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(Original Article)

How Does the Strength of Selection Influence Genotypic Matrix, Path-Analysis and Sensitivity to Environments?

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Abstract

Three cycles of pedigree selection started in the F2 were conducted during the four summer seasons of 2020 to 2023 to study the effect of single and multiple trait selection on the genotypic matrix, path analysis and sensitivity of the selected families of sesame to environments. The experiments were carried out at reclaimed loamy sand soil. The third cycle was evaluated in the reclaimed and clay soils. The genotypic correlations among traits differed for all types of selection in the two sites of evaluation. The direct and indirect effects of seed yield components in the single and multiple trait selection suggest the use of selection indices rather than single trait selection to improve seed yield in sesame. The performance of the selected families was higher in clay than in reclaimed soil. However, eight families (No. 273, 275, 355, 408, 604, 665, 692 and 764) were higher in seed yield (SY/P) in reclaimed compared to clay soil, three of them (No.273, 604 and 692) yielded higher in reclaimed than the average in clay soil. Such families can be considered promising families for inclusion in a breeding program to produce sesame strains that thrive in newly reclaimed soil. The correlation between the family's performance in reclaimed and clay soils reached 0.76 indicating that the performance in SY/P mostly controlled by the same genes. But there may be genes that affect performance that differ from one location to another, especially in the families that outperformed in reclaimed compared to clay soil.

Keywords: *Path-analysis, Selection index, Sensitivity to environment, Sesamum indicum L., Single trait selection.*

Introduction

Sesame (*Sesamum indicum* L. 2n = 26) is an annual self-pollinated crop plant of the Pedaliaceae family and one of the most ancient oilseed crops known to man. Sesame has been grown in the Near East and Africa for over 5000 years, for cooking and medicinal needs (Sharma *et al.*,2014). It is adapted to grow in tropical and sub-tropical areas. Generally, 65% of world sesame production is used as edible oil, and 35% for confectionary purpose. Its oil content is 50–60% and a protein content is 20–30% (Makinde and Akinoso, 2014). The cultivated area of

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sesame in Egypt in the summer of 2023 season was about 37222 ha (88623 Feddan, Faddan = 4200m^2) which produced about 47325 tones with an average 1.27 t/h (Economic Affairs Sector, Ministry of Agriculture, Egypt, 2023). Through this production, the genotypic correlation provides the association for the heritable part and shows the true picture of effective selection. The true picture of that correlation between seed yield and its contributing traits was reflected from direct and indirect effects to perceive the most influencing characters to be utilized as selection criteria in the sesame breeding program. Saravanan *et al.* (2020) indicated that the magnitude of genotypic (GCV) and phenotypic coefficients of variability (PCV) were high for seed yield per plant (SY/P), number of capsules per plant (NC/P) and number of branches per plant. Mahdy *et al.* (2015a) found slight discrepancy between GCV and PCV. High heritability and genetic advance in percentage of the mean were recorded for seed yield per plant and number of capsules per plant, indicating that selection could be effective for improving these characters (Mahdy *et al.,* 2015b). The expected genetic advance from the mean for oil% reached 31.50% (Mohanty, *et al.,* 2020). Capsules/Plant showed positive significant ($p \leq 0.01$) correlation with SY/P (Mahdy *et al.,* 2015b) and days to maturity showed negative correlation with yield/plant. Srikanth and Ghodke (2022) stated that plant height (PH, 0.225), number of capsules/plant (NC/P, 0.806), number of seeds/capsule (NS/C, 0.372), 1000SW (0.657) and oil content (0.532) positively correlated with seed yield at genotypic level. Aye *et al.* (2024) stated that number of primary branches per plant, NC and NS/C were strongly correlated with SY/P. Tidke *et al.* (2018) clearly revealed that the NS/C, SY/P, and NC/P showed high direct positive effects and indirect effects via other components traits. Abate (2019) stated that maximum positive direct effect on seed yield was exerted by number of capsules, biomass yield, days to maturity and harvest index. The direct effect of NS/C (0.661) on seed yield was positive and highly significant followed by NC/P (0.524), oil content (0.181) and 1000 seed weight (0.117) Patidar *et al.* (2020). Srikanth and Ghodke (2022) reported positive direct effects of NC/P (0.746), 1000SW (0.356), oil content (0.007), NS/C (0.267) and PH (0.034) on seed yield. The highest positive direct effect on yield was for NS/C, NC/P and at genotypic level (Aye *et al.*, 2024). Islam *et al.* (2024) noted that plant height (0.856), days to 80% maturity (0.227), number of primary branches per plant (0.467), number of secondary branches per plant (0.441), capsule length (0.258), and NS/C (0.213) had a positive direct effect on the SY/P. This work aimed to study the effect of single trait selection and selection index on the genotypic correlation, path-analysis and sensitivity to environment.

Materials and Methods

Plant materials and field trials

Three cycles of pedigree selection were conducted during the four summer seasons of 2020 to 2023 to study the effect of selection on the genotypic matrix, path analysis and sensitivity of the selected families to environments of sesame (*Sesamum indicum* L.) (Table 1).

The experiments were carried out at Arab El-Awamer (reclaimed loamy sand soil) research station (ARC), Assiut Egypt (latitude 27°, 03′ N, longitude 31°, 01′ E and the altitude of the area is 71 m), and Fac. Agric. Assiut Univ. Expr. Farm (Clay soil), Assiut, Egypt (Longitude: 31.125 N, Latitude: 27.25 E and Elevation :45m/148 Feet).

Table 1. Growing season, planting dates, genetic materials, experimental design and site of evaluation

Season	Date	Generation	Experimental design	Site
2020	10th June 2020	F_2	Non- replicated experiment	Arab El-Awamer
2021	13th June 2021	F_3	RCBD with three replications	Arab El-Awamer
2022	15th June 2022	F_4	RCBD with three replications	Arab El-Awamer
2023	20th and 21th June	F_5	RCBD with three replications	Arab El-Awamer and University

The recommended cultural practices for fertilization, irrigation and combat wilt and root rot diseases were adopted.

The genetic materials were F_2, F_3, F_4 and F_5- generations of sesame (*Sesamum indicum* L.) generated from a cross Shandaweel 3 × Sohag 2000. The F_2-generation was represented by 1000 single plants, and the data were recorded on 499 plants.

The recorded data in all seasons were days to first flower (DFF) in the F_2 and days to 50% flowering (DF) in the other generations, plant height (PH, cm), height to first capsules (HFC, cm), length of fruiting zone (LFZ, cm) as the difference between plant height and height to first capsule, number of capsules per plant (NC/P), seed yield per plant (SY/P, g), 1000 seed weight (SW, g), seed oil percentage (oil %). Oil content (%) was determined by a Soxhlet extraction method according to AOAC (2002), and number of seeds/capsule (NS/C) which was determined by counting seeds of 10 capsules/plant or family.

Selection procedures were single trait selection for PH, LFZ, NC/P, SY/P, SW and oil%, and four models of desired-genetic-gain index according to Pešek and Baker (1969). The characters incorporated in each index were:

1-Index 1 involved PH, LFZ, NC/P, SY/P and SW.

2-Index 2 involved LFZ, NC/P, SY/P and SW.

3-Index 3 involved NC/P, SY/P and SW.

4-Index 4 involved LFZ, NC/P and SY/P

Field procedures

Season 2020 (F_2- generation)

In reclaimed soil, 1000 F_2 plants of the population Shandaweel 3 × Sohag 2000 were sown in non-replicated rows of 5 m long and 50 cm width. Seeds were sown in hills 10 cm apart. The two parents were sown each in five rows. After full emergence, seedlings were thinned to one plant per hill. Data were recorded on 499 plants of the F_2-population and on 25 plants from each parent. The best 40-plant for each of PH, LFZ, NC/P, SY/P, SW and oil % were saved for the next generation. The plants were ranked according to Pešek and Baker (1969) desired gain selection index, and the 40 plants with the highest index scores were saved for each index for evaluation in the next season.

Season 2021 (F_3-generation)

In reclaimed soil, the selected F_3-families along with the two parents were sown in RCBD with three replications. The plot size for this and in subsequent generations was one row, 5 m long and 50 cm width, and seeds were sown in hills 10 cm apart. The characters were recorded as in the previous season as an average of 10 guarded plants from each family. After harvest, the best plant from the best 20 families for each single trait were saved for the next generation. The 20 highest-scoring families for each selection index were identified and the best plant in each family was saved for the next season.

Season 2022 (F_4-generation)

In reclaimed soil, the selected F_4-families along with the two parents were sown as in the previous season. After harvest, the best plant from the best 10 families for each single trait were saved for the next generation. The 10 highest-scoring families for each index were identified and the best plant from each family was saved for the next season.

Season 2023 (F_5-generation)

In both of reclaimed and clay soils the selected F_5-families along with the two parents were sown in RCBD with three replications. The plot size was one row, 2 m long, 50 cm width and seeds were sown in hills 10 cm apart.

Soil analysis of experimental sites

It is obvious that the loamy sand soil has a light texture (Table 2), resulting in a proper porosity that causes a good balance between soil moisture and air contents compared to those of clay soil that display a heavy texture. The loamy sand soil has a good physical properties and conditions that encourage plant roots to extend in more rhizosphere area to absorb water and nutrients. Also, the irrigation water goes through the clay soil very slowly causing the root zone to be saturated with water on the charge of soil air that is necessary for root respiration and spread.

For the chemical and nutritional point of view, the loamy sand soil has a lower salt content (0.68 ds/m), and higher available phosphorus "P" (29.9 mg/kg) than the clay soil (1.07 ds/m and 11.17 mg/kg; respectively), even though, both are not saline. The plants potentially grow under saline soil and higher nutritional soil conditions. The available P content of the loamy sand soil is extremely sufficient for plant needs. However, the available P of the clay soil is considered marginal. In conclusion, the physical properties (Soil texture, porosity and water distribution) and some chemical and nutritional properties (Salinity and available P) of loamy sand soil are preferable for plant growth than those of the clay one. In other words, clay soil conditions obstruct the growth and spread of plant roots, the loamy sand ones encourage the root growth and spread.

Table 2. Some physical and chemical properties of representative soil samples in the experimental sites before sowing (0-30 cm depth)

Soil property	Assiut Res. Stn. Arab El_Awamer	Fac. Agric. Res. Farm
Particle - size distribution		
Sand (%)	78.24	27.4
Silt (%)	9.76	24.3
Clay (%)	12.00	48.3
Texture grade	Loamy sand	Clay
EC (1:1 extract) dSm^{-1}	0.68	1.07
pH (1:1 suspension)	8.19	8.01
Total $CaCO_3$ (%)	25.0	3.4
Organic matter (%)	0.06	0.24
$NaHCO_3$-extractable P (mg kg^{-1})	29.9	11.17
NH_4OAC-extractable K (mg kg^{-1})	130	300
Total nitrogen (%)	0.04	0.08
Soluble Ca (mg kg^{-1})	100	190
Soluble Mg (mg kg^{-1})	12	72
Soluble Na (mg kg^{-1})	4.6	140
Soluble K (mg kg^{-1})	11.7	39
Soluble Cl (mg kg^{-1})	177.5	142
Soluble HCO_3 (mg kg^{-1})	610	427

* Each value represents the mean of three replications

Statistical analysis

The analysis of variance, covariance, phenotypic (σ^2p) and genotypic variance (σ^2g) and significance tests were performed according to Steel *et al.* (1997) on a plot-mean basis.

The genotypic (GCV) coefficient of variation and the genotypic correlations among pairs of traits were estimated as outlined by Miller *et al.* (1958).

The path coefficient analysis was done as outlined by Dewey and Lu (1959).

Heritability in the broad sense (H) and the expected genetic advance (selection of 10% of the superior plants) in the F_2 were computed using the formula adopted by Falconer (1989).

The sensitivity of the selected families to environments (clay and reclaimed soils) was measured by:

1-Reduction% = (Mean at clay-mean at reclaimed soil)/ mean at clay.

2-Sensitivity test of Falconer (1990) which measures the difference in the performance of a line under two environments relative to the difference in a base population or contemporaneous unselected control. The difference in mid-parents was used.

3-Stress susceptibility index as outlined by Fischer and Maurer (1978).

Results and Discussion

Description of the F_2 (Base population)

The range of all traits in the base population fell outside the range of their respective parents except for DFF (Table 3). The phenotypic variance in the F_2-

generation was very high for all traits. This could be due to some plants showed transgressive segregation and feasibility of selection. The PCV% in the F_2 was high for plant height (PH, 14.70), height to first capsule (HFC, 30.42), length of fruiting zone (LFZ, 24.90), number of capsules/plant (NC/P, 36.66), seed yield/plant (SY/P, 45.17) and number of seeds/capsule (NS/C, 26.62), and small to moderate for oil%, days to first flower (DFF) and 1000 seed weight (SW). Broad sense heritability estimates were moderate for DFF and NC/P (0.57) and high for the other traits (0.69-0.90). The expected genetic advance in percentage of the mean, from selection 10% superior plants ranged from 6.31% for oil% to 65.74% for SY/P. It could be noticed that the expected genetic advance was more affected by PCV% than heritability estimates. Mahdy *et al.* (2005) found low coefficient of variation for earliness and PH, and high for HFC, LFZ and SY/P in three base populations in the F_5-generation under artificial infection of *M. phaseolina.* Mahdy *et al.* (2015a, b) recorded very high estimates of heritability in broad sense in two F_2-populations. Abd-Elaziz (2018) noted coefficient of variation in the F_2-generation of 11.34, 27.34 and 49.88% for PH, HFC and SY/P and heritability of 84.65, 94.89 and 96.59% for the same respective traits.

Table 3. Means of the studied traits ±SE in the F_2 (Base population), parents, heritability in broad sense(H) and genetic advance (GA) under selection of 10%superior plants at reclaimed soil

Item	DFF	PH	HFC	LFZ	NCP	SY/P	SW	NS/C	oil %
Mean ± SE	42.63 ±0.14	138.81 ±0.91	58.94 ± 0.80	79.87 ±0.89	51.24 ±0.84	7.08 ±0.14	3.48 ±0.01	40.28 ±0.48	50.94 ± 0.12
MAX	51.00	210.00	100.00	155.00	149.00	23.68	4.80	77.20	61.00
MIN	35.00	100.00	20.00	35.00	13.00	1.34	2.60	11.17	40.00
PHV	10.17	416.10	321.36	395.52	352.72	10.23	0.10	87.49	6.61
GV	5.84	357.77	228.99	272.60	202.56	8.46	0.09	87.49	4.70
GCV %	5.67	13.63	25.68	20.67	27.78	41.08	8.53	23.22	4.25
PCV%	7.48	14.70	30.42	24.90	36.66	45.17	9.00	26.62	5.05
Hb	0.57	0.86	0.71	0.69	0.57	0.83	0.90	0.76	0.71
GA	3.22	30.87	22.48	24.12	18.98	4.65	0.50	14.36	3.22
GA/mean *100	7.55	22.24	38.15	30.20	37.05	65.74	14.23	35.66	6.31
Parent1 (Shandaweel 3)									
Mean ±SE	39.8 ±0.65	142.00 ±2.71	36.50 ±2.79	105.50 ±3.20	81.40 ±3.33	11.13 ±0.46	4.88 ±0.03	28.35 ±1.4	51.00 ±0.49
PHV	4.18	73.33	78.06	102.50	111.16	2.11	0.01	19.57	2.44
MAX	42.00	155.00	50.00	120.00	97.00	13.34	5.00	34.12	53.00
MIN	37.00	125.00	25.00	95.00	67.00	9.14	4.70	20.87	49.00
Parent 2 (Sohag 2000)									
Mean ±SE	49.60 ±0.67	164.00 ±2.08	83.00 ±3.27	81.00 ±3.79	86.60 ±4.53	7.63 ±0.38	3.472 ±0.04	25.99 ±1.88	49.40 ±0.37
PHV	4.49	43.33	106.67	143.33	189.16	1.43	0.01	35.34	1.38
MAX	53.00	175.00	95.00	105.00	103.00	9.32	3.64	38.60	51.00
MIN	47.00	155.00	65.00	60.00	61.00	5.09	3.28	15.81	48.00

DFF=days to first flower, PH= plant height, HFC= height to first capsule, LFZ= length of fruiting zone, NC/P= number of capsules/plant, SY/P=seed yield/plant, SW=1000sw, NS/C=number of seeds/capsules, Mean± SE, MAX=maximum, MIN=minimum, PHV=phenotypic variance, GV=genotypic variance, GCV%=Genotypic coefficient of variation, PCV=phenotypic coefficient of variation.

The Phenotypic correlation among traits in the F_2-population at reclaimed soil

Pleiotropy and linkage are the main genetic causes of correlation. Days to first flower (Table 4) showed positive and significant with PH and HFC and negative with LFZ, NC/P and SY/P, indicating that the late plants were tall in PH and HFC and short in LFZ, low in NC/P and yield. Islam *et al.* (2024) reported positive correlation of earliness and each of plant height and height to the first capsule. Aye *et al.* (2024) noted a negative correlation of DFF and each of seed yield, NC/P and seed weight. Seed weight gave significant ($p > 0.01$) correlations with LFZ, NC/P and yield, and low negative correlations with the other traits. Similar results were reported by Agrawal *et al.* (2018).

The phenotypic correlation of oil% was negative and significant with all traits except NS/C. It is of interest to indicate that the significance of SW with LFZ, NC/P and SY/P could be considered very low because of the coefficient of determination of that correlations ranged from 0.0121 to 0.0676%. This means that 0.0121 to 0.0676% of these correlations are due to the relationship between the traits, and the high significance is due to the high degree of freedom, which is close to 500.

The main features of the correlations were the positive significant ($p >0.01$) correlations among PH, HFC, LFZ, NC/P and SY/P, indicating that the tall Plants were tall in the fruiting zone and had a high yielding ability. Therefore, PH, NC/P and LFZ should be considered for improving seed yield in these materials. Srikanth and Ghodke (2022) came to the same conclusion.

The negative correlations of DFF (Table 4) with LFZ, NC/P and SY/P could adversely affect and reduce the observed gains in these traits. However, the positive significant ($p > 0.01$) correlations among PH, LFZ, NC/P and SY/P could be reflected in the improvements in these materials. These results are in line with those reported by (Mustafa *et al*., 2015).

Table 4. The Phenotypic correlation among traits in the F_2-population at reclaimed soil

	PH	HFC	LFZ	NC/P	SY/P	SW	NS/C	Oil%
DFF	0.36**	0.63**	-0.19**	-0.02	-0.03	-0.04	0.00	-0.05
PH		0.47**	0.60**	0.28**	0.23**	0.07	-0.04	-0.30**
HFC			-0.42**	-0.21**	-0.23**	-0.05	-0.06	-0.16**
LFZ				0.48**	0.45**	0.11**	0.01	-0.16**
NC/P					0.77**	0.12**	-.18**	-0.15**
SY/P						0.26**	0.42**	-0.04
SW							-0.06	-0.16**
NS/C								0.13**

**=significant at 0.01 level of probability, DFF=days to first flower, PH= plant height, HFC= height to first capsule, LFZ= length of fruiting zone, NC/P= number of capsules/plant, SY/P=seed yield/plant, NS/C=number of seeds/capsules

The genotypic matrix after three cycles of selection

The genotypic correlation provides the association for the heritable part and shows the true picture of effective selection. With respect to index1 (involved PH, LFZ, NC/P, SY/P and SW), the genotypic correlations in the F_5 among the traits (Table 5) involved in the index became stronger after three cycles of selection in most cases than those in the F_2-genration. In general, the correlations among the index traits varied from reclaimed to clay soil, and were higher than those in the F_2-generation.

The correlations of plant height were higher in clay than in reclaimed soil, however, the reverse was for the correlations among LFZ, NC/P, SY/P and SW. At reclaimed soil the traits in index 1 accompanied with positive genotypic correlations with oil%.

After three cycles of selection, the correlation among traits of index 2 (involved LFZ, NC/P, SY/P and SW) were higher at reclaimed than at clay soil, and both were higher than those before selection. The traits in index 2 accompanied with positive genotypic correlations with oil%.

The correlation among traits of index 3 (included NC/P, SY/P and SW) were higher at clay than at reclaimed soil, and both were higher than those before selection in the F_2-generation.

The correlation among traits of index 4 (included LFZ, NC/P and SY/P) were comparable at clay than at reclaimed soil, and both were higher than those before selection in the F2-generation.

It could be noticed that (Table 5) the four types of selection index in both locations greatly improved the correlations of SW and oil% with SY/P, LFZ, and NC/P and altered the negative correlations of oil% to positive compared to the F2-generation.

It is worth noting that the sesame plant can be tall with short fruiting zone due to the HFC, and the plant can be somewhat short and the fruiting zone can be long based on the HFC. Also, the fruiting zone can be long and bear high or few capsules due to the long or short internodes on the stem.

This is why the correlations are inconsistent. Hence, for a plant breeder engaged in the improvement of sesame yield in this population, it would be necessary to lay the maximum emphasis on SY/P, LFZ, and NC/P.

Respect to single trait selection, direct selection for PH increased its correlations with LFZ, NC/P and SY/P compared to the base population, and they are better in clay than in reclaimed soil (Table 6). However, the correlations among these traits were lower than those in the base population. Selection for PH at reclaimed soil adversely affected all the correlations of oil% except for NC/P.

That is, selection for plant height can improve these characteristics but negatively affect the oil content at reclaimed soil.

Table 5. The genotypic correlation among traits after three cycles of multiple traits selection (in the F5) at reclaimed (Rec.) and clay soil (Clay)

Trait	Index 1		Index 2		Index 3		Index 4	
Correlation	Rec.	Clay	Rec.	Clay	Rec.	Clay	Rec.	Clay
DF × PH	-0.05	0.54	-0.25	0.19	0.11	0.16	0.16	0.41
× HFC	0.21	0.45	-0.06	0.28	0.27	0.24	0.14	0.77
× LFZ	-0.28	0.36	-0.10	-0.13	0.00	-0.16	0.03	0.09
× NC/P	-0.49	-0.02	-0.23	0.30	0.08	0.20	-0.04	0.04
× SY	-0.27	0.10	-0.15	-0.07	0.30	0.27	-0.36	-0.08
× SW	-0.48	-0.06	-0.20	-0.18	0.45	0.27	-0.22	-0.21
× oil%	0.17	-0.16	0.45	0.09	0.52	-0.18	0.17	-0.30
× NS/C	0.60	0.16	0.11	-1.43	0.11	0.01	-0.54	0.00
PH ×HFC	0.58	0.79	0.39	0.56	-0.01	0.67	0.47	0.46
× LFZ	0.51	0.72	0.24	0.36	0.93	0.12	0.56	0.90
× NC/P	0.55	0.62	0.50	0.71	0.61	0.48	0.81	0.61
× SY/P	0.48	0.26	0.27	0.40	0.79	0.53	0.44	0.45
× SW	-0.07	0.48	0.10	0.02	0.57	0.19	0.04	0.29
× OIL %	0.59	0.06	-0.01	0.27	0.49	1.95	0.25	0.31
× NS/C	-0.09	-0.45	-0.27	-0.98	-0.13	-0.18	-0.24	-0.57
HFC × LFZ	-0.40	0.13	-0.80	-0.57	-0.37	-0.66	-0.47	0.04
× NC/P	-0.21	0.65	-0.37	0.02	0.54	0.06	0.41	0.35
× SY/P	-0.42	0.39	-0.67	-0.41	-0.12	0.21	0.08	0.28
× SW	-0.79	0.01	-0.70	-0.70	0.12	-0.21	-0.69	-0.11
× OIL %	0.05	0.48	-0.58	-0.14	-0.48	-0.30	0.19	-0.12
× NS/C	0.20	-0.10	-0.59	-1.07	-0.74	0.26	0.25	-0.03
LFZ × NC/P	0.84	0.26	0.71	0.69	0.37	0.41	0.42	0.51
× SY/P	0.97	-0.02	0.88	0.86	0.78	0.25	0.36	0.33
× SW	0.75	0.75	0.80	0.80	0.49	0.47	0.69	0.31
× OIL %	0.61	-0.45	0.61	0.42	0.62	0.60	0.07	0.38
× NS/C	-0.32	-0.62	0.45	0.23	0.15	-0.54	-0.47	-0.62
NC/P × SY/P	0.75	0.69	0.81	0.95	0.47	0.85	0.86	0.88
× SW	0.60	0.45	0.59	0.37	0.20	0.73	0.28	0.57
× OIL %	0.12	0.72	0.03	0.57	-0.19	0.61	0.24	0.74
× NS/C	-0.68	-0.20	-0.13	0.15	-0.62	-0.68	-0.03	-0.65
SY/P × SW	0.56	0.08	0.90	0.63	0.43	0.68	0.51	0.85
× OIL %	0.50	0.67	0.52	0.69	0.74	0.75	0.55	0.92
× NS/C	-0.10	0.50	0.38	0.23	0.28	-0.19	0.28	-0.31
SW × OIL %	0.11	-0.21	0.33	0.30	0.57	0.60	-0.17	0.86
× NS/C	-0.61	-0.72	0.34	0.01	-0.24	-0.51	-0.45	-0.13
Oil% × NS/C	0.26	0.26	1.00	0.90	0.65	-0.12	0.96	-0.14

DF=days to 50% flowering, PH= plant height, HFC= height to first capsule, LFZ= length of fruiting zone, NC/P= number of capsules/plant, SY/P=seed yield/plant, NS/C=number of seeds/capsules.

Direct selection for LFZ increased its correlations among LFZ, NC/P and SY/P compared to the base population, and they were better in clay than in reclaimed soil. Selection for LFZ (Table 6) can improve these characteristics in addition to the oil percentage and plant height better than selection for plant height at both locations.

Selection for NC/P enhanced its genetic correlation with SY/P and oil% in both sits of valuation, and PH in one site.

Direct selection for SY/P resulted in positive genotypic correlation with PH, LFZ, NC/P, SW and oil%. This indicates that the high SY/P depends on all these traits. Selection for SW showed the same picture as selection for SY/P, and was better at reclaimed than at clay soil.

Table 6. The genotypic correlation among traits after three cycles of single trait selection (in the F5) at reclaimed (Rec.) and clay soil (Clay)

Trait	PH		LFZ		NC/P		SY/P		SW		Oil%	
Correlation	**Rec.**	**Clay**	**Rec.**			**Clay**	**Rec.**	**Clay**	**Rec.**	**Clay**	**Rec.**	**Clay**
DF × PH	-0.14	0.57	-0.07	0.39	-0.15	0.48	-0.09	0.32	0.28	0.35	0.34	0.64
× HFC	0.60	0.38	-0.17	0.51	0.51	0.73	0.33	0.14	0.17	0.61	0.25	0.30
× LFZ	-0.62	0.47	0.06	-0.26	-0.64	0.26	-0.49	0.26	0.33	0.49	0.06	0.66
× NC/P	-0.39	0.15	-0.37	-0.50	0.27	0.18	0.96	0.09	0.26	0.31	0.10	0.32
× SY	-0.65	-0.01	0.07	-0.64	0.52	-0.04	0.61	0.50	0.07	0.41	0.16	0.37
× SW	-0.36	-0.47	0.13	0.04	-0.27	-0.19	-0.18	0.06	0.02	0.55	0.22	0.19
× oil%	-0.43	-0.05	0.33	-0.47	0.32	-0.25	0.33	0.06	0.20	0.30	0.10	0.05
× NS/C	-0.23	0.05	0.64	-0.81	0.52	-0.35	0.68	0.42	0.29	§	0.31	0.32
PH × HFC	0.17	0.87	0.66	0.39	0.61	0.76	0.63	0.81	0.04	0.65	0.41	0.83
× LFZ	0.49	0.46	0.74	0.28	-0.38	0.94	0.30	0.20	0.93	0.01	0.48	0.44
× NC/P	0.29	0.63	0.99	0.19	-0.27	0.54	-0.05	0.44	0.74	0.39	0.48	0.85
× SY/P	0.46	0.55	0.73	0.12	-0.57	0.27	0.36	0.72	0.87	0.42	0.03	0.65
× SW	0.59	0.06	-0.39	0.06	-0.26	-0.12	0.50	-0.20	0.79	0.59	0.21	0.33
× OIL %	-0.26	0.31	-0.03	-0.14	-0.87	0.10	0.14	0.62	0.63	0.52	0.24	0.25
× NS/C	0.01	0.08	-0.33	-0.11	-0.34	-0.49	0.33	0.28	0.35	§	0.45	0.09
HFC × LFZ	-0.77	-0.04	-0.02	-0.77	-0.97	0.51	-0.56	-0.42	0.33	0.75	0.61	0.13
× NC/P	-0.20	0.56	0.85	-0.56	-0.29	0.59	0.14	0.15	0.48	0.03	0.27	0.81
× SY/P	-0.31	0.48	0.26	-0.31	-0.33	0.37	0.06	0.38	0.01	0.02	0.05	0.68
× SW	-0.22	-0.10	-0.86	0.44	-0.88	-0.11	-0.24	-0.09	0.26	0.19	0.66	0.18
× OIL %	-0.13	0.53	-0.47	-0.37	-0.43	0.01	0.11	0.59	0.13	0.08	0.10	0.38
× NS/C	-0.09	0.16	-0.64	-0.27	0.55	-0.33	0.26	0.25	0.76	§	0.18	0.17
LFZ × NC/P	0.36	0.27	0.55	0.72	0.25	0.42	-0.22	0.43	0.52	0.38	0.16	0.22
× SY/P	0.57	0.24	0.74	0.41	0.19	0.14	0.30	0.48	0.82	0.34	0.08	0.05
× SW	0.57	0.30	0.25	-0.41	0.94	-0.17	0.82	-0.16	0.65	0.26	0.82	0.30
× OIL %	-0.05	-0.32	0.39	0.30	0.22	0.11	0.02	-0.02	0.55	0.55	0.30	0.16
× NS/C	0.09	-0.12	0.13	0.21	-0.75	-0.50	0.04	0.01	0.05	§	0.56	0.10
NC/P × SY/P	0.39	0.84	0.65	0.79	0.90	0.82	0.94	0.72	0.70	0.99	0.78	0.71
× SW	0.35	0.21	-0.82	-0.36	0.12	0.24	0.25	0.22	0.58	0.46	0.35	0.31
× OIL %	0.22	0.21	-0.49	0.71	0.70	0.67	0.68	0.51	0.31	0.82	0.14	0.43
× NS/C	-0.70	0.03	-0.21	0.69	-0.44	-0.53	0.90	-0.58	0.69	§	0.13	0.03
SY/P × SW	1.04	0.19	-0.33	0.26	0.14	0.76	0.51	0.28	0.69	0.64	0.44	0.26
× OIL %	-0.07	0.74	0.16	0.21	0.66	0.95	0.52	0.61	0.70	0.75	0.32	0.77
× NS/C	0.40	0.48	0.62	0.94	-0.11	0.02	0.85	0.04	0.07	§	0.57	0.63
SW × OIL %	-0.07	-0.19	0.81	-0.54	0.30	0.81	-0.11	-0.28	0.77	0.59	0.16	0.12
× NS/C	0.52	-0.48	0.35	0.23	-0.62	0.62	0.02	-0.47	0.47	§	0.33	0.37
Oil% × NS/C	-0.37	0.29	0.72	-0.21	-0.30	0.21	0.55	0.20	0.03	§	0.78	0.71

DF=days to 50% flowering, PH= plant height, HFC= height to first capsule, LFZ= length of fruiting zone, NC/P= number of capsules/plant, SY/P=seed yield/plant, NS/C=number of seeds/capsules, §=negative mean square of NS/C.

Direct selection for oil% showed negative or negligible correlations with the other traits except with SY/P at reclaimed soil. However, it showed positive correlation with PH, NC/P and SY/P at clay soil. Hence, it is difficult to recommend direct selection for oil%.

Comparing the results of single trait selection, direct selection for SY/P showed the best results and could be recommended.

Yield is a dependable complex inherited character as a result of interaction of several contributing attributes that may be related or unrelated. From these studies it is evident that NC/P and LFZ had a definite, positive and highly significant correlation with yield after three cycles of selection.

Considering that the most important traits in this study that affect the SY/P are the NC/P and the LFZ, the average correlations among the three traits at the two sites of evaluation suggests that the best selection methods to increase the SY/P are the index 2, followed by the index 3, and then selection for the LFZ.

Path analysis after three cycles of multiple traits selection

Path-coefficient analysis is a standard tool to partition a correlation to direct and indirect effects and helps the breeder to restrict selection for few important traits and reduce time and effort.

The genotypic correlation coefficients of SY/P with its contributing traits were partitioned to direct and indirect effects and shown in Table 7. Seed yield/plant is a result of NC/P, SW, and NS/C.

The genotypic correlation coefficient of NC/P with SY/P (Table 7) for index1 was positive and large in magnitude (0.75) under reclaimed, and 0.69 under clay soil. However, the direct effect of NC/P on SY/P was high (0.67) under clay, and (0.51) at reclaimed soil. The direct effect of NC/P on SY/P was high for index 2 and index 4, and very high for index 3, and higher at clay than at reclaimed soil in all indices (Table 7). Lenka and Misra (1973) noted that “for the direct and indirect effects a value of >1 is considered as very high; 0.3—0.99 high; 0.2—0.29 moderate; 0.1—0.19 low and <0.1 as negligible”. Tidke *et al.* (2018) noted that number of capsules per plant showed higher direct positive effects and indirect effects via other components traits.

Table 7. Path analysis for multiple trait selection at reclaimed (Rec.) and clay soil (Clay)

Item	Index 1		Index 2		Index 3		Index 4	
	Rec.	clay	Rec.	clay	Rec.	clay	Rec.	clay
NC/P VS. SY/P (r14)	0.75	0.69	0.81	0.95	0.47	0.85	0.86	0.88
Direct effect of NC/P, p14	0.51	0.67	0.56	0.81	1.01	1.23	0.72	0.82
Indirect effect via SW, r12p24	0.05	0.22	0.28	0.12	0.09	0.11	0.15	0.24
Indirect effect via NS/C, r13p34	0.19	-0.2	-0.03	0.02	-0.63	-0.49	-0.02	-0.18
SW VS. SY/P, r24	0.56	0.08	0.90	0.63	0.43	0.68	0.51	0.85
Direct effect SW, p24	0.08	0.49	0.47	0.33	0.47	0.15	0.56	0.42
Indirect effect via NC/P, r 12p14	0.30	0.30	0.33	0.30	0.20	0.90	0.20	0.47
Indirect effect via NS/C, r23p34	0.17	-0.71	0.10	0.0	-0.24	-0.37	-0.25	-0.04
NS/C VS. SY/P, r34	-0.68	0.50	0.38	0.23	0.28	-0.19	0.28	-0.31
Direct effect of NS/C, P34	-0.29	0.99	0.28	0.10	1.02	0.73	0.55	0.28
Indirect via NC/P. r13p14	-0.34	-0.13	-0.06	0.12	-0.62	-0.84	-0.02	-0.54
Indirect via SW, r23p24	-0.05	-0.35	0.16	0.00	-0.11	-0.08	-0.25	-0.05
Residual	0.62	0.09	0.11	0.05	0.20	0.11	0.24	0.08

PH= plant height, LFZ= length of fruiting zone, NC/P= number of capsules/plant, SY/P= seed yield/plant, SW= 1000seed weight, 1=NC/P, 2=1000sw, 3=NS/C, 4= SY/P

The indirect effect of NC/P on SY/P via SW was low to moderate in the four indices, and higher at clay than at reclaimed soil except index2. However, the indirect effect via NS/C was low and negative in six out of the eight cases.

Partitioning the genotypic correlation coefficient of SW with SY/P (0.56 at reclaimed and 0.08 at clay soil) to their direct and indirect effects indicated that the direct effect of SW was low to high and mostly high at reclaimed soil. The indirect effect of SW via NC/P was moderate to high and differed in the two sites of evaluation. However, the indirect effect of SW on SY/P was negative or negligible.

The genotypic correlation coefficient of NS/C with SY/P was inconsistent, and the direct effect of NS/C was low to very high, and higher at reclaimed than at clay soil except for index 1. The indirect effects of NS/C were negative or negligible.

It could be concluded that the direct and indirect effects of SY/P components varied greatly under both environments, and LFZ, NC/P and SW should be considered in selection indices at clay and reclaimed soils when selection practiced for SY/P in sesame.

Path analysis after three cycles of single trait selection

The genotypic correlations of NC/P and SY/P were positive and high, and differed in the two sites of evaluation (Table 8). Furthermore, the direct effect of NC/P was positive and high or very high indicating that the correlation explains the true relationship and direct selection through this trait will be effective (Raghuwanshi, 2007). However, the indirect effects via SW and NS/C were negligible to low, negative or positive.

Respect to the genotypic correlations of SW and SY/P, they were positive and ranged from low to high, and differed in the two sites of evaluation. Except when selection practiced for LFZ at reclaimed soil which was negative (-0.33), and the direct effect of SW on SY/P was positive. Under these circumstances, a restricted simultaneous selection model is to be followed, i.e. restriction is to be imposed to nullify the undesirable indirect effects in order to make use of direct effects.

The genotypic correlations of NS/C and SY/P ranged from negative or negligible to high and varied from type of selection to another. But, the direct effects of NS/C on SY/P were positive and ranged from low to high.

It could be concluded that in the direct selection for PH, LFZ, NC/P, SY/P, SW and oil% the genotypic correlations were inconsistence and varied with evaluation sites. However, the direct effects of NC/P, SW and NS/C were positive irrespective of their magnitude, and indirect effects varied greatly. In this condition, the restricted selection and/or multiple trait selection should be followed, i.e., restriction is to be imposed to nullify the undesirable indirect effects in order to make use of direct effects. Srikanth and Ghodke (2022) noted high positive direct effect of number of capsules (NC/P), number of seeds (NS/C) and

1000-seed weight. They suggested simultaneous selection for these traits for improvement of seed yield in sesame.

Table 8. Path analysis for single trait selection at reclaimed (Rec.) and clay soil (Clay)

Item	PH		LFZ		NC/P		SY/P		SW		Oil%	
	Rec.	**clay**	**Rec.**	**clay**	**Rec.**	**clay**	**Rec.**	**clay**	**Rec.**	**clay**	**Rec.**	**clay**
NC/P VS. SY/P (r14)	0.39	0.84	0.65	0.79	0.90	0.82	0.94	0.72	0.70	§	0.78	0.71
Direct effect of NC/P, p14	0.56	0.75	0.98	0.69	1.13	0.72	0.44	1.16	0.99		0.53	0.82
Indirect effect via SW, r12p24	0.19	0.07	-0.17	-0.15	0.05	0.13	0.10	0.10	0.30		0.16	-0.10
Indirect effect via NS/C, r13p34	-0.36	0.02	-0.16	0.25	-0.28	-0.03	0.40	-0.54	-0.59		0.09	-0.02
SW VS. SY/P, r24	1.00	0.19	-0.33	0.26	0.14	0.76	0.51	0.28	0.69		0.44	0.26
Direct effect SW, p24	0.54	0.33	0.21	0.42	0.40	0.55	0.39	0.46	0.52		0.47	0.32
Indirect effect via NC/P, r 12p14	0.19	0.16	-0.80	-0.25	0.14	0.17	0.11	0.25	0.57		0.19	-0.26
Indirect effect via NS/C,r23p34	0.26	-0.29	0.26	0.08	-0.39	0.04	0.01	-0.44	-0.40		-0.22	0.20
NS/C VS. SY/P,r34	0.40	0.48	0.62	0.94	-0.11	0.02	0.85	0.04	-0.07		0.57	0.63
Direct effect of NS/C, P34	0.51	0.61	0.75	0.37	0.63	0.06	0.44	0.93	0.86		0.66	0.54
Indirect via NC/P. r13p14	-0.39	0.02	-0.21	0.48	-0.50	-0.38	0.40	-0.67	-0.68		0.07	-0.02
Indirect via SW, r23p24	0.28	-0.16	0.07	0.10	-0.25	0.34	0.01	-0.22	-0.24		-0.16	0.12
Residual	0.20	0.10	0.06	0.02	0.06	0.10	0.09	0.03	0.09		0.07	0.08

PH= plant height, LFZ= length of fruiting zone, NC/P= number of capsules/plant, SY/P= seed yield/plant, SW= 1000seed weight. 1=NC/P, 2=1000sw, 3=NS/C, 4= SY/P, §= NS/C showed negative σ^2g.

Sensitivity to environment

The selected families after three cycles of selection for single traits or selection indices (53 families) were evaluated at clay (high environment) and at reclaimed soils (low environment). The sensitivity to environment was measured by three methods; reduction% in SY/P, stress susceptibility index (SSI, Fischer and Maurer, 1978) and sensitivity test (Falconer, 1990).

The SY/P in reclaimed was less than in clay soil (Table 9). The reduction % for 45 families ranged from 0.81(family no.226) to 35.49% (family no. 131) indicating that reclaimed soil decreased SY/P to large extent. However, eight families (No. 273, 275, 355, 408, 604, 665, 692 and 764) were higher in SY/P at reclaimed compared to clay soil by an amount ranging between 10.95 and 30.00%. This indicates differential response of the families to the two locations. Three of the eight families mentioned above (No. 273, 604 and 692) had a higher yield at reclaimed than at clay soil. Therefore, the reduction% should be linked to the overall mean.

Respect to stress susceptibility index (SSI), families with average susceptibility or resistance to stress have SSI value of 1.0, values less than 1.0 indicate less susceptibility and great resistance to stress. Meanwhile, a value of S = 0.0 indicates maximum possible stress resistance (no effect of stress on yield). Also, the scale of sensitivity to the environment, low values indicate low sensitivity to the stress and vice versa (Falconer, 1990).

Table 9. Mean selected families for SY/P, g in F_5-generation and sensitivity to environment

Fam. No.	Recl	Clay	Red%	SSI	Sens.	Fam. No.	Recl	Clay	Red%	SSI	Sens.
9	15.82	16.11	1.76	0.17	0.20	341	13.50	17.16	21.31	2.02	2.62
12	11.04	14.44	23.57	2.24	2.44	351	13.37	15.33	12.81	1.22	1.41
23	11.25	13.47	16.50	1.57	1.59	355	11.17	9.49	-17.70	-1.68	-1.20
39	18.78	19.03	1.35	0.13	0.18	375	15.52	16.73	7.27	0.69	0.87
71	9.54	12.83	25.62	2.43	2.35	376	14.15	16.83	15.94	1.51	1.92
82	17.25	18.41	6.32	0.60	0.83	386	8.61	10.31	16.52	1.57	1.22
89	14.00	17.47	19.86	1.89	2.48	408	14.17	11.41	-24.22	-2.30	-1.98
118	8.35	9.86	15.31	1.45	1.08	419	10.80	13.74	21.42	2.03	2.11
130	11.29	13.02	13.28	1.26	1.24	481	14.32	15.51	7.69	0.73	0.85
131	10.15	15.73	35.49	3.37	4.00	486	15.27	17.54	12.91	1.23	1.62
133	12.44	13.37	6.96	0.66	0.67	501	11.15	14.17	21.27	2.02	2.16
138	10.31	14.51	28.95	2.75	3.01	533	13.14	15.91	17.41	1.65	1.98
159	16.51	18.82	12.27	1.17	1.65	540	12.02	14.28	15.82	1.50	1.62
163	6.87	9.33	26.34	2.50	1.76	597	13.32	16.41	18.79	1.78	2.21
171	15.91	17.02	6.50	0.62	0.79	604	15.39	12.31	-25.03	-2.38	-2.21
190	9.67	11.13	13.15	1.25	1.05	665	14.04	11.82	-18.81	-1.79	-1.59
194	14.96	18.18	17.72	1.68	2.31	667	12.71	14.30	11.10	1.05	1.14
209	18.29	20.02	8.61	0.82	1.23	680	13.17	17.22	23.48	2.23	2.89
215	13.88	18.07	23.15	2.20	3.00	692	14.81	11.51	-28.68	-2.72	-2.36
226	10.21	10.30	0.81	0.08	0.06	703	14.60	16.65	12.31	1.17	1.47
238	11.88	14.06	15.48	1.47	1.56	710	14.35	15.07	4.77	0.45	0.51
273	15.63	12.07	-29.49	-2.80	-2.55	719	16.35	20.07	18.54	1.76	2.66
275	9.79	8.83	-10.95	-1.04	-0.69	733	11.58	13.96	17.03	1.62	1.70
279	17.19	20.09	14.40	1.37	2.07	764	12.45	9.58	-30.00	-2.85	-2.06
298	17.91	19.39	7.60	0.72	1.05	Mean	13.15	14.69	10.53		
303	14.20	16.79	15.45	1.47	1.86	MP	11.39	12.78	10.93		
328	8.55	10.28	16.83	1.60	1.24	D=		1.40			
337	12.03	14.24	15.48	1.47	1.58		r_{rc}	0.76			

SSI= stress susceptibility index, Sens= sensitivity test, Recl. =reclaimed soil, Red%=mean in clay-mean in reclaimed/mean in clay×100

The results indicate a near-identical match between the two scales. Nine families indicate less susceptibility and great resistance to the stress of reclaimed soil. Only three families (No.273, 604 and 692) yielded higher in reclaimed than in clay soil. Such families can be considered promising families for inclusion in a breeding program to produce sesame strains that thrive in newly reclaimed soil.

One last point, Falconer (1990) stated that measurements of the same trait in two different environments are considered to be different traits from a genetic context. The physiology in the two environments will be different and the performance will be influenced to some extent by different genes, though partly also by the same genes. The magnitude of the correlation of the performance reflects the extent to which the same genes are involved. The correlation between the performance in reclaimed and clay soils reached 0.76 indicating that the performance mostly controlled by the same genes. But, there may be genes that affect performance that differ from one location to another, especially in the families that outperformed in reclaimed compared to clay soil.

Conclusion

The correlation between the family's performance in reclaimed and clay soils reached 0.76, indicating that the performance in seed yield per plant is mostly controlled by the same genes. But there may be genes that affect performance that differ from one location to another, especially in the families that out-performed in reclaimed compared to clay soil.

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كيف تؤثر قوة الانتخاب على المصفوفة الجينية ومعامل المرور والحساسية للبيئات؟

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الملخص

أجريت ثلاث دورات من الانتخاب المنسب للسمسم بدأت من الجيل الثاني لأربعة أعوام من 2020 حتى 2023 لدراسة تأثير الانتخاب لصفة واحدة ولصفات متعددة على الارتباط الوراثي بين الصفات ومعامل المرور والحساسية للبيئة. أجرى الانتخاب في الأرض المستصلحة وقيمت الدورة الثالثة من الانتخاب في الأرض المستصلحة الطميية الرملية والأرض الطينية. اختلف الارتباط الوراثي بين الصفات لكل طرق الانتخاب واختلف كذلك في منطقتي التقييم. ويشير التأثير المباشر والغير مباشر لمكونات محصول البذرة/نبات الى أفضلية استخدام الانتخاب للصفات المتعددة (أدلة الانتخاب) عن استخدام الانتخاب للصفات المفردة لتحسين محصول البذرة/نبات في السمسم. وكان أداء العائلات المنتخبة في الأرض الطينية أفضل منه في الأرض المستصلحة. تفوقت ثماني عائلات في المحصول في الأرض المستصلحة عن الأرض الطينية (275،273، 408،604،665،692،764، و355) ثلاثة منها وهي (273، 604 و692) كانت أفضل محصولا في الارض المستصلحة عن متوسط الإنتاج في الأرض الطيني. ويكن أدخال هذه الثلاثة عائلات في برنامج تربية لإنتاج سلالات من السمسم تجود في الأراضي حديثة الاستصلاح. بلغت قيمة الارتباط بين أداء العائلات المنتخبة بالنسبة للمحصول في التربة المستصلحة والطينية 0.76 مما يدل على أن الأداء في التربة المستصلحة والطينية يتحكم فيه في الغالب نفس الجينات، ولكن قد تكون هناك جينات تؤثر على الأداء تختلف من موقع إلى آخر، خاصة في العائلات التي تفوقت في التربة المستصلحة مقارنة بالتربة الطينية.

الكلمات المفتاحية: *اختيار سمة واحدة، تحليل المسار، الحساسية للبيئة، السمسم، مؤشر الاختيار.*