Evaluation of Performance and Estimation of Genetic Parameters for (Sesamum indicum L.) Genotypes under Different Concentrations of Nano-Potassium Foliar Spray

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Abstract

A field experiment was conducted at the Research Station of the Department of Field Crops, College of Agriculture, Tikrit University, located at 43.679° E longitude and 34.616° N latitude in Salah Al-Din Governorate, characterized by gypsiferous soil, to evaluate growth traits, yield, and its components of ten sesame genotypes: Rafidain, Baytam, Local, Had, Jezah, GIOMMUROS, Malaysian Black, Sumer, Wada'a, and NAGHALI57 under three foliar spray concentrations of nano-potassium (0, 2, and 4 1-g. L). A factorial experiment was applied using a randomized complete block (R.C.B.D) with design split plots and three replications. The main plots were assigned to the three concentrations of nano-potassium foliar spray, while the sub plots were assigned to the genotypes. Phenotypic variance components (genetic and environmental), their coefficients of variation, broad-sense heritability, and expected genetic improvement as a percentage for the studied traits were estimated in the three environments (nano-potassium spray concentrations). The results showed that the 4 1-g. L concentration achieved the highest means for days to 50% flowering (52.200 days), plant height (149.67 cm), leaf area (3830.15 cm²), number of seeds per capsule (52.535 seeds capsule^{-1}), total seed yield (2.570 1-tons ha), and total biological yield (17.211 1-tons ha). The Rafidain genotype recorded the highest means for leaf area (4362.98 cm²), total seed yield (3.059 tons ha^{-1}), and total biological yield (17.535 1-tons ha). The combined treatment of Rafidain genotype with 4 1-g. L concentration surpassed others in giving the highest means for leaf area (5156.49 cm²), number of seeds per capsule (57.053 seeds capsule^{-1}), total seed yield (3.878 1-tons. ha), and total biological yield (20.707 1-tons. ha). Genetic variance values were higher than environmental variance for all studied traits in the three environments, which was reflected in the increase of broad-sense heritability values, being high for most traits. The expected genetic improvement as a percentage was moderate for total seed yield across the three studied environments.

Introduction

Sesame (Sesamum indicum L.) belongs to the Pedaliaceae family and is considered one of the oldest oilseed crops known to humans, with its oil widely used. It is an important crop in many countries, adapted to hot, semi-arid, and temperate climates. Humans have cultivated it primarily for its seeds, and it ranks as the fourth major oilseed crop worldwide [21]. Its nutritional value is very high due to its oil content ranging from 45 to 60%, protein content of 20 to 25%, carbohydrates about 15%, and minerals ranging between 5 to 7%. It is also rich in

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calcium, phosphorus, and vitamins such as vitamin B12. Moreover, the residual by-products from industrial processing are used as livestock feed, and sesame is involved in several industries including dyes, soaps, perfumes, pharmaceuticals, and pesticides

Despite the economic importance of this crop, its yield per unit area remains low in Iraq compared to global production. According to the Iraqi Ministry of Agriculture data, the cultivated area was 2088 thousand donums with a production of 781,956 kg per donum and productivity of 374.5 kg per donum. Globally, the cultivated area was 11,134,078 million hectares with a total production of 5,723,704 million kg and productivity of 514 1-kg. ha [9]. This is attributed to several reasons, including the absence of high-yielding genotypes and non-use of fertilizers according to international standards, which is a major limiting factor affecting production. Therefore, improving the production efficiency of this crop requires adopting modern agricultural practices such as the use of nanofertilizer technology. Nanofertilizers have emerged recently and gained widespread use in various fields, particularly agriculture, to improve plant performance. These nanofertilizers have been applied to reduce the use of conventional fertilizers due to their easier absorption. Potassium is one of the major essential elements influencing many chemical, biological, and physiological processes in plants. It plays a role in controlling membrane potential, regulating cellular osmotic pressure, stomatal opening and closing, enzyme activity, nutrient balance, and protein synthesis [19]. Selecting high-yielding cultivars is a primary goal in plant breeding programs. Yield is a complex trait controlled by many genes, and direct selection for yield often does not produce encouraging results due to its low heritability and environmental influence. Plant breeders can improve yield indirectly by enhancing traits correlated with it, estimating phenotypic variance components, some genetic parameters, and determining the suitable breeding method for each trait studied [18.[

This study aims to demonstrate the effect of nano-potassium foliar spray concentrations on growth traits, yield, and its components, as well as to identify the suitable genotype for cultivation under gypsiferous soil conditions. Additionally, it aims to estimate phenotypic variance components and some genetic parameters to determine the appropriate breeding method for each trait under the three studied environments (nano-potassium foliar spray concentrations.(

Materials and Methods:

Preparation of the Experimental Field

The experimental field was plowed using a disc plow, then the soil was leveled and amended. Afterwards, it was divided into three blocks, each containing 30 experimental units per replication. Replications were separated by 2 meters, and there was 1 meter spacing between main plots. The area of each main plot was 40 m². Phosphatic fertilizer was applied before planting at a rate of 120 1-kg. ha in the form of triple superphosphate (46% P_2O_5 as a phosphorus source. Nitrogen fertilizer was added at 120 1-kg ha as a nitrogen source in two doses: the first during the vegetative growth stage and the second at flowering stage Seeds were sown in rows spaced 40 cm apart and plants spaced 20 cm apart within the row on 15/5/2024, with five rows per experimental unit. Treatments were randomly assigned to main and subplots.

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Nano-potassium Origin and country of import: Iran, and recommended quantity 2 1-g. L was prepared by dissolving concentrations of 2 and 4 1-g. L in water to obtain the desired concentrations. Spraying was conducted on the vegetative canopy early in the morning in three applications at 30, 45, and 60 days after planting. The control treatment was sprayed with distilled water only, ensuring complete wetting of leaves using a 16-liter capacity sprayer. The details of the ten sesame genotypes used in the experiment are shown in Table (1.(

Table (1). Names of the ten sesame genotypes, year of release, source institute, and origin

Origin	Source Institute	Year Released	Genotype Name	No.
Desert Studies Center / University of Anbar	Iraqi Atomic Energy Organization	9/6/1992	Rafidain (Taqa 12)	1
	Desert Studies Center / University of Anbar	Introduced	Baytam	2
	Desert Studies Center / University of Anbar	-	Local	3
	Desert Studies Center / University of Anbar	Introduced	Had	4
Desert Studies Center / University of Anbar	Agricultural Research Center, Egypt	Introduced	Jezah	5
Desert Studies Center / University of Anbar	Golestan University, Iran	Introduced	GOLMMUROS	6
	Desert Studies Center / University of Anbar	Introduced	Malaysian Black	7
Desert Studies Center / University of Anbar	Ferdowsi University, Mashhad, Iran	Introduced	NAGHALI57	8
Desert Studies Center / University of Anbar	Ministry of Science and Technology / Agricultural Research Directorate	1/3/2011	Sumer	9
Desert Studies Center / University of Anbar	Ministry of Science and Technology / Agricultural Research Directorate	4/2/2009	Wada'a	10

Before planting, random soil samples were taken from the experimental field at 30 cm depth to study some chemical and physical properties. Details are shown in Table (2.(

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Table (2): Physical and chemical properties of the experimental field soil before planting at 30 cm depth

Value	Unit	Property
7.64	—	Soil pH
3.78	dS M	Soil Electrical Conductivity .E.C
19	$^{1-}$mg. kg soil	Available Nitrogen
7.64	$^{1-}$mg. kg soil	Available Phosphorus
112	$^{1-}$mg. kg soil	Available Potassium
0.91	%	Organic Matter
364	$^{1-}$mg. kg soil	Sand
281	$^{1-}$mg kg soil	Clay
355	$^{1-}$mg kg soil	Silt
Sandy loam	—	Texture

Five plants were randomly selected from each experimental unit from the middle rows after excluding border (guard) plants. Harvesting started on 1/9/2024 according to plant maturity stages and their appearance [12]. The studied traits included days from planting to 50% flowering, plant height, leaf area, number of capsules per plant, number of seeds per capsule, 1000-seed weight, total seed yield, and total biological yield. Data were statistically analyzed according to a randomized complete block design with split plot arrangement and means were compared using Duncan's multiple range test as described.

Genetic analysis of trait data was performed by estimating genetic, environmental, and phenotypic variances in the three studied environments and traits following the method described by [34].[37 .[

The standard error for phenotypic variance was calculated following [22 .[

Genotypic, environmental, and phenotypic coefficients of variation (GCV, ECV, and PCV) for studied traits

Broad-sense heritability was estimated for the studied traits according to [10.[

Expected genetic advance (E.G.A) as a percentage of the trait mean

The genetic advance as a percentage of the trait means (M.E.G.A(%

The programs Excel and Genes were used to estimate genetic parameters of the studied traits in the three environments (nano-potassium foliar spray concentrations.(

Results and Discussion

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Table (3) Analysis of variance shows the sources of variation, degrees of freedom, and sum of squares of the studied characteristics according to the complete randomized block design.

S.O.V	d.f.	S.S	M.S
Mainp-plat	—	—	—
R	(r-1)	R- c.f	SSR/ d.f
A	(a-1)	A- c.f	SSA/ d.f
R(A)	(a-1)(r-1)	AR-A- R +c .f	—
Sub-plat			—
B	b-1)(	B-c.f	SSB/ d.f
AB	a-1)(b-1)(	AB-A-B+c.f	SSAB/ d.f
R(AB)	a (b-1)(r-1)	ABR-AB-AR+c.f	—
Total	abr-1		—

.1Number of Days from Planting to 50% Flowering (days(

Table (4) shows that the effect of nano-potassium foliar spray concentrations was significant on this trait according to Duncan's multiple range test. Plants treated with 4 g L^{-1} concentration flowered earlier, with the lowest mean of 52.200 days, while control plants had the longest duration at 55.333 days. This early flowering with 4 g L^{-1} concentration is attributed to the shortening of the period from planting to first flowering, which accelerated this trait. These results agree with those of [30]. Significant differences were also observed among genotypes, where the genotypes Jezah and NAGHALI57 recorded the shortest durations of 52.222 and 52.555 days, respectively, while the Local genotype had the longest period of 55.888 days. This variation among genotypes in response to environmental factors, particularly photoperiod and temperature, accelerated thermal time accumulation, hastening the transition from vegetative to reproductive growth stages. These findings align with [35].[36]. [15.[

The interaction effect was significant; the combined treatment of Jezah genotype with 4 g L^{-1} concentration showed the shortest time to 50% flowering at 50.666 days, which was significantly different from Rafidain and Wada'a genotypes at the same concentration with 51.666 days. Conversely, Baytam and Local genotypes treated with distilled water spray had the longest durations of 57.333 and 57.666 days, respectively. The early flowering of Jezah is due to its genetic nature as an early flowering variety, and the foliar application of nano-potassium enhanced carbon assimilation efficiency, which reflected in increased vegetative growth and faster transition to reproductive growth.

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Table (4): Effect of nano-potassium foliar spray concentrations, genotypes, and their interaction on the number of days from planting to 50% flowering (days(

Mean	4 g L^{-1}	2 g L^{-1}	0 g L^{-1}	Genotype	No.
54.000 c	51.666 kl	54.333 def	56.000 c	Rafidain	1
55.000 b	52.333 ijk	55.333 cd	57.333 ab	Baytam	2
55.888 a	53.666 eh	56.333 bc	57.666 a	Local	3
53.888 cd	52.333 ijk	54.000 efg	55.333 cd	Had	4
52.222 e	50.666 l	52.333 ijk	53.666 eh	Jezah	5
54.666 b	53.000 gj	54.666 de	56.333 bc	GOLMMUROS	6
53.333 d	52.333 ijk	53.333 fi	54.333 def	Malaysian Black	7
52.555 e	52.000 jk	52.666 hk	53.000 fi	NAGHALI57	8
53.333 d	52.333 ijk	53.333 fj	54.333 def	Sumer	9
53.777 cd	51.666 kl	54.333 def	55.333 cd	Wada'a	10
$\bar{x}$=53.866	52.200 c	54.066 b	55.333 a	Mean	

.2Plant Height (cm(

Results in Table (5) indicate that increasing nano-potassium foliar spray concentrations significantly increased plant height, with the highest mean height of 149.671 cm recorded at 4 g L^{-1}, significantly different from 2 g L^{-1} concentration. The control treatment showed the lowest mean height of 137.359 cm. The increase in height is attributed to potassium's positive role in activating meristematic cell division and enhancing production of growth hormones gibberellin and auxin, which stimulate cell division and elongation, especially in stem cells. These findings agree with [8]. [6.[

Among genotypes, Sumer showed the highest significant plant height of 148.864 cm, while NAGHALI57 recorded the lowest at 136.628 cm. The variation is attributed to genetic differences and their environmental responses, reflected in vegetative growth traits including plant height. These results align with [24.[

The interaction between genotypes and spray concentrations was significant; GOLMMUROS sprayed with 4 g L^{-1} potassium showed the highest height (154.693 cm), statistically similar to Jezah, Baytam, Local, and Sumer genotypes at the same concentration. The lowest mean height (126.460 cm) was recorded for Jezah under control treatment. These findings are consistent with [3]. [7.[

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Table (5): Effect of nano-potassium foliar spray concentrations, genotypes, and their interaction on plant height (cm(

Mean	**4 g L^{-1}**	**2 g L^{-1}**	**0 g L^{-1}**	**Genotype**	**No.**
145.465 b	149.540 bc	144.313 efg	142.543 fi	Rafidain	1
144.480 bc	153.693 a	141.347 gj	138.400 jm	Baytam	2
146.317 b	150.757 ab	146.783 cde	141.413 gj	Local	3
145.073 bc	152.410 ab	145.383 def	137.297 klm	Had	4
138.956 d	153.597 a	136.813 klm	126.460 n	Jezah	5
144.331 bc	154.693 a	142.747 fi	135.793 lm	GOLMMUROS	6
143.254 c	144.383 efg	142.690 fi	142.690 fi	Malaysian Black	7
136.628 e	142.650 fi	139.173 il	128.063 n	NAGHALI57	8
148.864 a	151.593 ab	148.820 bcd	145.880 cf	Sumer	9
139.551 d	143.333 eh	140.267 hk	135.053 m	Wada’a	10
$\bar{x}$=143.292	149.671 a	142.846 b	137.359 c	Mean	

.3Leaf Area per Plant (cm^2(

Results in Table (6) reveal a significant effect of nano-potassium concentrations on mean leaf area. Plants sprayed with 4 g L^{-1} exhibited the highest mean leaf area (3830.15 cm^2), while control plants had the lowest mean (3214.16 cm^2). The increase is explained by potassium’s effective role in delaying leaf senescence and promoting a large vegetative canopy, which enhances photosynthetic efficiency and increases cell division leading to larger leaf area [23]. These results agree with [30.[

Significant differences among genotypes were observed, with Rafidain having the highest leaf area (4362.98 cm^2), and Had the lowest (3085.46 cm^2). These results are consistent with [25]. [15.[

Significant interaction between genotypes and spray concentrations was found; Rafidain sprayed with 4 g L^{-1} had the highest leaf area (5156.49 cm^2). In contrast, Baytam, Had, and Sumer sprayed with distilled water recorded the lowest means of 2854.22, 2870.30, and 2950.14 cm^2, respectively. These findings align with [7.[

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Table (6): Effect of nano-potassium foliar spray concentrations, genotypes, and their interaction on leaf area (cm²(

Mean	4 g L⁻ ¹	2 g L⁻ ¹	0 g L⁻ ¹	Genotype	No.
4362.98 a	5156.49 a	4585.17 fgh	3347.28 jk	Rafidain	1
3122.31 g	3385.22 ij	3127.48 l	2854.22 m	Baytam	2
3327.64 f	3549.60 gh	3388.34 ij	3044.98 l	Local	3
3085.46 g	3284.95 jk	3101.11 l	2870.30 m	Had	4
3473.41 d	3736.37 de	3636.85 efg	3047.01 l	Jezah	5
3397.29 de	3646.97 efg	3486.98 hi	3057.93 l	GOLMMUROS	6
4312.85 b	4465.81 c	4238.17 c	4234.57 c	Malaysian Black	7
3411.44 de	3576.61 fgh	3406.10 ij	3251.61 k	NAGHALI57	8
3304.64 f	3654.05 efg	3355.38 jk	2950.14 m	Sumer	9
3689.30 c	3845.42 d	3693.92 ef	3528.57 gh	Wada'a	10
$\bar{x}$=3548.79	3830.15 a	3601.25 b	3214.16 c	Mean	

.4Number of capsules per plant (capsule plant⁻ ¹:(

This is one of the main components of seed yield in sesame and is determined by the number of floral buds emerging on the plant. It is influenced by the genetic nature of the genotypes as well as the main environmental factors surrounding the plant, including the concentrations of potassium nano-spray.

Results in Table (7) indicate significant differences in the number of capsules per plant with increasing potassium spray concentrations. The 4 g L⁻ ¹ concentration achieved the highest mean value of 149.752 capsules per plant, whereas the control treatment sprayed with distilled water recorded the lowest mean of 109.877 capsules per plant. The increase in the number of capsules with increased potassium concentrations is attributed to the improved efficiency of transferring photosynthates from vegetative parts to reproductive parts, including the trait of the number of capsules per plant. These results agree with those of [5]. [27.[

Table (7) shows that the Rafdin genotype recorded the highest average number of capsules per plant at 172.990 capsules, while the Jeza genotype recorded the lowest at 101.471 capsules per plant. The superiority of Rafdin in this trait is attributed to its higher leaf area (Table 6), which enhanced photosynthetic efficiency and increased dry matter production, reflected in the increase of a key yield component, i.e., the number of capsules per plant. These findings are consistent with [1[

The interaction between the two study factors (Table 7) resulted in a significant increase in the number of capsules per plant, with the greatest increase observed in Rafdin plants sprayed with 4 g L⁻ ¹ potassium nano-spray, averaging 183.767 capsules per plant. In contrast, Jeza plants in the control treatment showed the lowest average of 81.370 capsules per plant. These results align with those of [30.[

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Table (7): Effect of potassium nano-spray concentrations, genotypes, and their interaction on the number of capsules per plant (capsule plant^{-1}(

Mean	**4 g L^{-1}**	**2 g L^{-1}**	**0 g L^{-1}**	**Genotype**	**No.**
172.990 a	183.767 a	184.433 a	150.770 def	Rafdin	1
145.718 c	172.680 abc	162.530 cd	101.943 pq	Baytam	2
108.820 d	113.897 mno	126.520 jki	86.043 rs	Al-Mahali	3
147.336 c	162.157 cd	147.057 efg	132.793 hk	Had	4
101.471 e	115.853 lmn	107.190 nop	81.370 s	Jeza	5
157.324 b	170.287 c	156.767 de	144.920 s	GOLMMUROS	6
151.721 bc	177.310 ab	148.843 efg	129.010 ik	Malaysian Black	7
113.469 d	137.650 gi	112.440 mno	90.317 qrs	NAGHALI57	8
108.869 d	123.660 klm	107.367 nop	95.580 pqr	Somer	9
107.788 de	140.263 fi	97.077 pqr	86.023 rs	Weda	10
$\bar{x}$=131.550	**149.752 a**	**135.022 d**	**109.877 c**	Mean	

.5Number of seeds per capsule (seed capsule^{-1}:(

Results in Table (8) indicated that spraying plants with potassium nano-spray at 4 g L^{-1} achieved the highest mean number of seeds per capsule of 52.535 seeds per capsule, significantly differing from the 2 g L^{-1} concentration which recorded a mean of 48.559 seeds per capsule. The control treatment sprayed with distilled water had the lowest mean of 45.964 seeds per capsule. This is attributed to the superiority of the 4 g L^{-1} concentration in increasing the number of capsules per plant (Table 7), which led to an increase in the number of seeds per capsule. These results are in agreement with [26]. [5.[

Table (8) shows that the GOLMMUROS genotype significantly outperformed others with the highest mean of 51.535 seeds per capsule and did not differ significantly from the HAD genotype which recorded a similar mean of 51.165 seeds per capsule. However, both differed significantly from the NAGHALI57 genotype which recorded the lowest mean of 45.672 seeds per capsule. The reason is that the GOLMMUROS and HAD genotypes more efficiently exploited environmental conditions, leading to enhanced photosynthesis and thus an increased number of seeds per capsule. This finding agrees with [33]. [2], but not with [32.[

The table also indicates a significant interaction effect between genotypes and potassium nano-spray concentrations. Rafdin genotype sprayed with 4 g L^{-1} potassium nano-spray recorded the highest mean number of seeds per capsule at 57.053 seeds, whereas Malaysian Black and NAGHALI57 genotypes sprayed with distilled water recorded the lowest means of 42.033 and 42.416 seeds per capsule, respectively. These results agree with [30.[

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Table (8): Effect of potassium nano-spray concentrations, genotypes, and their interaction on the number of seeds per capsule (seed capsule^{-1}(

Mean	4 g L^{-1}	2 g L^{-1}	0 g L^{-1}	Genotype	No.
50.186 bc	57.053 a	48.403 hij	45.103 k	Rafdin	1
50.394 b	53.040 bc	50.180 ef	47.963 hij	Baytam	2
49.557 cd	51.943 cd	49.196 fgh	47.533 j	Al-Mahali	3
51.165 a	54.273 b	51.790 cd	47.433 j	Had	4
47.512 ef	49.290 fgh	47.906 hij	45.340 k	Jeza	5
51.535 a	54.050 b	51.023 de	49.290 fg	GOLMMUROS	6
46.950 f	51.180 de	47.636 ij	42.033 l	Malaysian Black	7
45.672 g	51.836 cd	42.763 l	42.416 l	NAGHALI57	8
49.315 d	53.680 b	49.003 fi	45.263 k	Somer	9
47.905 e	49.003 fi	47.693 ij	47.020 j	Weda	10
$\bar{x}$=49.019	**52.535 a**	**48.559 b**	**45.964 c**	Mean	

-1000 .6seed weight (g:(

Results in Table (9) showed significant differences among potassium nano-spray concentrations in the trait of thousand-seed weight. The 4 g L^{-1} concentration achieved the highest mean value of 2.255 g compared to plants sprayed with distilled water, which gave the lowest mean of 2.347 g. This can be attributed to the role of potassium in efficiently transporting photosynthates from sources (leaves) to sinks (seeds), which increased the thousand-seed weight. These findings agree with [26]. [5.[

Results in the same table indicated that the Rafdin genotype significantly outperformed others with the highest mean of 2.778 g, differing significantly from the Jeza genotype, which recorded the lowest mean of 2.244 g. This is due to the genetic nature of Rafdin, which utilized soil nutrients more effectively, increasing photosynthetic efficiency and dry matter production, consequently increasing thousand-seed weight. This result did not agree with [32.[

The interaction between study factors was significant for this trait; the combined treatment of Rafdin genotype with 4 g L^{-1} potassium spray recorded the highest mean of 2.960 g, while Jeza genotype with control treatment had the lowest mean of 2.133 g. These results align with [3]. [7.[

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Table (9): Effect of potassium nano-spray concentrations, genotypes, and their interaction on 1000-seed weight (g(

Mean	**4 g L⁻ ¹**	**2 g L⁻ ¹**	**0 g L⁻ ¹**	**Genotype**	**No.**
2.777 a	2.960 a	2.740 bc	2.636 def	Rafdin	1
2.353 ef	2.450 ij	2.340 ko	2.270 nop	Baytam	2
2.620 c	2.710 cd	2.616 efg	2.533 ghi	Al-Mahali	3
2.314 f	2.423 jk	2.283 mp	2.236 p	Had	4
2.244 f	2.350 kn	2.250 op	2.133 q	Jeza	5
2.681 b	2.816 b	2.636 cde	2.553 fgh	GOLMMUROS	6
2.371 dc	2.516 hi	2.336 km	2.260 nop	Malaysian Black	7
2.415 d	2.560 fgh	2.426 jk	2.260 nop	NAGHALI57	8
2.317 f	2.370 jm	2.266 nop	2.316 lp	Somer	9
2.362 ef	2.426 jk	2.423 jkl	2.276 nop	Weda	10
$\bar{x}$=2.445	**2.558 a**	**2.431 b**	**2.347 c**	Mean	

.7Total seed yield (1-tons. ha:(

Results in Table (10) showed statistical differences among potassium nano-spray concentrations in the trait. Sesame plants sprayed with 4 g L⁻ ¹ recorded the highest mean seed yield of 2.570 1-tons. ha, significantly differing from the control treatment sprayed with distilled water which recorded the lowest mean of 1.502 1-tons. ha. This is attributed to the increase in individual plant yield, leading to higher total seed yield. These results are consistent with [14]. [27.[

Significant differences were also observed among genotypes in seed yield (Table 10). Rafdin genotype significantly outperformed all genotypes, recording the highest mean of 3.059 1-tons ha, while Somer and Weda genotypes recorded the lowest means of 1.540 and 1.570 1-tons. ha, respectively. The superiority of Rafdin is attributed to its higher leaf area (Table 5), which increased dry matter production during photosynthesis, thus increasing the average individual plant yield, reflected in increased seed yield per unit area. These findings agree with [1.[

The interaction between genotypes and potassium spray concentrations was significant; Rafdin sprayed with 4 g L⁻ ¹ achieved the highest mean of 3.878 1-tons. ha, while Jeza genotype under control treatment recorded the lowest mean of 0.982 1-tons. ha. These results agree with [3] [30.[

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Table (10): Effect of potassium nano-spray concentrations, genotypes, and their interaction on total seed yield (ton ha⁻ ¹(

Mean	4 g L⁻ ¹	2 g L⁻ ¹	0 g L⁻ ¹	Genotype	No.
3.059 a	3.878 a	3.056 c	2.244 gh	Rafdin	1
2.181 c	2.803 de	3.356 fg	1.386 no	Baytam	2
1.672 d	2.006 j	1.302 op	1.302 g	Al-Mahali	3
2.199 c	2.665 e	2.173 hi	1.760 k	Had	4
1.367 f	1.636 kl	1.443 mno	0.982 qr	Jeza	5
2.736 b	3.240 b	2.671 e	2.298 gh	GOLMMUROS	6
2.173 c	2.854 d	2.069 ij	1.596 mn	Malaysian Black	7
1.677 d	2.459 f	1.457 mno	1.114 qr	NAGHALI57	8
1.570 e	2.040 ij	1.186 op	1.183 pq	Somer	9
1.540 e	2.084 ij	1.378	1.158 pq	Weda	10
$\bar{x}$=2.017	**2.570 a**	**1.980 b**	**1.502 c**	Mean	

.8Total biological yield (1-tons. ha:(

Results from Table (11) showed that potassium nano-spray concentrations had a significant effect on total biological yield. The 4 g L⁻ ¹ concentration achieved the highest mean of 17.211 1-tons ha, while plants sprayed with distilled water recorded the lowest mean of 14.119 1-tons ha. This is due to the superiority of the 4 g L⁻ ¹ treatment in plant height (Table 4), leaf area (Table 5), and seeds per capsule (Table 6), which led to increased average seed yield per plant and thus total biological yield. These results agree with [26]. [27.[

Significant differences among genotypes were also evident. Rafdin genotype recorded the highest mean biological yield of 17.535 ton ha⁻ ¹, whereas Weda and Somer genotypes recorded the lowest means of 13.551 and 13.508 ton ha⁻ ¹, respectively. The superiority of Rafdin is attributed to its higher biological yield per plant, reflected in increased total biological yield. These findings agree with [25.[

The interaction between genotypes and potassium spray concentrations was significant; Rafdin sprayed with 4 g L⁻ ¹ recorded the highest mean of 20.707 ton ha⁻ ¹, while Somer and Al-Mahali recorded the lowest means of 12.288 and 12.175 ton ha⁻ ¹, respectively. This is attributed to the combined effect of the Rafdin genotype and the 4 g L⁻ ¹ potassium spray concentration on dry matter yield, leading to superiority in this trait. These results agree with [30.[

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Table (11): Effect of potassium nano-spray concentrations, genotypes, and their interaction on total biological yield (1-tons ha(

Mean	4 g L⁻ ¹	2 g L⁻ ¹	0 g L⁻ ¹	Genotype	No.
17.535 a	20.707 a	17.226 e	14.685 kl	Rafdin	1
15.783 f	17.249 e	15.704 h	14.397 lm	Baytam	2
13.848 h	15.148 j	14.107 m	12.288 p	Al-Mahali	3
14.721 g	16.102 g	14.618 kl	13.445 no	Had	4
16.434 e	18.330 bc	15.761 h	15.210 ij	Jeza	5
16.822 c	17.629 d	17.093 e	15.744 h	GOLMMUROS	6
17.223 b	18.618 b	16.949 e	16.102 g	Malaysian Black	7
16.822 d	18.059 c	16.483 f	15.352 ij	NAGHALI57	8
13.551 i	14.766 k	13.712 n	12.175 p	Somer	9
13.508 i	15.503 hi	13.225 o	11.796 q	Weda	10
$\bar{x}$=15.606	**17.211 a**	**15.488 b**	**14.119 c**	Mean	

.9Components of Phenotypic Variance and Some Genetic Parameters of the Studied Traits

Results in Table (12), which illustrates components of phenotypic variance and genetic parameters for all studied traits across the three environments (potassium nano-spray concentrations), showed that the genetic, environmental, and phenotypic variance values were all greater than zero for all traits. This confirms the importance of estimating these parameters for crop breeders. The genetic variance values were higher than the environmental variance across the three environments and for all studied traits, indicating the greater role of genetic factors compared to environmental factors in the inheritance of these traits. However, the reverse was observed for leaf area in the first and third environments and total biological yield in all three environments, where higher environmental variance values indicate a greater influence of environmental factors compared to genetic control. Similar findings were reported by [31]. [32.[

The genetic coefficient of variation (G.C.V.) was low across the three environments for most studied traits, except for leaf area in the second environment and total seed yield in all three environments, where it was moderate. This suggests a high heritability in a broad sense for the aforementioned traits, consistent with findings by [13]. [29]. The phenotypic coefficient of variation (P.C.V.) was low and showed similar behavior to G.C.V. for all traits in the three environments, except leaf area in the second environment, with phenotypic variation values ranging from low to high as observed by [20]. [16.[

Heritability in the broad sense (h^2b-S) was generally high for the studied traits in the three environments, except for leaf area, which was low in the first and third environments and moderate in the second. Heritability values ranged from low to high, consistent with [17]. [28.[

Genetic advance as a percentage of the mean (G.A%) was moderate for leaf area in the second environment and moderate for total seed yield in the three environments, while the expected genetic gain showed moderate to high values. This suggests good potential for breeders to perform selection easily, as

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supported by [11]. [4], who reported expected genetic gains ranging from low to high for the studied traits.

From these results, it can be concluded that the Rafdin genotype excelled in achieving the highest seed yield and showed a strong response to the 4 g L⁻ ¹ potassium nano-spray concentration, reflected in superior vegetative growth and yield traits. Hence, selection for seed yield improvement is feasible due to the high expected genetic gain percentage.

Table (11): Estimation of Phenotypic Variance Components and Genetic Parameters for Studied Traits in Three Environments (Potassium Nano-spray Concentrations(

G.A %	(G.A)	h^2b-S	P.C.V (%)	E.C.V (%)	G.C.V (%)	Phenotypic Variance	Environmental Variance	Genetic Variance
53.960	2.622	0.864	3.195	1.177	2.970	2.974 ± 0.809	± 0.270	2.750 ± 1.273
53.8	1.554	0.657	2.499	1.463	2.025	1.808 ± 0.492	0.620 ± 0.413	1.188 ± 0.794
53.83	2.274	0.783	3.066	1.428	2.713	2.724 ± 0.741	0.591 ± 0.394	2.133 ± 1.174
143.25	7.327	0.785	3.701	1.716	3.280	28.131 ± 7.656	6.048 ± 4.059	22.083 ± 12.137
143.50	8.128	0.700	5.098	2.518	3.846	43.528±11.846	13.058 ± 9.171	30.470±18.983
143.11	5.269	0.555	3.769	2.430	2.808	29.102 ± 7.920	12.956 ± 8.667	16.152 ± 12.137
6.209	219.99	0.359	9.828	7.868	5.888	121230.97±32994.890	77708.53±52059.296	43521.63±18073.695
15.377	522.919	0.514	16.997	11.849	12.186	334132.16±90939.255	162388.62±51679.699	171744.35±55933.405
5.726	200.704	0.336	9.683	7.890	5.612	115189.07±31350.493	76485.54 ± 51300.16	38703.53 ± 14715.50
14.381	18.717	0.631	12.950	7.866	10.287	284.057 ± 77.310	104.817 ± 70.322	179.240 ± 125.519
12.470	16.628	0.613	11.558	7.190	9.049	237.566 ± 64.657	91.938 ± 61.44	145.628 ± 105.167
15.093	19.795	0.672	12.761	7.280	10.480	281.140 ± 76.516	91.188 ± 61.813	188.960 ± 123.294
7.944	3.898	0.705	6.705	3.476	5.377	9.872 ± 2.686	2.912 ± 1.749	6.96 ± 3.869
7.781	3.82	0.730	6.063	3.129	5.192	8.860 ± 2.411	2.362 ± 1.609	6.498 ± 3.866
7.270	3.565	0.681	6.066	3.425	5.006	8.848 ± 2.408	2.822 ± 1.890	6.026 ± 3.873
4.637	0.113	0.724	3.651	1.916	3.107	0.007 ± 0.005	0.002 ± 0.001	0.005 ± 0.003
4.946	0.121	0.703	4.001	2.178	3.356	0.009 ± 0.007	0.002 ± 0.001	0.006 ± 0.004
4.807	0.117	0.670	4.077	2.342	3.337	0.009 ± 0.006	0.003 ± 0.002	0.006 ± 0.004
13.574	0.270	0.639	20.901	12.582	16.742	0.173 ± 0.047	0.062 ± 0.042	0.111 ± 0.076

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G.A %	(G.A)	h^2b-S	P.C.V (%)	E.C.V (%)	G.C.V (%)	Phenotypic Variance	Environmental Variance	Genetic Variance
22.146	0.452	0.658	19.164	11.172	15.571	0.153 ± 0.041	0.052 ± 0.035	0.101 ± 0.067
23.616	0.477	0.652	20.580	12.120	16.633	0.173 ± 0.047	0.060 ± 0.040	0.113 ± 0.076
2.326	0.361	0.159	8.313	7.623	3.096	1.672 ± 0.450	1.406 ± 0.953	0.266 ± 0.841
0.058	0.317	0.140	0.236	0.219	0.088	1.657 ± 0.450	1.425 ± 0.953	0.232 ± 0.030
1.741	0.272	0.121	8.177	7.666	2.844	1.636 ± 0.445	1.438 ± 0.962	0.198 ± 0.130

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