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Correlation and path analysis of yield and related traits in sunflower (*Helianthus annuus* L.) Under normal and drought stress conditions

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In order to investigate the correlation and path analysis of yield and related traits in sunflower under normal and drought stress conditions, twelve sunflower genotypes were evaluated using a randomized complete block design with three replications. Fifteen different agronomic traits were measured for analyses. The results showed in the normal irrigation condition, seed number per head and head diameter were significantly correlated with seed yield, respectively, while the strongest significant correlation of oil yield were observed with seed yield, seed number per head and head diameter. In the drought stress condition, as same as normal-irrigated, seed number per head and head diameter were significantly correlated with seed and oil yield, respectively. Path coefficient analysis revealed that seed number per head and 1000-seed weight have shown considerable positive direct effects on seed yield, while seed number per head and 1000-seed weight and oil content had positive direct effects on oil yield. In the drought stress condition, as same as normal-irrigated, seed number per head and 1000-seed weight had significantly positive direct effect on seed yield. It is concluded that these seed number per head and 1000-seed weight characters may be good selection criteria to improve the seed and oil yield of sunflower in both normal and drought stress conditions.

Keywords: Correlation, direct effect, drought stress, path analysis, sunflower

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops in semi-arid environments grown as edible oil, after soybean, rapeseed and peanut (Putt, 1997; Razi and Assad 1999; Roshdi et al., 2005; Hu et al., 2010). Sunflower breeding programs in Iran focuses on producing new hybrids and introducing high yield open-pollinated and hybrids from abroad (Zeinalzadeh-Tabrizi, 2011; Tabrizi, 2012).

Due to the increasing population, the majority of country edible oil requirements are met via imports. It has great ability to meet domestic needs of the country (Darvishzadeh et al., 2011). To reach this purpose, selection of superior and high yielding sunflower varieties is very important. The success of selection depends on the choice of selection criteria for improving seed yield (Samonte et al., 1998). Seed yield in sunflower is a quantitative character and dependent on its own component characters (Arshad et al., 2007). Plant breeders commonly prefer yield components that indirectly increase yield. Indirect selection of yield components such as 1000-seed weight, plant height, and head diameter can increase grain yield. Therefore, it is important to know the relationships among yield traits in sunflower to get higher yields (Kaya et al., 2007). Simple correlation analysis does not depict the clear picture of mutual relationships among the plant traits (Habib et al., 2007). Selections based on simple correlation only without considering interactions among yield components may mislead the breeders to reach their main breeding goals (Kaya et al., 2009).

The path coefficient analysis being a more precise method partitions the direct and indirect effects of independent variables on the dependent variable. Therefore, the path analysis explains the clear impact of independent variables on the dependent one. This method has been extensively used by the sunflower researchers (Singh and Labana, 1990; Marinković, 1992; Mogali and Virupakshappa, 1994; Teklewold et al., 2000; Sujalha and Nandini, 2002; Tahir et al. 2002; Arshad et al., 2007; Habib et al., 2007; Kaya et al., 2007; Machikowa and Saetang, 2008; Ilahi et al., 2009; Yasin and Singh, 2010; Darvishzadeh et al., 2011; Kholghi et al., 2011; Pandya et al., 2016).

Drought stress is the most important limiting factor for crop production in the world (Passioura, 1996; Passioura, 2007; Rauf, 2008). One of the main problems in breeding plant genotypes resistant to water deficit in semi-arid areas is the understanding of interrelationships between plant characters in optimal and stress conditions (Razi and Assad, 1999). Sunflower is classified as a low to medium drought sensitive crop (Mudassar et al., 2009). Its distribution and production is greatly influenced by drought (Fereres et al., 1986; Rauf, 2008). Drought stress affects every developmental stage of sunflower (Mudassar et al., 2009). However, progress in drought tolerance breeding is slow due to inappropriate selection criteria and faulty breeding strategies (Rauf, 2008). Therefore, finding appropriate selection criteria to assess correlated effects of various traits on seed and oil yield under drought stress conditions in very important.

The objectives of this study were i) to investigate the correlation coefficients of seed and oil yield with related traits in sunflower genotypes ii) to find out direct and indirect effects of agronomic traits on seed and oil yield of sunflower genotypes by path analysis in both normal-irrigated and drought stress conditions.

MATERIALS AND METHODS

Plant material and experimental design

Seeds of twelve sunflower genotypes (Table 1) were sown in a randomized complete block design (RCBD) with three replications in both normal and limited irrigation conditions. The experiment was conducted in Agricultural and Natural Resources Research Station of Khoy, Iran (44° 58´ N, 38° 33´ E) with 1100 m altitude during crop season 2004. The minimum, average and maximum annual temperature of this station were -30, 12.5 and 42°C, respectively and the average annual rainfall was 292.6 mm during the experiment.

Each plot of the experiment consisted of four 5 m rows with spacing 60 cm between rows and 20 cm between hills. Each hill was planted with 3-4 seeds and thinned to one seedling per hill 14 days after germination. First irrigation was applied immediately after sowing. Weed control was done manually. Next irrigation was applied 14 days after sowing for both fields to well establish of the genotypes.

Table 1. List of sunflower genotypes used in this study

No.	Type	Genotype name	Origin
1	Open-pollinated	Record	Romania
2	Open-pollinated	Armavirsky	Russia
3	Hybrid	Hysun33	Australia
4	Hybrid	Euroflor	France
5	Hybrid	Allstar	France
6	Hybrid	Azargol	Iran
7	Hybrid	$R_{43} \times F_{1/21}$	Iran*
8	Hybrid	$R_{95} \times F_{1/9}$	Iran*
9	Hybrid	$R_{95} \times F_{1/19}$	Iran*
10	Hybrid	$R_{95} \times F_{1/23}$	Iran*
11	Hybrid	$R_{256} \times F_{1/6}$	Iran*
12	Hybrid	$R_{256} \times F_{1/14}$	Iran*

* Three-way-cross hybrids developed in National Sunflower Breeding Program, West Azarbaijan Agricultural and Natural Resources Research Station, AREEO, Khoy, Iran

Nitrogen fertilizer was applied in the form of urea (based on 200 kg/ha) before the second irrigation. Subsequent irrigation intervals were 7 days for normal field (regarding local farmers' practices) and 21 days for drought stress field. Totally, normal field was irrigated 10 times, while limited field was irrigated 4 times during the experiment. Therefore, drought stress for limited irrigation field was implemented by long irrigation intervals. In order to prevent bird's damage, all heads were covered by paper coverage at the end of physiological maturity stage, R9 (Schneiter and Miller, 1981).

Measurement of traits

Samples of 15 sunflower genotypes after omitting marginal effects were taken randomly. Different agronomic traits were measured such as: budding initiation (BI), flowering initiation (FI), flowering completion (FC), flowering period (FP), seed filling period (SFP), maturity (MA), plant height (PH), leaf number (LN), leaf area index (LAI), head diameter (HD), stem diameter (SD), number of seeds per head (SPH), 1000-seed weight (SW), kernel/hull ratio (KHR), oil content (OC), seed yield (SY) and oil yield (OY).

Statistical analysis

Outlier detection and normality of the data was performed by Grubbs' test and Kolmogorov-Smirnov test using Statgraphics (Statgraphics Centurión, 2006) computer package. Linear regression analysis assumptions were verified by Z score transformation of predictors and log transformation of dependent variables (seed and oil yield) to avoid multi collinearity and variance infiltration factor (VIF). The path analysis was done by using only the relevant independent variables identified by the stepwise multiple regression analysis. Statistical analyses were done using SPSS version 19.0 (Spss, 2010) computer package.

RESULTS AND DISCUSSION

Normal Irrigation

In the normal irrigation condition, seed number per head (r=0.966**) and head diameter (r=0.912**) were highly and significantly correlated with seed yield, respectively, while the strongest significant correlation of oil yield was observed with seed yield (r=0.900**), seed number per head (r=0.881**) and head diameter (r=0.834**) (Table 4). This is in agreement with the findings of (Mogali and Virupakshappa, 1994; Razi and Assad, 1999; Machikowa and Saetang, 2008; Kaya et al., 2009; Darvishzadeh et al., 2011; Kholghi et al., 2011).

Significant and positive correlations between seed and oil yield with seed number per head point that it might be explained by the pleiotropic effect of a single gene; physical linkage among multiple genes (Burke et al., 2002; Darvishzadeh et al., 2011) or the genetic association among the characters (Habib et al., 2007). Pleiotropic effects, which are the main causes for correlations among traits were reported by Aastveit and Aastveit (1993) and Falconer et al., (1996).

Table 2. Direct and indirect effects of different agronomic traits of sunflower on seed yield in normal irrigation condition

Variable	Direct effect	Indirect effect		Correlation Coefficient
		SPH	SW	
SPH	0.777**	-	0.502	0.966**
SW	0.293**	0.189	-	0.795**
Residual effect 0.141				

Adjusted R^2=0.980

Table 3. Direct and indirect effects of different agronomic traits of sunflower on oil yield in normal irrigation condition

Variable	Direct effect	Indirect effect			Correlation Coefficient
		SPH	OC	SW	
SPH	0.898**	-	-0.507	0.580	0.881**
OC	0.434**	-0.245	-	-0.164	-0.208
SW	0.353**	0.228	-0.134	-	0.769**
Residual effect 0.195					

Adjusted R^2=0.962

Table 4. Correlation coefficients among different agronomic traits of sunflower in normal irrigation condition

	BI	FI	FC	FP	SFP	MA	PH	LN	LAI	HD	SD	SPH	SW	KHR	OC	SY	OY
BI	1																
FI	0.955**	1															
FC	0.920**	0.961**	1														
FP	-0.627*	-0.662*	-0.429	1													
SFP	-0.035	-0.035	-0.077	-0.092	1												
MA	0.834**	0.877**	0.895**	-0.437	0.375	1											
PH	0.767**	0.738**	0.801**	-0.239	0.137	0.800**	1										
LN	0.223	0.230	0.193	-0.230	-0.248	0.070	0.267	1									
LAI	0.754**	0.723**	0.670*	-0.549	0.002	0.618*	0.571	0.365	1								
HD	0.498	0.530	0.434	-0.555	0.224	0.506	0.261	0.219	0.861**	1							
SD	0.738**	0.807**	0.712**	-0.707*	0.010	0.667*	0.370	0.114	0.852**	0.833**	1						
SPH	0.512	0.490	0.419	-0.465	0.280	0.516	0.372	0.284	0.879**	0.956**	0.737**	1					
SW	0.424	0.374	0.291	-0.434	0.810**	0.628*	0.404	-0.026	0.479	0.550	0.448	0.646*	1				
KHR	0.322	0.287	0.327	-0.053	-0.567	0.049	0.212	0.384	0.029	-0.224	-0.075	-0.241	-0.495	1			
OC	-0.768**	-0.814**	-0.862**	0.323	-0.056	-0.825**	-0.882**	-0.437	-0.746**	-0.517	-0.604*	-0.565	-0.379	-0.258	1		
SY	0.568	0.536	0.453	-0.522	0.457	0.624*	0.467	0.215	0.835**	0.912**	0.712**	0.966**	0.795**	-0.310	-0.587*	1	
OY	0.289	0.243	0.114	-0.486	0.519	0.339	0.128	0.029	0.641*	0.834**	0.576	0.881**	0.769**	-0.543	-0.208	0.900**	1

Where * significant at $P<0.05$ and ** significant at $P<0.01$, BI=budding initiation, FI=flowering initiation, FC=flowering completion, FP=flowering period, SFP=seed filling period, MA=maturity, PH=plant height, LN=leaf number, LAI=leaf area index, HD=head diameter, SD=stem diameter, SPH=number of seeds per head, SW=1000-seed weight, KHR=kernel/hull ratio, OC=oil content, SY=seed yield and OY=oil yield.

Table 5. Direct and indirect effects of different agronomic traits of sunflower on seed yield in drought stress condition

Variable	Direct effect	Indirect effect			Correlation Coefficient
		SPH	SW	LAI	
SPH	0.887**	-	0.090	-0.014	0.962**
SW	0.281**	0.283	-	-0.087	0.477
LAI	-0.170*	0.072	0.143	-	0.045
Residual effect 0.167					

Adjusted R^2=0.972

Table 6. Direct and indirect effects of different agronomic traits of sunflower on seed yield in drought stress condition

Variable	Direct effect	Indirect effect	Correlation Coefficient
		-	
SPH	0.959**	-	0.959**
Residual effect 0.298			

Adjusted R^2=0.911

In the next step, some other studied traits including 1000-seed weight (r=0.795**, r=0.769**) and leaf area index (r=0.835**, r=0.641**) showed significant positive correlations with seed and oil yield, respectively (Table 4). Razi and Assad (1999) reported that head diameter is the most important yield component in sunflower under well-watered conditions. Head diameter had considerable effect on seed yield in the(Ahmad et al., 1991); (Mogali and Virupakshappa 1994) and Darvishzadeh et al., (2011) studies.

Path coefficient analysis is a suitable statistical technique that separates the phenotypic correlation coefficients into its direct and indirect effects via regression analysis, so that the contribution of each trait to seed and oil yield could be estimated. Results revealed that traits including seed number per head (β=0.777**) and 1000-seed weight (β=0.293**) had positive direct effects on seed yield (Table 2), while seed number per head (β=0.898**) and 1000-seed weight (β=0.353**) and oil content (β=0.434**) had positive direct effects on oil yield in normal irrigation conditions (Table 3). Despite the non-significant negative correlation of oil content with oil yield, direct effect of oil content and oil yield was positively significant. Negative indirect effect of oil content with seed number per head and 1000-seed weight revealed that identifying a trait as an indirect selection criterion based only on positive direct effect and disregarding the nature and magnitude of correlation of that trait with oil yield would be misleading (Das and Taliaferro, 2009; Darvishzadeh et al., 2011).

Results exhibiting highly significant and positive direct effect of seed number per head and 1000-seed weight on seed yield as obtained in the present investigation were reported by Ahmad et al., (1991) for plant height, days to physiological maturity and oil content; Marinković (1992) for 1000-seed weight and number of seed per head; Arshad et al., (2007) for days to flowering initiation, plant height and head diameter; Machikowa and Saetang (2008) for head diameter and plant height; Ilahi et al., (2009) for internodal length, stem diameter at base and head diameter; Kaya et al., (2009) for seed volume, high oil content, plant height, head diameter, and husk contents; Yasin and Singh (2010) and Kholghi et al., (2011) for number of seeds per head, 1000-seed weight and head diameter and Darvishzadeh et al., (2011) for head diameter and number of achene per head. In Habib et al., (2007) study, genotypic path analysis revealed that days to flower completion, days to maturity and oil content had positive direct effect on oil yield whereas days to flower initiation, flowering period and plant height has negative direct effects on oil yield. According to the results, flowering period (r=-0.486) exhibited negative and non-significant correlation with oil yield (Table 4). Habib et al., (2007) also reported similar results in their respective study. It is evident from this association that decrease in flowering period may increase oil yield ultimately.

Drought stress

In the drought stress condition as same as normal-irrigated, seed number per head (r=0.962**, r=0.959**) and head diameter (r=0.812**, r=0.781**) were highly and significantly correlated with seed and oil yield, respectively (Table 7).

Table 7. Correlation coefficients among different agronomic traits of sunflower in drought stress condition

	BI	FI	FC	FP	SFP	MA	PH	LN	LAI	HD	SD	SPH	SW	KHR	OC	SY	OY
BI	1																
FI	0.891**	1															
FC	0.794**	0.894**	1														
FP	-0.355	-0.391	0.062	1													
SFP	0.321	0.377	0.122	-0.591*	1												
MA	0.813**	0.917**	0.876**	-0.242	0.583*	1											
PH	0.133	0.303	0.192	-0.282	0.319	0.310	1										
LN	0.514	0.633*	0.486	-0.413	-0.102	0.358	0.161	1									
LAI	0.319	0.144	-0.003	-0.330	0.516	0.255	-0.203	0.077	1								
HD	0.356	0.376	0.074	-0.686*	0.767**	0.434	0.485	0.238	0.511	1							
SD	0.116	0.032	-0.006	-0.084	0.719**	0.352	0.255	-0.350	0.457	0.605*	1						
SPH	0.041	0.199	-0.105	-0.661*	0.520	0.154	0.677*	0.222	0.081	0.812**	0.286	1					
SW	-0.025	-0.110	-0.108	0.023	0.529	0.176	0.238	-0.325	0.510	0.628*	0.876**	0.319	1				
KHR	0.598*	0.519	0.724**	0.332	-0.109	0.548	-0.316	0.159	0.121	-0.349	-0.143	-0.693*	-0.212	1			
OC	-0.372	-0.455	-0.594*	-0.207	-0.062	-0.519	-0.133	-0.367	-0.113	-0.140	-0.187	0.025	-0.268	-0.320	1		
SY	-0.033	0.126	-0.124	-0.538	0.497	0.131	0.656*	0.129	0.045	0.812**	0.407	0.962**	0.477	-0.705*	-0.025	1	
OY	-0.089	0.073	-0.191	-0.557	0.482	0.068	0.618*	0.092	0.021	0.781**	0.369	0.959**	0.423	-0.741**	0.106	0.990**	1

Where * significant at $P<0.05$ and ** significant at $P<0.01$, BI=budding initiation, FI=flowering initiation, FC=flowering completion, FP=flowering period, SFP=seed filling period, MA=maturity, PH=plant height, LN=leaf number, LAI=leaf area index, HD=head diameter, SD=stem diameter, SPH=number of seeds per head, SW=1000-seed weight, KHR=kernel/hull ratio, OC=oil content, SY=seed yield and OY=oil yield.

Darvishzadeh et al., (2011) reported that in both well-watered and water-stress conditions, head diameter had the highest significant positive correlation with seed yield. In this way, screening for high head diameter may bring increase in sunflower seed yield under water-stressed condition.

According to path analysis, as same as normal-irrigated, seed number per head (β=0.887**) and 1000-seed weight (β=0.281**) had significantly positive direct effect on seed yield, while leaf area index (β=-0.170*) had negative significant direct effect on seed yield (Table 5). Correlations of leaf area index with seed and oil yield in normal (r=0.835**, r=0.641*) and water stress conditions (r=0.045, r=0.021) were positively significant and non-significant, respectively (Table 7).

Pandya et al., (2016) reported a positive significant correlation of leaf area index with seed yield for the first year of their experiment, while the value for the second year was negative significant correlation. According to their path analysis, a negative but low direct effect of leaf area at flowering was observed on seed yield. Leaves are the food manufacturing factories of the plant and the greater number of leaves ensured the better crop yield due to higher photosynthetic capacity by increasing LAI (Darvishzadeh et al., 2011).

(Fereres et al., 1986) found that sunflower leaf surface rapidly decreases by the effect of drought stress and thereby causes a negative effect on seed yield. Yegappan et al., (1982) stated that drought stress caused aging leaves, reduced leaf number, diameter, leaf area index and yield of sunflower. The moderately low negative direct effect of leaf area index on seed yield was compensated by the highly positive indirect effects seed number per head (0.072) and 1000-seed weight (0.143), respectively (Table 5). In order to identify a trait as an indirect selection criterion for seed yield through path coefficient, the trait should have positive direct effect on seed yield as well as significant positive correlation with seed yield (Das et al., 2009).

Oil content had negative significant correlation with seed yield and negative non-significant correlation with oil yield in normal irrigation condition. Correlation coefficients of oil content with seed and oil yield in drought stress condition was same as normal irrigation but non-significant. Mudassar et al., (2009) reported positive and non-significant correlation of oil contents with achene yield under drought conditions. But Ashok et al., (2000), Teklewold et al., (2000) reported positive and significant.

Seed number per head only had significant direct positive effect (β=0.959**) on oil yield in drought stress condition. In Mudassar et al., (2009) study, path analysis based on oil content as dependent variable revealed that number of leaves, total leaf area, stem diameter and achene yield exerted positive direct effects on the oil contents being stem diameter at the top of the list. Stem diameter exposed the highest indirect positive effects on oil contents through head diameter, whorls per head and fertile whorls per head. These studies revealed that the selection of traits positively associated with oil contents and having positive direct and indirect effects on it could be an efficient selection criterion for oil contents in sunflower under waters stress conditions. (Darvishzadeh et al., 2011) concluded that selection based on head diameter, number of achene and chlorophyll content would be more effective to improving seed yield of sunflower in water-stress conditions. The positive association among various traits gave a free hand to the sunflower breeders to select these traits simultaneously especially under water stress conditions (Mudassar et al., 2009).

CONCLUSION

Seed number per head and 1000-seed weight have shown considerable positive direct effects on seed yield, while seed number per head and 1000-seed weight and oil content had positive direct effects on oil yield in normal irrigation conditions. In the drought stress condition, as same as normal-irrigated, seed number per head and 1000-seed weight had significantly positive direct effect on seed yield, while leaf area index had negative significant direct effect on seed yield. About oil yield, seed number per head had only significantly direct positive effect on oil yield in drought stress condition. Positive association of seed and oil yield with other characters along with their direct and indirect effects is vital and must be identified and explored by the sunflower breeders with special reference to drought stress conditions. It is concluded that seed number per head and 1000-seed weight characters may be good selection criteria to improve the seed and oil yield of sunflower in both normal and drought stress conditions.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

HZT designed and performed the experiment. MG provided the plant materials and helped for statistical analysis. HZT and AH wrote and reviewed the manuscript. All authors read and approved the final version.

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