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Research Article

Evaluating Genetic Variability in Sesame (*Sesamum indicum* L.) Genotypes for Yield and Oil Content

Aamir Ali Lakho¹, Piar Ali Shar^{1*}, Ayaz Ali Soomro², Nawal Naz¹, Zarnaz¹ and Mehran Ali Chahwan¹

¹Department of Plant Breeding & Genetics, Sindh Agriculture University, Tandojam, Pakistan, ²Department of Plant Breeding & Genetics, Sindh Agriculture University, Sub-campus Umerkot, Pakistan

(*Corresponding author: pasher@sau.edu.pk)

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Abstract | Exploiting the variation among crops and their genotypes is very essential for low-input sustainable agriculture. This study was conducted to evaluate the variability among sesame genotypes for yield and oil-related traits. The research was carried out at the Experimental Fields of Oilseeds Research Institute, Agriculture Research Center, Tandojam, Sindh, during the Kharif-2023. The experiment was laid-out in a randomized complete block design with three replications. Seven different sesame genotypes, viz. ARS-I (white), Tandojam-1, K-3, Irani, S-04, TS-5, and S-17 (Check variety) were involved for screening in relation to eleven selected parameters. The mean squares from ANOVA were significant for all the parameters. The genotypes ARS-1 (white) displayed the highest germination (%) after seven days, plant population per plot, plant height (cm), number of branches per plant and 1000-seed weight. The genotype Tandojam-1 showed minimum days to first flowering, days to 90% maturity and maximum number of branches per plant, 1000-seed weight, seed yield (g per plot and kg ha⁻¹) and oil content (%). The genotype S-4 displayed maximum plant population (per ha), plant height (cm), number of capsules per plant, seed yield (g per plot and kg ha⁻¹). The correlation coefficient revealed that seed yield was positive related to its contributing traits. Heritability in broad sense estimated high heritability, less influenced by environment was observed for all the studied material which exhibited that characters should be improved through selection program. We conclude that ARS-1 (white) and Tandojam-1 proved to be the better candidates for further breeding, hybridization and selection programs to develop new varieties.

Keywords: Sesame, Correlation, Heritability, Breeding programs, Seed yield, Oil content

Introduction

Sesame (*Sesamum indicum* L.) is one of the crucial and the most ancient oilseed crops. It is widely grown across the globe, generally common in tropical to temperate parts of the world (Khuntia et al., 2024).

Sesame seeds provide ~63% oil and 25% protein and contain a considerable quantity of oleic and linoleic acids and a remarkable antioxidant effect that resists oxidation (Abate & Firew, 2015).

Consuming sesame seeds provides calcium, potassium, methionine, and tryptophan. The biggest number of antioxidants is found in sesame oil, which also includes a number of fatty acids, including 43% oleic acid and 7% stearic acid, linoleic acid (35%) and palmitic acid (11%) (Yogranjan et al., 2015).

In Pakistan, sesame is grown as a rain crop and an irrigated crop in around 65 districts. It grows in Baluchistan, NWFP, Sindh, and Punjab province. The yield and oil production from sesame has been fluctuating over the past few years in Pakistan (GoP, 2025). This may be associated with sesame notwithstanding nutrient depletion and declining yields due to inadequate fertilizer application and decreased soil fertility (organic matter).

Applying compost-whether in combination with or without artificial fertilizer-is regarded as a sustainable agricultural production strategy (Noor & Shahzad, 2020). Other management practices also contribute to increased plant growth and oil content as observed in the case of variable yield and oil content of sunflower as influenced by row spacing (Odho et al., 2024), potassium nutrition

(Chhajro et al., 2014) and 4R phosphorus management (Arain et al., 2025).

In addition to management practices, the application of natural growth promoters has also been found essential for improved plant growth (Rind et al., 2024). This clarifies that other than nutrient deficiencies, several other factors play meaningful roles in increased or reduced plant growth.

Sesame cultivation has a long history, particularly in tropical regions where it has been grown since ancient times. In recent years, attention has turned to the potential of sesame seed oil for biodiesel production as an alternative energy source.

To enhance its utilization, further exploration of the ethno-botanical and medicinal properties of this highly nutritious and economically important oilseed is essential (Wacal et al., 2024).

Due to the changing climate, various unfavorable environmental conditions have arisen (Jamali & Zia-ul-hassan, 2025), while it is reported that sesame is known to be among moderately sensitive crops when exposed to salinity stress (Sridhar et al., 2025).

This indicates that regular monitoring of salinity and quality of growing medium and irrigation water becomes necessary for optimum crop output (Tareen et al., 2025).

Landraces of traditional sesame, together with associated wild species, constitute the foundation of agricultural production and a valuable source of genetic variety for breeders.

Choosing high-yielding varieties with more adaptability will aid in boosting output on a local and international level. However, a crop's performance is influenced by a variety of elements, including the climate, nutrients, water availability, pests and diseases, intra- and inter-specific competition, socio-cultural and socioeconomic factors, and so on (Rauf et al., 2024).

The choice and development of premium, high-yielding cultivars to increase output will be aided by the genetic variety in germplasm. It is essential to examine genetic characteristics such as genotypic and phenotypic variances, heritability (broad sense), and genetic advancement when examining variability with regard to quantitative traits.

When predicting gain under selection, high heritability estimates combined with a strong genetic advance are typically more useful than heritability estimates alone (Farrah et al., 2023).

In the light of the background discussed above, a field experiment was conducted to evaluate the genetic variability among seven sesame genotypes with respect to their yield and oil-related traits and heritability and correlations among the studied parameters to identify promising genotypes for potential use in future breeding programs.

Materials and Methods

The research was carried out at the Experimental area of Oilseeds Research Institute, Agriculture Research Center

(ARC), Tandojam, Sindh, during the Kharif season 2023. The experiment was laid-out in a Randomized Complete Block Design (RCBD), repeated thrice.

Genotypes: In total, seven genotypes were involved in this significant study, viz. ARS-I(white), Tandojam-1, K-3, Irani, S-04, TS-5, S-17 (Check variety).

Parameters recorded: Selected important parameters of sesame genotypes were recorded for screening purpose. Germination (%) after seven days, days to first flowering, days to (90%) maturity, plant population plot⁻¹, plant height (cm), number of branches plant⁻¹, number of capsules plant⁻¹, 1000-seed weight (g), seed yield plot⁻¹ (g), and seed yield (kg ha⁻¹).

Chemical analysis: Seed oil content was analyzed using Soxhlet apparatus following Folch et al. (1957).

Statistical analysis: The analysis of variance (ANOVA) was determined according to Gomez and Gomez (1984). While the broad-sense heritability was determined according to Falconer (1989). Correlation coefficient was worked after Snedecor and Cochran (1980).

Results

Analysis of variance: Mean squares from ANOVA are presented in Table 1, expressing that genotypes were highly significant ($P < 0.01$) for all the studied parameters except for oil content, which was found significant ($P < 0.05$) only.

Mean performance: The highest germination % after seven days (GP) of sesame was observed in top two genotypes ARS-1 (81.33), & K-3 (83.66), while in Tandojam-1 (74.33), followed by IRANI (57.00) observed lowest germination % of sesame.

Days to first flowering (DFF) was observed minimum in two genotypes, Tandojam-1 (40.45) & K-3 (39.15) produced minimum first flowering days and S-4 (43.51) displaced maximum days followed by S-17 check (43.84).

The genotype Tandojam-1 took minimum maturity days (DM) (109.54) followed by IRANI (107.26) among selected genotypes. While S-17 check (114.80), & TS-5 (115.58) showed the maximum maturity days.

The maximum plant population in plot⁻¹ showed in two genotypes ARS-1 (white) (75.00), & S-04 (77.00). While the minimum plant population genotypes are S-17 (check) (69.00), & TS-5 (68.33).

The tallest plant height (PH) was recorded in ARS-1 (white) (137.90), & S-4 (134.20). Whereas the shortest plant height was observed in Tandojam-1 (102.07) & K-3 (99.27).

Maximum number of branches plant⁻¹ (NBP) was obtained in ARS-1 (white) (6.33) and Tandojam-1 (8.66). While the lowest number of branches plant⁻¹ (NBP) were found in IRANI (4.00) & S-17 check (4.00) (Table 2a).

The optimum number of capsules plant⁻¹ (NCP) was observed in S-04 (178.33) & S-4 (178.67). While in ARS-1 (white) (105.33) & IRANI (150.67). An inferior number of unfilled grain panicle⁻¹ was observed.

Table 1. Mean squares from ANOVA for yield and oil related traits in sesame genotypes

Parameters	Replication (DF.2)	Genotype (DF.6)	Error (DF.12)
Germination % after seven days	27.19	235.49**	4.96
Days to first flowering	0.30	9.34**	0.52
Days to 90 % maturity	0.28	25.71**	0.61
Plant population plot ⁻¹	49.47	30.93**	10.86
Plant height (cm)	13.07	731.67**	22.59
Number of branches plant ⁻¹	0.04	8.09**	1.38
Number of capsules plant ⁻¹	70.86	2031.10**	80.52
1000 seed weight (g)	0.04	0.58**	0.06
Seed yield plot ⁻¹ (g)	546.50	21028.30**	569.40
Seed yield kg (ha ⁻¹)	673.20	25908.60**	702.40
Oil content (%)	0.84	19.10*	0.23

* = Significant at 5% probability level

** = Highly significant at 1% probability level

Table 2a. Mean performance of sesame genotypes for yield and oil related traits

Genotypes	Germination (%) after seven days	Days to first flowering	Days to 90% maturity	Plant population plot ⁻¹	Plant height (cm)	Number. of branches plant ⁻¹
ARS-1 (White)	81.33	42.79	113.43	75.00	137.90	6.33
Tandojam-1	74.33	40.45	109.54	71.00	102.07	8.66
K-3	83.66	39.15	111.55	74.33	99.27	5.00
IRANI	57.00	42.88	107.26	72.00	108.70	4.00
S-04	80.66	43.51	112.09	77.00	134.20	6.33
TS-5	75.33	40.95	115.58	68.33	120.73	6.33
S-17 (Check)	75.33	43.84	114.80	69.00	128.50	4.00
LSD at 5%	3.96	1.28	1.39	5.86	8.45	2.09

The 1000-seed weight (SW) ARS-1 (white) (4.00), & Tandojam-1 (4.40) genotypes produced highest seed index among selected genotypes and minimum recorded in K-3 (3.34) & IRANI (3.14). Maximum seed yield plot⁻¹ (SYP) was obtained in Tandojam-1 (962.00) & S-4 (841.67), while minimum seed yield plot⁻¹ was found in K-3 (710.33) & Irani (729.67). Maximum seed yield (kg ha⁻¹) (SYKG) was obtained in Tandojam-1 (1068.30) & S-4 (934.70), while minimum seed yield (kg ha⁻¹) was found in K-3 (789.00) & Irani (810.30). The maximum oil content (%) found in two genotypes Tandojam-1 (50.52) & TS-5 (48.55), while the minimum oil content

(%) was found in S-4 (43.88) & S-17 check (43.96) (Table 2b).

Correlation coefficient

Germination (%) after seven days: Germination (%) (GP) exhibit positive significant association with days to 90 (%) maturity (DM) (0.62**), 1000-seed weight (SW) (0.68**), and seed yield (kg ha⁻¹) (SYKG) (0.62**).

The GP was found non-significant in terms of its relationship with days to first flowering (DFF) (-0.26^{NS}), plant population plot⁻¹ (0.18^{NS}), plant height (PH) (0.26^{NS}), branches plant⁻¹ (NBP) (0.26^{NS}), capsules plant⁻¹ (NCP) (0.02^{NS}), seed yield plot⁻¹ (g) SYP (0.06^{NS}), and oil content (%) OC (-0.23^{NS}).

Table 2b. Mean performance of sesame genotypes for yield and oil related traits

Genotypes	Number. of capsules plant ⁻¹	1000 Seed weight (g)	Seed yield (g plot ⁻¹)	Seed yield (kg ha ⁻¹)	Oil content (%)
ARS-1 (White)	105.33	4.00	767.67	852.70	48.49
Tandojam-1	175.00	4.40	962.00	1068.30	50.52
K-3	168.67	3.34	710.33	789.00	45.71
IRANI	150.67	3.14	729.67	810.30	47.73
S-04	178.67	3.99	841.67	934.70	43.88
TS-5	157.33	3.47	807.00	896.00	48.55
S-17 (Check)	178.33	3.61	795.33	883.30	43.96
LSD at 5%	15.96	0.44	42.44	47.14	0.87

Table 3. Correlation Coefficient (r) of sesame genotypes for yield and oil related traits

Traits	Germination (%) after seven days	Days to first flowering	Days to 90% maturity	Plant papulation plot ⁻¹	Plant height (cm)	Number of branches plant ⁻¹	Number of capsules plant ⁻¹	1000- seed weight (g)	Seed yield (g plot ⁻¹)	Seed yield (kg ha ⁻¹)
Days to first flowering	-0.26 ^{NS}									
Days to 90 % maturity	0.62**	0.07 ^{NS}								
Plant papulation plot ⁻¹	0.18 ^{NS}	0.16 ^{NS}	-0.19 ^{NS}							
Plant height (cm)	0.26 ^{NS}	0.70**	0.52*	0.61**						
Number of branches plant ⁻¹	0.26 ^{NS}	-0.22 ^{NS}	-0.03 ^{NS}	0.02 ^{NS}	-0.04 ^{NS}					
Number of capsules plant ⁻¹	0.02 ^{NS}	-0.43**	-0.46*	-0.11 ^{NS}	-0.35 ^{NS}	0.04 ^{NS}				
1000- seed weight (g)	0.68**	0.12 ^{NS}	0.01 ^{NS}	0.50*	0.21 ^{NS}	0.64**	0.01 ^{NS}			
Seed yield (g plot ⁻¹)	0.06 ^{NS}	-0.01 ^{NS}	-0.45*	-0.04 ^{NS}	0.56*	0.69**	0.63**	0.72**		
Seed yield (kg ha ⁻¹)	0.62**	-0.01 ^{NS}	-0.03 ^{NS}	-0.44*	-0.10 ^{NS}	0.69**	0.30 ^{NS}	0.72**	0.74**	
Oil content (%)	-0.23 ^{NS}	-0.41*	-0.28 ^{NS}	-0.16 ^{NS}	-0.44**	0.50*	-0.41*	0.28 ^{NS}	0.54*	0.56*

Days to first flowering: Days to first flowering showed positive significant association with PH (0.70**), DFF displaced negative significant correlation with NCP (-0.43**) and OC (-0.41), DFF associate non-significant with DM (0.07^{NS}), PPH (0.16^{NS}), NBP (-0.22^{NS}), SW (0.12^{NS}), SYP (-0.01^{NS}) and SYKG (-0.01^{NS}).

Days to 90% maturity: Days to 90% maturity DM displaced positive significant correlation with PH (0.52*), DM displaced negative significant correlation with NCP (-0.46*) and SYP (-0.45), DM exhibit non-significant correlation with PPH (-0.19^{NS}), NBP (-0.03^{NS}), SW (0.01^{NS}), SYKG (-0.03^{NS}) and OC (-0.28^{NS}).

Plant population plot⁻¹: Plant population plot⁻¹ showed significant positive correlation with PH (0.61**) and SW (0.50*), PPH displaced negative significant correlation with SYKG (-0.44*), PPH exhibit non-significant correlation with NBP (0.02^{NS}), NCP (-0.11^{NS}), SYP (-0.04^{NS}) and OC (-0.16^{NS}).

Plant height (cm): Plant height (PH) showcased significant positive association with SYP (0.56*), displaced negative significant correlation with OC (-0.44**), PH displace non-significant association with NBP (-0.04^{NS}), NCP (-0.35^{NS}), SW (0.21^{NS}) and SYKG (-0.10^{NS}).

Number of branches plant⁻¹: NBP exhibited a highly significant positive correlation with SW (0.64**), SYP (0.69**), SYKG (0.69**) and OC (0.50*), while NBP showed non-significant correlation with NCP (0.04^{NS}).

Number of capsules plant⁻¹: Number of capsules plant⁻¹ (NCP) showed significant positive association with SYP (0.63**), & while displaced negative significant correlation with OC (-0.41*), and NCP showed negative non-significant with SW (0.01^{NS}) and SYKG (0.30^{NS}).

1000-seed weight: 1000-seed weight (SW) showed positive significant association with SYP (0.72**) and SYKG (0.72**), SW displaced non-significant correlation with OC (0.28^{NS}).

Seed yield plot⁻¹ (g): Seed yield plot⁻¹ (g) was significantly positively correlated with SYKG (0.74**) and OC (0.54*).

Seed yield kg ha⁻¹: SYKG displaced a significantly positive correlation with OC (0.56*) (Table 3).

Heritability estimates in broad sense (h² b.s %) for several traits in sesame genotypes

The heritability estimation for various traits of sesame genotypes was designated in (Table 4). For the parameter of germination % after seven days showed that genetic variance ($\sigma^2_g = 230.53$) was smaller than phenotypic variance ($\sigma^2_p = 237.14$), result in high heritability estimates ($h^2 = 97.21\%$).

Genetic variance ($\sigma^2_g = 8.82$) was lower than phenotypic variance ($\sigma^2_p = 9.51$) in days to first flowering and expressed high heritability ($h^2 = 92.74\%$). In case of days to 90 % maturity genotypic variance ($\sigma^2_g = 25.43$) was lesser than phenotypic variance ($\sigma^2_p = 26.21$) and demonstrated high heritability estimates ($h^2 = 97.02\%$).

Genetic variance ($\sigma^2_g = 20.07$) was lower than phenotypic variance ($\sigma^2_p = 34.55$). In plant population plot⁻¹, consisted high heritability ($h^2 = 58.08\%$). In plant height, genotypic variance ($\sigma^2_g = 709.08$) was lower than phenotypic variance ($\sigma^2_p = 739.20$) and which indicated higher value for heritability ($h^2 = 95.92\%$).

Genetic variance ($\sigma^2_g = 6.71$) lesser than phenotypic variance ($\sigma^2_p = 8.55$) in number of branches plant⁻¹ and recorded high heritability ($h^2 = 78.47\%$). Genetic variance ($\sigma^2_g = 1950.58$) was lesser than phenotypic variance ($\sigma^2_p = 2057.94$) in number of capsules plant⁻¹ and recorded high heritability ($h^2 = 94.78\%$).

Genetic variance ($\sigma^2_g = 0.52$) was lesser than phenotypic variance ($\sigma^2_p = 0.60$) in 1000- seed weight and recorded high heritability ($h^2 = 86.66\%$). In seed yield plot⁻¹ (g) genotypic variance ($\sigma^2_g = 2106.20$) was lower than phenotypic variance ($\sigma^2_p = 2242.73$) and disclose high

Table 4. Heritability estimates in broad sense (h^2 b.s %) for several traits in sesame genotypes

Traits	Genetic variance (σ^2_g)	Phenotypic variance (σ^2_p)	Heritability (h^2 b.s%)
Germination (%), after seven days	230.53	237.14	97.21
Days to first flowering	8.82	9.51	92.74
Days to 90 % maturity	25.43	26.21	97.02
Plant population plot ⁻¹	20.07	34.55	58.08
Plant height (cm)	709.08	739.2	95.92
Number of branches plant ⁻¹	6.71	8.55	78.47
Number of capsules plant ⁻¹	1950.58	2057.94	94.78
1000- seed weight (g)	0.52	0.6	86.66
Seed yield (g plot ⁻¹)	2106.2	2242.73	93.91
Seed yield (kg ha ⁻¹)	2058.9	2118.1	97.2
Oil content (%)	18.87	19.17	98.43

heritability ($h^2=93.91\%$). For the character of seed yield kg ha⁻¹ which represented genotypic variance ($\sigma^2_g=2058.90$) and phenotypic variance ($\sigma^2_p=2118.10$) which resulted in high heritability estimates ($h^2=97.20\%$).

Genetic variance ($\sigma^2_g=18.87$) was lower than phenotypic variance ($\sigma^2_p=19.17$) in oil content % and expressed high heritability ($h^2=98.43\%$) (Table 4).

Discussion

In view of the increasing soil degradation, nutrient mining (Zia-ul-hassan & Arshad, 2006; Ahmed et al., 2024; Ameer et al., 2023), and heavy metal stresses (Bux et al., 2022, 2023), the exploitation of variation among crops and their genotypes for growth, yield and quality traits is an important tool for climate-resilient, sustainable agriculture (Nawaz et al., 2006; Zia-ul-hassan et al., 2011; 2014a,b; Suthar et al., 2018a,b; 2019; 2025).

Previous studies have reported genotypic variation among crops and their varieties, e.g. wheat (Baloch et al., 2012; Kubar et al., 2023; Memon et al., 2024), maize (Nawaz et al., 2006; Rajpar et al., 2011), cotton (Zia-ul-hassan et al., 2011; 2014a,b; Shah et al., 2014), sunflower (Chhajro et al., 2014), and guar (Suthar et al., 2018a,b; 2019; 2025) for their significant plant traits, especially under certain stresses to identify those genotypes that can be ideal candidate for low-nutrient-input, climate-resilient sustainable agriculture.

In the present study, the mean squares of seven sesame genotypes for all quantitative traits were highly significant ($P<0.01$) except for oil content which was significant ($P<0.05$) only. The mean performance according to data the average performance of sesame characters among the seven sesame genotypes, ARS-1 (white) displayed maximum germination (%), plant population plot⁻¹, plant height (cm), maximum number of branches plant⁻¹ and maximum 1000-seed weight.

While Tandojam-1 showed minimum days to first flowering, days to 90% maturity and maximum number of branches plant⁻¹, maximum 1000-seed weight, maximum seed yield plot⁻¹ (g), seed yield (kg ha⁻¹) and maximum oil content (%). S-4 displayed maximum plant

population plot⁻¹, maximum plant height (cm), maximum number of capsules plant⁻¹, seed yield plot⁻¹ (g) and seed yield (kg ha⁻¹).

According to the findings of current study, more selection programs should employ these genotypes. Similar findings have been reported in various studies have been reported previously for these traits (Dossa & Zhang, 2019; Zhao et al., 2019). Other researchers, such as Mahdy et al. (2021), Gedifew et al. (2023), and Saxena and Bisen (2016) also find similar association between the same studied characteristics/traits of sesame genotypes.

The heritability estimation for various plant traits of sesame genotypes (germination % after seven days, days to first flowering, days to 90% maturity, plant population plot⁻¹, plant height (cm), number of branches plant⁻¹, number of branches plant⁻¹, 1000 seed weight (g), seed yield plot⁻¹ (g), seed yield kg ha⁻¹, and oil content%) demonstrated elevated heritability which showed that characteristics were less affected by environment, characters should be improved with simple selection. A previous study on the same aspect also aligns with the findings of our study, reporting high heritability for various traits in sesame genotypes (Thouseem et al., 2022). Other studies on genetic variability in sesame genotypes also reported significant differences among genotypes for key agronomic and yield-related traits.

The analysis of variance across multiple experiments revealed that sesame growth traits showed high phenotypic and genotypic coefficients of variation, indicating substantial genetic diversity.

The correlation and path analysis was also carried out which showed strong positive correlations of growth traits with seed yield (Kumar et al., 2022). However, some negative correlations have also been reported that improvement in one trait may sometimes compromise another (Tawir et al., 2019).

The identification of promising genotypes with desirable trait combinations provides a valuable resource for future breeding efforts aimed at developing new varieties and enhancing productivity and adaptability (Durge et al., 2022).

Conclusion

We conclude that ARS-1 (white) and Tandojam-1 proved to be the better candidates for further breeding, hybridization and selection programs to develop new varieties.

Author Contribution

PAS: Conceived, designed the experiments, contributed materials/analysis/tools, and analyzed the data; AAL: Performed the experiments, wrote the paper, and advised the format and proofreading before submission; All authors read and approved the final version of the manuscript.

Conflict of Interest

No competing interests are disclosed by the authors.

References

- Abate M, Mekbib F. 2015. Assessment of genetic variability and character association in Ethiopian low-altitude sesame (*Sesamum indicum* L.) genotypes. *Journal of Advanced Studies in Agricultural, Biological and Environmental Science* 10(2): 97-100.
- Ahmed N, Deng L, Wang C, Zia-ul-hassan, Deng L, Li Y, Li J, Chachar S, Chachar Z, Hayat, F. 2024. Advancements in biochar modification for enhanced phosphorus utilization in agriculture. *Land* 13(5), 644.
- Ameer I, Kubar KA, Ali Q, Ali S, Khan T, Shahzad K, Riaz M, Zia-ul-hassan, Rajpar I, Ahmed M, Talpur KH. 2023. Land degradation resistance potential of a dry, semiarid region in relation to soil organic carbon stocks, carbon management index, and soil aggregate stability. *Land Degradation & Development* 34(3): 624-636.
- Arain JA, Zia-ul-hassan, Tunio IH, Talpur NA, Jamali IA, Memon N, Khan H, Depar N. 2025. Growth, Biomass Production and Phosphorus Relations of Sunflower under 4R Management Strategy *Planta Animalia* 4(3): 161-172.
- Baloch MJ, Dunwell J, Denmet M, Zia-ul-hassan, Rajpar I, Jatoti WA, Veesar NF. 2012. Evaluating spring wheat cultivars for drought tolerance through yield and physiological parameters at booting and anthesis. *African Journal of Biotechnology* 11(53): 11559-11565.
- Bux RK, Batool M, Shah SM, Solangi AR, Shaikh AA, Haider SI, Zia-ul-hassan. 2023. Mapping the spatial distribution of soil heavy metals pollution by principal component analysis and cluster analyses. *Water, Air, & Soil Pollution* 234(6): 330.
- Bux RK, Haider SI, Batool M, Solangi AR, Zia-ul-hassan, Karimi-Maleh H, Sen F. 2022. Assessment of heavy metal contamination and its sources in urban soils of district Hyderabad, Pakistan using GIS and multivariate analysis. *International Journal of Environmental Science and Technology* 19: 7901-7913.
- Chhajro MA, Zia-ul-hassan, Shah AN, Talpur KH, Kubar KA. 2014. Response of two hybrid sunflower genotypes to applied different levels of soil potassium. *Persian Gulf Crop Protection* 3(2): 45-52.
- Dossa K, Zhang X. 2019. The genetic basis of drought tolerance in the high oil crop yield based on variability heritability and genetic advance studies. *Pure Applied Biological Science* 11(1): 226-231.
- Durge BD, Geethanjali S, Sasikala R. 2022. Assessment of genetic variability for seed yield and its components in sesame (*Sesamum indicum* L.) based on multivariate analysis. *Electronic Journal of Plant Breeding* 13(3): 974-982.
- Falconer DS. 1989. *Introduction to Quantitative Genetics*, 2nd ed. Longman, New York, USA.
- Farrah Z, Shahzad A, Ahsan M, Hameed G, Shahzad M, Gul S, Mohammed S. 2023. Evaluation of genetic variation among maize inbred lines for salinity stress at seedling stage through salt-stress-responsive traits. *Acta Universitatis Sapientiae, Agriculture and Environment* 14(1): 62-84.
- Folch J, Lees M, Stanley GS. 1957. A simple method for the isolation and purification of total lipides from animal tissues. *Journal of Biological Chemistry* 226(1): 497-509.
- Gedifew SA, Abate TD, Abebe T. 2023. Genetic variability in sesame (*Sesamum indicum* L.) for yield and yield related traits. *Harar Tarim ve Gıda Bilimleri Dergisi* 27(2): 153-165.
- Gomez KA, Gomez AA. 1984. *Statistical Procedures for Agricultural Research*, 2nd edn. John Wiley & Sons, New York, USA.
- GOP. 2025. Agricultural Statistics of Pakistan, 2023-24. Government of Pakistan, Ministry of National Food Security & Research (Economic Wing), Islamabad.
- Jamali IA, Zia-ul-hassan. 2025. Zinc-induced plant resilience against abiotic stresses: physiological, biochemical and molecular insights—A review. *Pakistan Journal of Agriculture* 2(1): 27-36.
- Khuntia JB, Dash AP, Kar RK, Lenka B, Pradhan H, Samal A, Pattanayak S, Mishra S, Pani B, Satapathy S. 2024. Unveiling genetic variability and character associations in sesame. *Biochemical and Cellular Archives* 24(1).
- Kubar KA, Ahmed Z, Baloch Q, Zia-ul-hassan, Korai PK, Chhajro MA, Kubar MS, Lakho HR, Sarfraz Q, Khaliq G. 2023. Phosphorus deficiency stress tolerance of six high-yielding wheat genotypes of Pakistan. *Journal of Applied Research in Plant Sciences* 4(2): 571-581.
- Kumar V, Sinha S, Sinha S, Singh RS, Singh SN. 2022. Assessment of genetic variability, correlation and path analysis in sesame (*Sesamum indicum* L.). *Electronic Journal of Plant Breeding* 13(1): 208-215.
- Mahdy E, El-Shimy AA, Sayed MA, Mahmoud AF, Salah A. 2021. Pedigree selection in sesame under artificial infection of *Fusarium oxysporum* f. sp. *sesami*. *SVU-International Journal of Agricultural Sciences* 3(4): 141-158.
- Memon SR, Zia-ul-hassan, Talpur KH, Jamali IA, Memon SP, Depar N. 2024. Evaluating advance wheat lines for enhanced zinc efficiency and climate resilience. *Pakistan Journal of Agriculture* 1(1): 1-7.
- Nawaz I, Zia-ul-hassan, Ranjha AM, & Arshad M. 2006. Exploiting genotypic variation among fifteen maize genotypes of Pakistan for potassium uptake and use efficiency in solution culture. *Pakistan Journal of Botany* 38, 1689-1696.
- Noor R, Shahzad. 2020. Effect of compost and chemical fertilizer application on soil physical properties and productivity of sesame (*Sesamum indicum* L.). *Biomass Conversion and Biorefinery* 13: 905-913.
- Odho WA, Soomro AA, Kandhro MN, Shar PA, Pathan HK, Arain JA. 2024. Growth, achene yield and oil content of sunflower (*Helianthus annuus* L.) as affected by row spacing. *Pakistan Journal of Agriculture* 1(1).
- Rajpar I, Jandan I, Zia-ul-hassan, Jamro GM, Shah AN. 2011. Enhanced fodder yield of maize genotypes under saline irrigation is a function of their increased K accumulation and better K/Na ratio. *African Journal of Biotechnology* 10(9): 1559-1565.
- Rauf S, Basharat T, Gebeyehu A, Elsafy M, Rahmatov M, Ortiz R, Kaya Y. 2024. Sesame, an underutilized oil seed crop: breeding achievements and future challenges. *Plants* 13(18): 2662.
- Rind WA, Talpur NA, Bhatti IP, Khooharo AA, Jamali K, Memon N, Khanzada IUH. 2024. Effect of foliar application of moringa leaf extract on biomass production and nutrient content of maize. *Pakistan Journal of Agriculture* 1(1): 1-5.
- Saxena K, Bisen R. 2016. Genetic variability, correlation and path analysis studies for yield and yield component traits in *Sesamum* (*Sesamum indicum* L.). *International Journal of Agriculture Sciences* 8(61): 3487-3489.
- Shah JA, Zia-ul-hassan, Rajpar I, Sial MA. 2014. Evaluating boron-use-efficiency of twenty cotton genotypes of Pakistan. *Pakistan Journal of Agriculture, Agriculture Engineering & Veterinary Sciences* 30(2): 147-158.
- Snedecor GW, Cochran WG. 1980. *Statistical Methods*, 7th edn. Iowa State University Press, Ames, Iowa, USA.

- Sridhar D, Alheswairini SS, Barasarathi J, Enshasy HAE, Lalitha S, Mir SH, Nithyapriya S, Sayyed R. 2025. Halophilic rhizobacteria promote growth, physiology and salinity tolerance in *Sesamum indicum* L. grown under salt stress. *Frontiers in Microbiology* 16: 1590854.
- Suthar JD, Rajpar I, Ganjegunte GK, Zia-ul-hassan. 2018a. Comparative study of early growth stages of 25 guar (*Cyamopsis tetragonoloba* L.) genotypes under elevated salinity. *Industrial Crops and Products* 123: 164-172.
- Suthar JD, Rajpar I, Ganjegunte GK, Zia-ul-hassan. 2018b. Evaluation of Guar (*Cyamopsis tetragonoloba* L.) genotypes performance under different irrigation water salinity levels: Growth parameters and seed yield. *Industrial Crops and Products* 123: 247-253.
- Suthar JD, Rajpar I, Ganjegunte GK, Grover KK. 2025. Seedling emergence of guar (*Cyamopsis tetragonoloba* L.) genotypes and their growth under irrigation water salinity. *Agrosystems, Geosciences & Environment* 8(2), e70130.
- Suthar JD, Rajpar I, Ganjegunte GK, Zia-ul-hassan, Niu G, Grover K. Germination, growth, and ion uptake of 15 Guar accessions under elevated salinity. *Agrosystems, Geosciences & Environment* 2 (1): 1-9.
- Tareen GS, Shahid T, Bibi S, Hayee AA, Shahzadi AK. 2025. Impact of different water qualities on germination and seedling growth of *Triticum aestivum*, *Hordeum vulgare*, *Coriandrum sativum*, and *Raphanus sativus*. *Pakistan Journal of Agriculture* 2(1): 22-26.
- Tawir AA, Farah GA, Bakheet OA, MI DY. 2019. Genetic variability and interrelationships of some traits in six sesame (*Sesamum indicum* L.) genotypes under rainfed conditions. *Journal of Agricultural Science* 4(1): 81-94.
- Thouseem N, Arya GK, Gayathri AM, Jo S, Geethanjali R, Sasikala R, Thavaprakash N. 2022. Assessment of genetic variability for yield and yield components in sesame (*Sesamum indicum* L.). *The Pharma Innovation Journal* 11(7): 2762-2768.
- Wacal C, Musinguzi SP, Ewaju E, Atibo C, Alowo D, Alipa J, Basalirwa D. 2024. Unravelling the potential benefits of sesame (*Sesamum indicum* L.) in cropping systems, nutritional, health, and industrial uses of its seeds – A review. *Cogent Food and Agriculture* 10(1): 2360766.
- Yogranjan GK, Satpute SP, Mishra. 2015. Genetic and genomics intervention to upsurge nutritive values of sesame (*Sesamum indicum* L.). *Asian Journal of Science and Technology* 6(4): 1296-1303.
- Zhao X, Han Y, Li Y, Liu D, Sun M, Zhao Y, Zhang A. 2019. Genetic diversity and population structure of sesame (*Sesamum indicum* L.) germplasm accessions in China as revealed by microsatellite markers. *Frontiers in Plant Science* 10: 1271.
- Zia-ul-hassan, Arshad M. 2006. Land degradation in Pakistan: A serious threat to environments and economic sustainability. ECO Services International. <https://www.eco-web.com/edi/060715.html>
- Zia-ul-hassan, Arshad M., Khalid A. 2011. Evaluating potassium-use-efficient cotton genotypes using different ranking methods. *Journal of Plant Nutrition* 34(13): 1957-1972.
- Zia-ul-hassan, Arshad M, Basra SMA, Rajpar I, Shah AN, Galani S. 2014a. Response of potassium-use-efficient cotton genotypes to soil applied potassium. *International Journal of Agriculture and Biology* 16: 771-776.
- Zia-ul-hassan, Kubar KA, Rajpar I, Shah AN, Tunio SD, Shah JA, Maitlo AA. 2014b. Evaluating potassium-use-efficiency of five cotton genotypes of Pakistan. *Pakistan Journal of Botany* 46(4): 1237-1242.

