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BREEDING SUNFLOWER FOR SALT TOLERANCE: PATH COEFFICIENT ANALYSIS FOR ACHENE YIELD IN SUNFLOWER (*Helianthus annuus* L.) UNDER NORMAL AND SALINE CONDITIONS

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ABSTRACT

Path coefficient analysis study was conducted under normal (EC_e 1.76 dSm^{-1}) and saline conditions (EC_e 15.30 dSm^{-1}) on four sunflower inbred lines and their possible single crosses excluding reciprocals. Path coefficient analysis revealed that head diameter followed by 100-achene weight, made the highest direct contribution to achene yield under normal conditions. Head diameter followed by K^+ concentration in young growing leaves showed highest direct effect on achene yield under saline conditions. Therefore, it is suggested that selection criteria would be different under normal and saline conditions to improve achene yield. Selection could be based on genotypes having large head diameter and higher 100-achene weight, under normal conditions, whereas, on large head diameter and high K^+ concentration imposing restriction on Na^+ concentration in young growing leaves, under saline conditions.

Key words: Path analysis, *Helianthus annuus* L., saline conditions, field experiment, selection criteria, salt tolerance.

INTRODUCTION

The menace of soil salinity is among the leading soil problems in irrigated agriculture throughout the world. It limits crop production seriously on 20 million hectares of the world's cultivated land (El-Ashry et al., 1985). In Pakistan about 6.3 million hectares, including about 18.4% of the country's canal-commanded area, is salt-affected (anonymous, 1989), still another 1.20 million ha of salt-affected area exists in patches (Chaudhri et al., 1978). This problem is on increase in Pakistan as 0.2 to 0.4% of the total cultureable land is being put out of cultivation each year due to salinity and waterlogging (Qureshi, 1978).

Saline soils contain a sufficient amount of salts to impair the growth of plants (Ponnamperuma and Bandyopadhya, 1980). Salinity of the root medium caused by NaCl interferes with the absorption and translocation of K^+ and Ca^{2+} by plants (Kuiper, 1984). Some toxic ions are also required for stimulating the growth of various species especially halophytes (Storey and Wyn Jones, 1979) but the range between beneficial and

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toxic concentrations is very narrow for most plants. Growth may be checked by metabolic limitations caused by ion toxicity due to the accumulation of Na^+ and Cl^- used for osmotic adjustment. In sunflower leaves, Cl^- and Na^+ concentration was increased while K^+ concentration was decreased under salinity (Cheng, 1984), whereas, it was also reported that sunflower was the ability to maintain Na^+ at lower level in young growing leaves under salinity (Hussain and Rehman, 1993). Low Na^+ concentration and a higher K^+/Na^+ ratio in young growing leaves of salt tolerant lines was also reported (Hussain and Rehman, 1984). Soil salinity reduced plant height, leaf number, and leaf area in sunflower (Girdhar, 1988; Rehman and Hussain, 1992). It delayed flowering in sunflower (Bhatti et al., 1978; Rehman and Hussain, 1992) but physiological maturity was comparatively less affected (Rehman and Hussain, 1992). Increasing level of salinity reduced 100-seed weight, disk diameter (Farah et al., 1980; Hussain and Rehman, 1992) and oil content (Muhammed and Makhdum, 1973; Hussain and Rehman, 1992). In sunflower, seed yield has been found to start decreasing beyond EC_e 2.5 dSm^{-1} and to reach to 30% losses at EC_e 11.3 dSm^{-1} (anonymous, 1992), but 49.21% seed yield losses at EC_e 10 dSm^{-1} have also been reported (Hussain and Rehman, 1992). Several traits affected achene yield in sunflower as plant height (Giriraj et al., 1979), days to flowering (Chaudhry and Anand, 1985), days to maturity (Mishra et al., 1985), number of leaves (Tanimu and Ado, 1989), head diameter (Giriraj et al., 1979; Velkov, 1980; Singh et al., 1985), seed filling percentage (Singh et al., 1985), and 100-achene weight (Singh et al., 1985; Carrasco et al., 1986).

The study of path coefficient analysis is important to develop cultivars in which various traits are combined to yield maximum benefit. Most of such studies relate to optimum soil conditions and no such information is available for sub-optimal conditions created by salt stressed environments because different genetic and physiological mechanism operate under these environments. Development of salt tolerant cultivars in sunflower thus require the study of various plant traits contributing towards salt tolerance. The present research studies on path coefficient analysis were conducted to observe the effect of yield contributing characters on yield under normal and saline conditions. It will also provide a selection criteria for salt tolerance in sunflower.

MATERIALS AND METHODS

The experimental material comprised of four inbred lines and their six possible single crosses (excluding reciprocals). These inbred lines had been developed from open pollinated Russian and Romanian cultivars and from segregating populations of commercial hybrids from the U.S.A. after six years of selfing and then alternate sibbing. The breeding material was:

1. GIMSUN-856	6. GIMSUN-856 X - 456
2. GIMSUN-603	7. GIMSUN-856 X - 198
3. GIMSUN-457	8. GIMSUN-603 X - 456
4. GIMSUN-198	9. GIMSUN-603 X - 198
5. GIMSUN-856 X - 603	10. GIMSUN-456 X - 198

The above listed material were used in path coefficient analysis for salt tolerance using a randomized complete block design with three replications in two independent experiments at the same time, season and year under two soil conditions differing in salinity levels i.e., normal and saline soil.

Experiment 1. The first experiment was conduced at an aggregate EC_e of 1.76 dSm^{-1}. The experimental unit comprised of 4.5 meter long double row with 60 and 30 cm row-to-row, and plant-to-plant distance, respectively. In total five irrigations were applied throughout the experiment with irrigation water of EC_e 0.21 dSm^{-1}. Nitrogen and phosphorous fertilizers were added in amounts equivalent to 86 and 62 kg ha^{-1}, respectively (Chaudhry, 1985). The phosphorous fertilizer was applied at the time of planting, while a half of the nitrogenous fertilizer was applied at planting and the rest at flowering.

Experiment 2. The second experiment was conducted under saline conditions in field where EC_e was ranging form 14.75 to 15. 85 dSm^{-1} with an aggregate of 15.30 dSm^{-1} (average of 50 soil samples mixed from top layer to 45 cm deep). Records of EC_e in dSm^{-1}, determined during experiment at different intervals are given in Apendix 1. All other agronomic and cultural operations like irrigation, nutrient application, hoeing, hilling, etc., were kept similar in the two experimental fields within the same location.

Data were recorded on twenty randomly selected guarded plants from each entry and replications in both experiments on the following parameters.

1. Days to flowering
2. Leaf area (cm^2)
3. Plant height (cm)
4. Head diameter (cm)
5. Achene setting percentage
6. 100 achene weight (g)
7. Achene Yield (g)
8. Oil content (%)
9. Cl^- (mol m^{-3}) conc. in leaves
10. Na^+ (ppm) concentration in leaves
11. K^+ (ppm) concentration in leaves.

In both experiments flowers were allowed to open pollinate and than achene setting (%) as well as achene yield was recorded and difference in achene setting (%) was actually created by difference in soil conditions. Therefore, no difference was created by self-incompatibility or compatibility system in sunflower.

The data thus collected were subjected to analysis of covariance (Stell and Torrie, 1980), genotypic correlation coefficient (Kwon and Torrie, 1964), and path coefficient analysis using genotypic correlations (Dewey and Lu, 1959), with seed yield contributing traits as casual variables.

RESULTS AND DISCUSSION

Path coefficient is simply a standardized partial regression coefficient and as such measures the direct and indirect influence of one variable upon another and permits the separation of correlation coefficient into direct and indirect effects. This helps in choosing the plant traits useful for manipulation in breeding program. In this study of path coefficient analysis, eleven plant traits of sunflower were included keeping achene yield as resultant variable. Path coefficient was calculated under normal and saline conditions to study the relative effect of various yield components on achene yield.

Table 1. Direct (in parenthesis) and indirect matrix in sunflower under normal conditions (Dependent variable is seed yield per plant).

Trait	Days to flower	Leaf area (cm^2)	Plant height (cm)	Head diameter (cm)	Achene setting (%)	100-achene weight (g)	Oil content (%)	Cl^- conc. (mol m^{-3})	Na^+ conc. (ppm)	K^+ conc. (ppm)	r_g with achene yield
Days to flower	(+1.520)	-0.210	-0.315	-0.474	+0.145	-1.183	+0.175	+0.022	-0.056	-0.067	-0.443
Leaf area (cm^2)	+0.397	(-0.805)	-0.214	+0.515	-0.037	+0.489	-0.090	+0.188	-0.027	+0.161	+0.577
Plant height (cm)	+1.234	-0.443	(-0.388)	+0.145	+0.034	-0.560	-0.016	+0.141	-0.086	+0.085	+0.146
Head diameter (cm)	-0.673	-0.388	-0.053	(+1.070)	-0.148	+0.873	+0.077	+0.022	-0.059	+0.147	+0.868
Achene setting (%)	-1.256	-0.170	+0.075	+0.904	(-0.175)	+1.030	-0.222	+0.328	-0.034	+0.192	+0.671
100-achene weight (g)	-1.281	-0.281	+0.155	+0.665	-0.129	(+1.403)	-0.175	+0.089	+0.035	+0.080	+0.563
Oil content (%)	-0.801	-0.217	-0.019	-0.248	+0.117	+0.737	(-0.333)	+0.345	+0.181	+0.632	+0.159
Cl^- conc. (mol m^{-3})	+0.065	-0.292	-0.106	+0.045	-0.111	+0.241	-0.222	(+0.517	-0.001	+0.141	+0.276
Na^+ conc. (ppm)	+0.458	-0.119	-0.180	+0.344	-0.032	-0.268	+0.325	+0.003	(-0.185)	-0.322	+0.023
K^+ conc. (ppm)	-0.195	-0.250	-0.064	+0.303	-0.065	+0.216	-0.404	+0.140	+0.115	(+0.520)	+0.316

Table 2. Direct (in parenthesis) and indirect matrix in sunflower under saline conditions (Dependent variable is seed yield per plant).

Trait	Days to flower	Leaf area (cm^2)	Plant height (cm)	Head diameter (cm)	Achene setting (%)	100-achene weight (g)	Oil content (%)	Cl^- conc. (mol m^{-3})	Na^+ conc. (ppm)	K^+ conc. (ppm)	r_g with achene yield
Days to flower	(+0.319)	+0.161	+0.400	-0.701	-0.055	+0.078	-0.081	+0.022	-0.740	+0.489	-0.745
Leaf area (cm^2)	+0.346	(-0.149)	-0.753	+1.767	-0.095	-0.084	-0.634	-0.052	+1.698	-1.056	+0.990
Plant height (cm)	+0.198	-0.174	(-0.645)	+0.662	+0.024	-0.074	+0.090	+0.126	+0.908	-0.423	+0.692
Head diameter (cm)	+0.179	-0.210	-0.342	(+1.249)	+0.051	-0.106	-0.402	+0.120	+0.736	-0.443	+0.833
Achene setting (%)	+0.147	+0.118	-0.130	+0.573	(+0.119)	-0.108	-0.379	+0.074	-0.347	-0.111	+0.615
100-achene weight (g)	+0.198	-0.099	-0.383	+1.055	+0.103	(-0.125)	-0.188	+0.150	+0.409	-0.193	+0.927
Oil content (%)	-0.041	-0.149	+0.091	+0.791	+0.071	-0.037	(-0.634)	-0.094	+0.706	+0.408	+0.296
Cl^- conc. (mol m^{-3})	-0.021	+0.023	-0.239	+0.442	+0.026	-0.055	+0.175	(+0.340)	-0.454	+0.271	+0.508
Na^+ conc. (ppm)	+0.468	-0.179	-0.115	+0.635	+0.029	-0.036	+0.318	-0.110	(-0.289)	-0.715	+0.086
K^+ conc. (ppm)	-0.206	+0.207	-0.359	-0.729	-0.017	+0.032	+0.341	+0.122	-0.326	(+0.752)	-0.458

Experiment 1. Path analysis under normal soil conditions.

The results presented in Table 1 under normal soil conditions showed that days to flowering showed direct positive effects to achene yield. Negative effects were higher enough in magnitude to nullify the positive effects of days to flowering. Therefore, achene yield cannot be increased by selection for early flowering due to its high negative indirect effects. Leaf area showed negative direct effects on achene yield. Negative indirect effects were small in magnitude whereas high positive indirect effects were observed. Plant height showed negative direct effects on achene yield. Negative indirect effects were small in magnitude, whereas, high positive indirect effects were observed which were maximum through days to flowering.

Head diameter showed high positive direct effects on achene yield. Negative indirect effects were smaller in magnitude than positive indirect effects. Therefore, achene yield could be increased by selecting lines with larger head diameter under normal soil. Achene setting percentage showed negative direct effects on achene yield. Negative indirect effects were smaller in magnitude than positive indirect effects. Negative direct effects suggest that direct selection for achene setting percentage would be ineffective to increase achene yield under normal soil. 100-achene weight showed high positive direct effects to achene yield. Negative indirect effects were smaller in magnitude than positive direct effects. Positive direct effects suggest that direct selection for 100-achene weight would be effective to increase achene yield under normal soil. Oil content (%) showed negative direct effects on achene yield. Negative indirect effects were smaller in magnitude than positive indirect effects. Negative direct effects suggest that direct selection for oil content (%) would be ineffective to increase achene yield under normal soil.

Cl^- concentration in young growing leaves showed positive direct effects on achene yield. Negative indirect effects were smaller in magnitude than positive indirect effects. Na^+ concentration showed negative direct effects on achene yield. Negative indirect effects were comparatively smaller in magnitude than positive indirect effects. K^+ concentration showed positive direct effects on achene yield. Negative indirect effects were comparatively smaller in magnitude than positive indirect effects.

Experiment 2. Path analysis under saline conditions

The results presented in Table 2 under saline conditions showed that days to flowering showed negative direct effects on achene yield. Positive indirect effects were low in magnitude and did not make any significant contribution. Therefore, achene yield cannot be increased by selection for early flowering. Leaf area showed negative direct effects on achene yield. Positive indirect effects were higher in magnitude than negative indirect effects. Negative directs effect suggest that direct selection based on leaf area would be ineffective to increase achene yield under saline soil. Plant height showed negative direct effects on achene yield. Positive indirect effects were higher in magnitude than negative indirect effects. Negative direct effect suggest that selection based directly on plant height would be ineffective to increase achene yield under saline soils.

Head diameter showed high positive direct effects on achene yield. Positive indirect effects were higher in magnitude than negative indirect effects. Therefore, achene yield could be increased by selecting lines with larger head diameter under saline soil. Seed setting percentage showed small positive direct effects on achene yield. Positive indirect effects were higher in magnitude than negative indirect effects. Therefore, achene yield could be increased by selecting lines with higher seed setting under saline soil. 100-achene weight showed negative direct effects on achene yield. Positive indirect effects were higher in magnitude than negative indirect effects. Negative direct effect suggest that selection could not be based on 100-achene weight but it was contributing positively on achene yield through head diameter under saline conditions. Oil content (%) showed negative direct effects on achene yield. Positive indirect effects were higher in magnitude than negative indirect effects. Negative direct effect suggest that selection could not be based on oil content (%) but it was contributing positively on achene yield through head diameter under saline soil.

Cl^- concentration showed positive direct effects on achene yield. Positive indirect effects were higher in magnitude than negative indirect effects. Direct effect of Cl^- concentration were smaller under saline soil than under normal soil which suggest that contribution of Cl^- concentration on achene yield were reduced under saline soil. Na^+ concentration showed negative direct effects on achene yield. Positive indirect effects were comparatively higher in magnitude than negative indirect effects. K^+ concentration showed high positive direct effects on achene yield. Indirect negative effects were higher in magnitude than positive indirect effects. Direct effects of K^+ concentration on achene yield were positive under saline soil, therefore, it is suggested that achene yield could be increased through selection for high K^+ concentration under saline soil. Restriction should be imposed on high Na^+ concentration while selecting high K^+ concentration under saline soil.

Appendix 1. A record of electrical conductivities and pH with respective range values in parenthesis and SAR during experiment at different intervals.

Time of soil sampling/Stage of plant growth	EC_e in dSm^{-1}!	pH!	SAR!
1. Before seed planting	15.30 (14.75-15.85)	8.23 (7.98-8.35)	12.65
2. Flower initiation	15.25 (14.68-15.83)	8.19 (8.00-8.32)	12.67
3. Seed setting	15.22 (14.65-15.80)	8.15 (8.00-8.25)	12.75
4. Physiological maturity	15.23 (14.65-15.82)	8.18 (8.05-8.28)	12.78

! Averages of fifty (before seed planting) and then thirty (later growth stages) soil samples in each case.

CONCLUSIONS

The traits having correlation coefficient with achene yield almost equal to their direct effect explains the true relationship and a direct selection through this trait will be effective. If the correlation coefficient is positive, but the direct effect is negative or negligible, the indirect effects seems to be the cause of correlation. In such situations, indirect causal factors are to be considered simultaneously for selection. Similarly, correlation coefficient may be negative but the direct effect is positive and high. Under these circumstances, a restricted simultaneous selection model is to be followed, i.e., restrictions are to be imposed to nullify the undesirable indirect effects in order to make use of the direct effect (Singh and Kakar, 1977).

The results of experiment 1 under normal soil conditions revealed that days to flowering and 100-achene weight, followed by head diameter, had maximum positive directs effects indicating their maximum contribution on achene yield. Higher negative indirect effects in days to flowering making its correlation negative while correlation coefficient are positive and almost equal to the positive direct effects of achene weight and head diameter. It suggests that emphasis should be given to achene weight and head diameter to improve achene yield under normal soil.

The results discussed in experiment 2 conducted under saline soil conditions exhibited that head diameter followed by K^+ concentration in young growing leaves showed maximum direct positive effects under saline conditions. Direct positive effects were almost equal to the positive correlation coefficient in case of head diameter which reflects a true relationship between head diameter and achene yield. K^+ concentration showed negative correlation coefficient and high positive direct effects. Therefore, achene yield can be improved by selecting genotypes with large head diameter and high K^+ concentration in young growing leaves, whereas, restriction should be imposed on Na^+ concentration. Achene setting percentage showed positive correlation coefficient and small but positive direct effect which suggest that achene setting percentage may also be included in selection criteria for high achene yield under salt stressed conditions.

It is concluded from the present studies that connecting paths for all the parameters under study were different under normal and saline conditions. Selection criteria would therefore be different under normal and saline soils but head diameter was found important under both conditions.

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MEJORA DEL GIRASOL PARA TOLERANCIA A SALINIDAD; ANALISIS DE COEFICIENTES DE SENDERO PARA TOLERANCIA A SALINIDAD GIRASOL (*Helianthus annuus* L.)

RESUMEN

Un estudio de analisis de sendero fué llevado a cabo bajo condiciones normales (EC_e 1.76 dSm^{-1}) y condiciones salinas (EC_e 15.0 dSm^{-1}) sobre cuatro lineas puras de girasol y todos los híbridos simples posibles entre ellas, excluyendo los recíprocos. El análisis de coeficiente de sendero reveló que los días a floración y diámetro de capítulo seguido por peso de 100 aquenios, tuvieron la contribución directa mas alta al rendimiento de aquenios en condiciones normales. El diámetro del capítulo seguido por la concentración de K^+ en hojas jóvenes en crecimiento mostraron el efecto mayor sobre rendimiento de aquenios en condiciones salinas. Por tanto se sugiere que los criterios de selección para mejorar el rendimiento serian diferentes bajo condiciones normal y salinas. La selección podría basarse en genotipos precoces con mayor diámetro de capitulo y peso de 100 aquenios, bajo condiciones normales, y en diámetro de capítulo mayores y alta concentración de K^+ en hojas pequežas en crecimiento, en condiciones salinas.

SÉLECTION DU TOURNESOL POUR LA TOLÉRANCE À LA SALINITÉ: ANALYSE PAR LE "PATH COEFFICIENT" DE LA TOLÉRANCE À LA SALINITÉ CHEZ LE TOURNESOL (*Helianthus annuus* L.)

RÉSUMÉ

Une analyse de correlation a été réalisée en conditions normales (EC_e 1.76 dSm^{-1}) et salines (EC_e 15.0 dSm^{-1}), sur 4 lignées fixées de tournesol et toutes leurs combinaisons possibles à l'exclusion des croisements réciproques. L'analyse par le "path coefficient" a révélé que le nombre de jours nécessaires à la floraison, le diamètre du capitule et dans une moindre mesure, le poids de 100 akènes présentent la plus forte contribution directe au rendement en akènes en conditions normales. Le diamètre du capitule puis la concentration en K^+ dans les feuilles jeunes en cours de croissance montrent l'effet direct le plus élevé sur le rendement en akènes en conditions salines. Cependant, il est suggéré que les critères de sélection pour améliorer le rendement en grains pourraient être différents en conditions normales ou salines. La sélection pourrait être basée sur les génotypes à floraison précoce à diametre de capitule important et à poids de 100 grains plus élevé, en conditions normales, tandis qu'en conditions salines elle serait basée un diamètre du capitule important et une concentration en K^+ élevée dans les jeunes feuilles en cours de croissance.