 21)	0.038	6.572	4.535	373.500	142,735.616	321.422
Sample error (DF = 224)	0.009	8.211	5.226	158.993	110,245.011	294.668
CV (%)	4.03	4.32	4.04	11.71	11.41	9.60
Lower mean	1.63	18.68	17.85	44.91	1,050.26	52.97
Higher mean	1.83	23.21	19.94	69.55	1,319.03	83.37
Mean	1.71	20.97	18.62	58.35	1,171.19	66.01

Note. Traits: PH: plant height, in m; SD: stem diameter, in mm; HD: head diameter, in cm; TAW: thousand achenes weight, in g; NAH: number of achenes per head (NAH = YAH × 1000/TAW) and YAH: yield of achenes per head, in g plant^{-1}.

DF: Degrees of freedom. *: Significant effect by F-test at 5% probability level. ^{ns}: Non-significant.

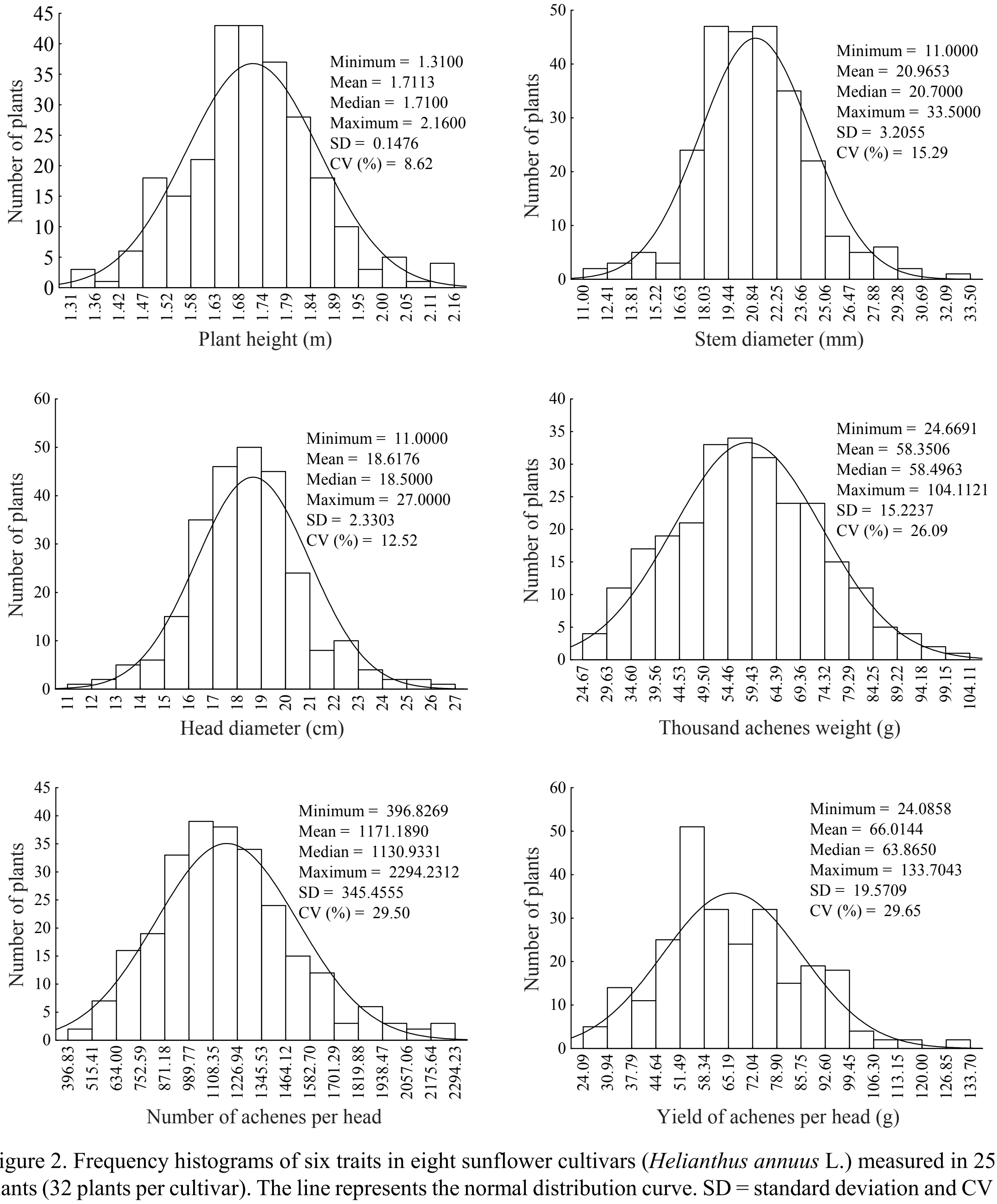

Figure 2. Frequency histograms of six traits in eight sunflower cultivars (*Helianthus annuus* L.) measured in 256 plants (32 plants per cultivar). The line represents the normal distribution curve. SD = standard deviation and CV = coefficient of variation

The cultivars presented a mean for PA of 1.71 m (ranging from 1.31 to 2.16 m), SD of 20.97 mm (ranging from 11.00 to 33.50 mm), HD of 18.62 cm (ranging from 11.00 to 27.00 cm), TAW of 58.35 g (ranging from 24.66 to 104.11 g), NAH of 1171.19 achenes (ranging from 396.82 to 2294.23 achenes) and PROD of 66.01 g (ranging from 24.08 to 133.70 g) (Figure 2). The mean values of the traits were similar to other studies carried out in Brazil to evaluate the agronomic performance of sunflower at sowing dates (Santos et al., 2012; Birk et al., 2017), indicating data representativeness for the study of linear relations and path analysis.

The high experimental precision associated with the number of evaluated sunflower cultivars and number of observations per trait (256 observations) confer suitability to the study of linear relations between traits through

Pearson's linear correlation and partial correlation (Table 2). The multicollinearity diagnoses in the phenotypic correlation matrices (r_f) among the explanatory traits PH, SD, HD, TAW and NAH presented a condition index of 9.64, which is considered low according to the criteria of Montgomery and Peck (1982). Therefore, we can infer that the path analyzes of yield of achenes per head (YAH) as a function of the explanatory variables PH, SD, HD, TAW and NAH were performed in an experiment with adequate condition.

Table 2. Pearson (above diagonal) and partial (below diagonal) correlation matrices among traits of eight sunflower cultivars (*Helianthus annuus* L.) measured in 256 plants (32 plants per cultivar)

Trait	PH	SD	HD	TAW	NAH	YAH
PH	1	0.3302*	0.0448^{ns}	-0.1697*	0.2073*	0.0893^{ns}
SD	0.3545*	1	0.5210*	-0.0628^{ns}	0.3825*	0.3051*
HD	-0.2130*	0.4173*	1	-0.0061^{ns}	0.6110*	0.5753*
TAW	-0.1551*	0.0670^{ns}	0.1023^{ns}	1	-0.4439*	0.4308*
NAH	-0.0746^{ns}	0.0708^{ns}	0.2322*	-0.9306*	1	0.5774*
YAH	0.1476*	-0.0727^{ns}	0.0204^{ns}	0.9322*	0.9127*	1

Note. Traits: PH: plant height, in m; SD: stem diameter, in mm; HD: head diameter, in cm; TAW: thousand achenes weight, in g; NAH: number of achenes per head (NAH = YAH × 1000/TAW) and YAH: yield of achenes per head, in g $plant^{-1}$.

* Significant at 5% probability level by Student's t-test with 254 degrees of freedom. ^{ns}: Non-significant.

The dispersion graphs among traits of eight sunflower cultivars evaluated in 256 plants (Figure 3) indicate a moderate classified linear relation between the traits YAH and HD (r = 0.5753), YAH and NAH (r = 0.5774) and NAH and HD (r = 0.6110). Moreoer, in addition to the correlation magnitude it is important to identify the direction of the same. These relations where highlighted as they are associated with more productive plants. However, inferences on which of the traits (PH, SD, HD, TAW, NAH) has a direct effect on the productivity of achenes were not possible to be performed only through the correlation coefficients.

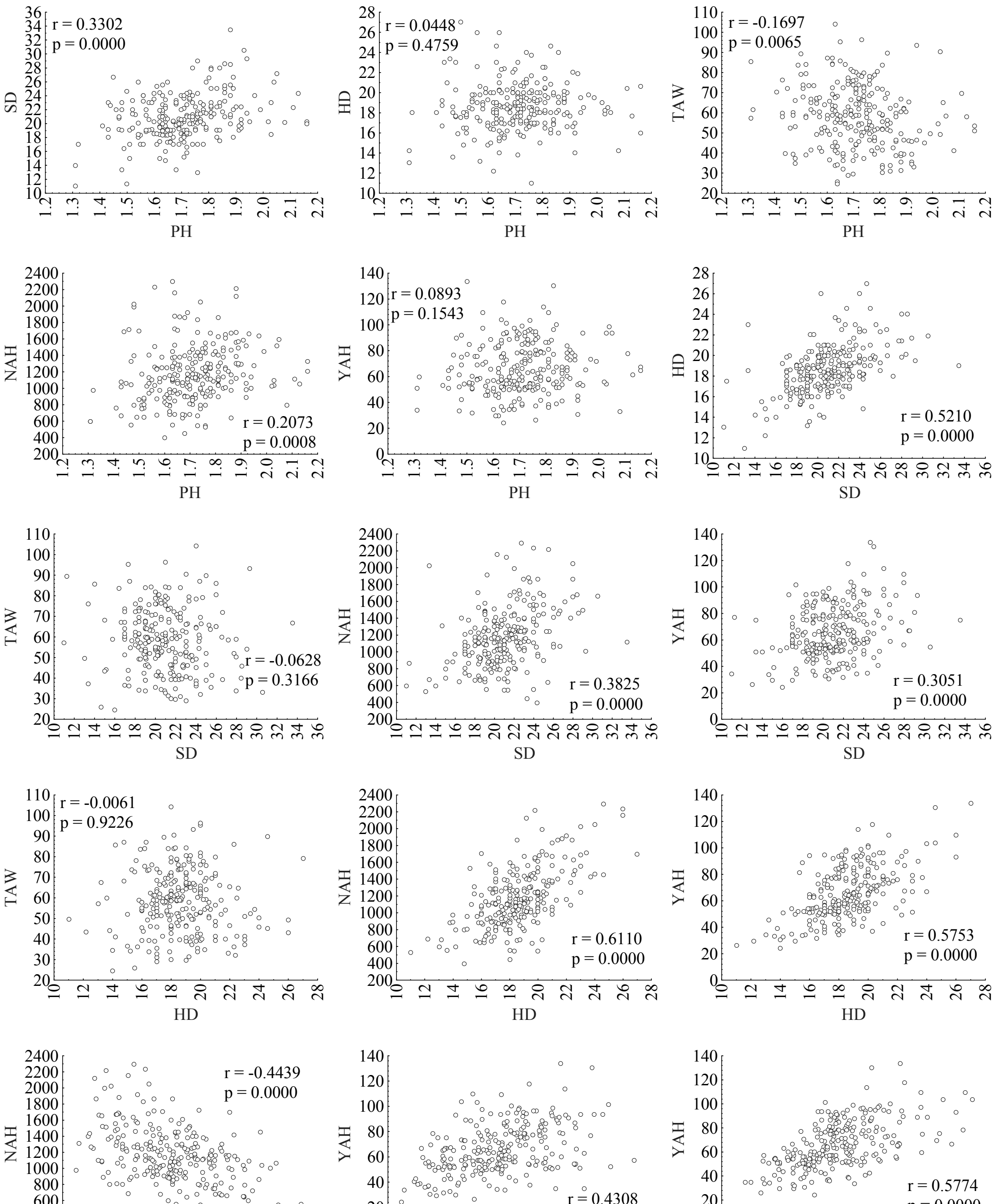

Figure 3. Dispersion of traits in eight sunflower (*Helianthus annuus* L.) cultivars measured in 256 plants (32 plants per cultivar), Pearson's correlation coefficient and p-value of Student's t-test with 254 degrees of freedom. Traits: PH: plant height, in m; SD: stem diameter, in mm; HD: head diameter, in cm; TAW: thousand achenes weight, in g; NAH: number of achenes per head (NAH = YAH × 1000/TAW); and YAH: productivity of achenes, in g plant^{-1}

Based on the path analysis, the traits TAW and NAH exhibited direct positive and high magnitude effects (0.8606 and 0.9545, respectively) on YAH (Table 3), demonstrating that indirect selection for grain yield using these traits is promising. Studies on sunflower path analysis in other growing sites also indicated a positive direct effect on YAH related to TAW (Yasin & Singh, 2010) and NAH (Yasin & Singh, 2010; Darvishzadeh et al., 2011;

Tyagi et al., 2013, Rigon et al., 2013, Chambó et al., 2017). The traits PH, SD and HD exhibited low direct effects on YAH.

Table 3. Direct and indirect effects in path analysis based on the Pearson's correlation matrix coefficient of determination, effect of residual variable and condition index of traits of eight sunflower cultivars (*Helianthus annuus* L.) measured in 256 plants (32 plants per cultivar)

Effects	PH	SD	HD	TAW	NAH
Direct effect on YAH	0.0454	-0.0254	0.0085	0.8606	0.9545
Indirect effect via PH		0.0150	0.0020	-0.0077	0.0094
Indirect effect via SD	-0.0084		-0.0132	0.0016	-0.0097
Indirect effect via HD	0.0004	0.0044		-0.0001	0.0052
Indirect effect via TAW	-0.1461	-0.0541	-0.0052		-0.3820
Indirect effect via NAH	0.1979	0.3651	0.5832	-0.4237	
Total	0.0893^{ns}	0.3051*	0.5753*	0.4308*	0.5774*
Coefficient of determination	0.9231				
Effect of residual variable	0.2773				
Condition index	9.64				

Note. Traits: PH: plant height, in m; SD: stem diameter, in mm; HD: head diameter, in cm; TAW: thousand achenes weight, in g; NAH: number of achenes per head (NAH = YAH × 1000/TAW) and YAH: yield of achenes per head, in g plant^{-1}.

* Significant at 5% probability level by Student's t-test with 254 degrees of freedom. ^{ns}: Non-significant.

The HD trait had no direct effect on achenes yield, with the indirect effect via NAH (0.5832) being the main responsible for the linear correlation between HD and YAH. This indicates that plants with greater head diameter produce a greater number of achenes, contributing to the increased achenes yield. Thus, HD can be used in indirect selection of more productive cultivars in subtropical environment with lower elevations. Furthermore, HD has greater ease of measurement in a non-destructive assessment in comparison to TAW and NAH. Studies in other cropping environments also corroborate with this result, indicating the relation between HD and YAH (Yasin & Singh, 2010; Darvishzadeh et al., 2011; Hassan et al., 2013; Tyagi & Khan, 2013; Chambó et al., 2017).

Indirect effect of NAH on TAW (-0.4237) was observed and it indicates that higher NAH implies lower TAW. Moreover, positioning cultivars with higher achene number is not always related with higher achene yield. Therefore, the NAH is not indicated as a single parameter to increase selection efficiency of more productive cultivars. Chambó et al. (2017) also found a negative relation between these traits and corroborated results observed in our study. Meanwhile, other studies have not observed this negative relation (Tyagi & Khan, 2013; Rigon et al., 2014), indicating the importance of these assessments under specific environmental conditions.

4. Conclusion

The traits thousand achenes weight and number of achenes per head present direct effect on achenes yield based on agronomic performance and path analysis of sunflower grown in subtropical region at lower elevations. The head diameter does not present direct effect on achenes yield but it has direct effect on the number of achenes per head, indicating cause-effect relation and becoming an important alternative for indirect selection of sunflower cultivars.

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