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RESEARCH ARTICLE

Effect of salicylic acid on stay-green efficiency in maize (*Zea mays* L.) varieties

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Abstract

A field experiment was conducted during the spring and autumn seasons of 2024 at a farm located northwest of Ramadi city to evaluate the effects of foliar application of salicylic acid at four concentrations (0, 150, 300 and 450 mg L^{-1}) on six maize genotypes. The study utilised a split-plot arrangement within a randomised complete block design (RCBD) with three replications. Results showed significant effects of salicylic acid concentration, genotype and their interaction on physiological and yield traits. The highest concentration (450 mg L^{-1}) significantly increased the number of stay-green, duration leaf area, kernels per row, 1000-kernel weight and overall grain yield, especially during the autumn season. The genotype Rabee exhibited the greatest number of stay-green (14.75) and the highest grain yield (12.33 t ha^{-1}). Salicylic acid also enhanced the stay-green characteristic, which correlated strongly with yield improvement by supporting photosynthetic efficiency and grain filling. Genotypes Rabee and Al-Maha demonstrated superior performance across most measured traits, highlighting their genetic potential. Additionally, salicylic acid application accelerated flowering by reducing the days to 50 % silking, particularly in spring. Environmental conditions in autumn provided greater stability in growth and reproductive phases. Based on these findings, applying 450 mg L^{-1} salicylic acid to responsive maize genotypes is recommended to improve physiological function and maximise yield under semi-arid conditions.

Keywords: flowering; genotypes; growth regulator; stay green; yield

Introduction

Maize (*Zea mays* L.) is considered one of the strategically important crops worldwide, ranking third in importance and production after wheat and rice. It serves as a major source of nutrition for both humans and animals and is widely used in industrial and medicinal sectors, including the production of dyes and biofuels. This versatility positions maize as a promising alternative to fossil fuels in some countries, earning it the title 'King of Crops'(1). Consequently, its significance has increased notably in recent decades due to global population growth and the expansion of livestock production projects. Despite its global importance, the yield in Iraq remains relatively low compared to international standards. In 2023, the cultivated area was approximately 130700 ha, with a mean yield of about 3.592 t ha^{-1}, a figure considered modest (2). This low productivity is attributed to several factors, primarily the limited use of high-yielding genetic materials adapted to local environmental conditions. Additionally, the inadequate implementation of integrated agricultural practices, coupled with insufficient soil fertility management and suboptimal crop management, plays a major role in widening the yield gap. This challenge is further intensified by the limited availability of varieties and hybrids that possess the genetic potential to achieve high productivity under optimal cultivation conditions. Among modern techniques employed to mitigate environmental stresses, plant growth regulators, particularly salicylic acid, have gained attention. Salicylic acid is a phenolic compound naturally classified as a plant hormone. It plays a crucial role in stimulating various physiological processes within the plant, including growth promotion, enhancement of photosynthetic efficiency and increased synthesis of chlorophyll and carotenoids (3). This is achieved by enhancing the development of chloroplasts and the formation of grana thylakoids. Salicylic acid also significantly regulates plant responses to various environmental stresses, such as osmotic, saline, heat and humidity stresses, as well as heavy metal toxicity (4). Its efficacy stems from its ability to reduce reactive oxygen species (ROS) levels and boost antioxidant enzyme activity, thereby improving plant adaptability under unfavourable conditions. Furthermore, it inhibits abscisic acid (ABA), which is associated with leaf senescence and suppresses ethylene synthesis, resulting in enhanced growth vitality (5). The external application of salicylic acid affects plants differently depending on factors such as concentration, plant species, growth stage and method of application. Therefore, it is essential to investigate its interaction with various maize genotypes and hybrids (6). This study evaluates the response of selected maize genotypes to foliar-applied salicylic acid by assessing physiological traits associated with leaf retention under central Iraqi conditions.

Materials and Methods

A field experiment was conducted during the spring and autumn cropping seasons of 2024 at an agricultural field located northwest of Ramadi city. The study aimed to investigate the effects of two factors on the growth and productivity of yellow maize. The land was prepared following standard agricultural practices, including perpendicular ploughing, levelling and smoothing, then divided into experimental units according to recommended technical guidelines (7).

Di ammonium phosphate (DAP) fertiliser was applied at a rate of 300 kg h^{-1} during land preparation and urea fertiliser was added at a rate of 130 kg h^{-1} in two splits: the first at the 25 cm plant height stage and the second at the beginning of the flowering stage (7). Six maize genotypes were used in the experiment: Bohooth 5012, Bohooth 5018, Al-Maha, Rabee, Safa and Bohooth 106. The second factor consisted of four salicylic acid concentrations: 0 (control), 150, 300 and 450 mg L^{-1}, which were applied as foliar sprays (8). Spraying was performed using a 15 L backpack sprayer during the late afternoon hours to ensure effective absorption and reduce volatilisation losses. Two consecutive sprayings were applied: the first at 25 days after emergence and the second 20 days after the first spraying. A surfactant (Zahi) was added to the spray solution at a concentration of 16 cm^3 per 100 L of water to reduce surface tension and ensure thorough leaf coverage. The control treatment was sprayed with water only, without salicylic acid (9).

The experiment was arranged in a split-plot design within a randomised complete block design (RCBD) with three replications. Salicylic acid concentrations were assigned to the main plots and maize genotypes were allocated to the subplots. The total number of experimental units was 72, with 24 units per replication. Each experimental unit measured 2.5 by 3.5 m, consisting of five rows, each 3.5 m long. The spacing between rows was 75 cm and the distance between plants within a row was 25 cm.

Data were collected from ten randomly selected guarded plants per experimental unit. The following growth and yield parameters were recorded: Number of days to 50 % silking (female flowering), number of stay green, leaf area (m^2), number of kernels per row, weight of 1000 kernels (g) and total grain yield per hectare (t ha^{-1}). Statistical analysis was performed using appropriate analysis of variance (ANOVA). Using the GenStat program, the mean comparisons among treatments were conducted. The least significant difference (LSD) test at a 5 % probability level was used to determine statistically significant differences.

Results and Discussion

Female flowering

The results revealed that the time required for 50 % of the maize plants to reach female flowering was significantly influenced by genotype, salicylic acid concentration and their interaction during both spring and autumn seasons (Table 1). In the spring season, a clear variation among genotypes was observed. The Safa genotype exhibited the longest flowering duration with a mean of 72.00 days, followed by Bohooth 5018 at 68.63 days, while Bohooth 5012 recorded the shortest period of 67.33 days. This variation can be attributed to genetic differences in flowering time, which may relate to physiological traits and tolerance to environmental conditions. Genotypes with delayed flowering often have a longer vegetative growth period or slower response to flowering-inducing stimuli (8). In the autumn season, a notable reduction in flowering duration was observed across all genotypes compared to the spring. Bohooth 5018 showed the longest period at 58.68 days, followed closely by Bohooth 106 at 58.60 days, while Bohooth 5012 had the shortest duration at 55.90 days. This reduction is likely due to environmental differences between seasons, such as higher temperatures and shorter day length in autumn, which accelerate physiological processes related to flowering. These findings are consistent with those reported previously (9, 10). Regarding the effect of salicylic acid concentrations, a significant influence on flowering time was particularly evident during the spring season. The control treatment (0 mg L^{-1}) exhibited the longest flowering duration at 70.26 days, whereas the highest concentration (450 mg L^{-1}) resulted in the shortest period of 67.30 days. This suggests that increasing salicylic acid concentration accelerates flowering by stimulating physiological processes involved in flower maturation, including activation of growth-regulating hormones and enzymes associated with floral bud development. In the autumn season, a similar trend was observed but with less pronounced differences, where flowering duration decreased from 58.17 days in the control to 56.17 days at the highest salicylic acid concentration. The limited effect in this season may be due to the already favourable environmental

Table 1. Effect of salicylic acid concentrations, genotypes and their interaction on the mean number of days from planting to 50 % female flowering

Varieties	Season	Salicylic acid concentration (mg L^{-1})				Season mean
		0	150	300	450	
Bohooth 5012	Spring	68.90	68.30	67.20	64.90	67.33
	Fall	56.10	56.10	56.10	55.30	55.90
Bohooth 5018	Spring	70.70	68.70	67.80	65.30	68.63
	Fall	59.60	58.50	58.00	58.60	58.68
Safa	Spring	73.60	72.80	72.30	69.30	72.00
	Fall	61.30	60.40	58.80	59.20	59.93
Rabee	Spring	67.60	66.40	66.10	65.70	66.45
	Fall	56.20	56.20	55.50	54.40	55.58
Al-Maha	Spring	69.20	67.20	68.20	70.50	68.28
	Fall	56.40	56.20	55.70	54.60	55.73
Bohooth 106	Spring	71.60	70.10	69.80	71.40	70.73
	Fall	59.40	56.20	57.90	58.90	58.60
Mean SA (Spring)		70.26	68.78	68.57	67.30	
Mean SA (Fall)		58.17	57.27	56.67	56.17	
L.S.D 5 % (Spring)		V	SA	V × SA		
		1.19	2.06	2.39		
L.S.D 5 % (Fall)		V	SA	V × SA		
		1.08	1.49	2.17		

conditions promoting flowering, thus diminishing the relative impact of salicylic acid. This agrees with findings from previous studies (11, 12). The interaction between genotype and salicylic acid concentration revealed significant differences in genotype responses to the treatments. In the spring, Safa at the control treatment had the longest flowering duration of 73.60 days, while Bohooth 5012 at 450 mg L^{-1} recorded the shortest duration of 64.90 days, highlighting variability in genetic responsiveness to foliar application. In the autumn, these patterns were generally similar but less pronounced, with flowering durations ranging from 61.30 days (Safa, 0 mg L^{-1}) to 54.40 days (Rabee, 450 mg L^{-1}). This indicates that the inhibitory effect of salicylic acid on flowering delay becomes limited under strongly favourable environmental conditions for plant growth and development. Overall, the results demonstrate that salicylic acid application reduced the time to female flowering, especially at higher concentrations and more noticeably in the spring season. Genotypic differences in response emphasise the importance of selecting appropriate genotypes and optimising growth regulator use according to seasonal and environmental conditions.

Number of stay green

The number of stay green serves as a vital indicator of the physiological efficiency of the plant, as it is closely associated with photosynthetic activity and carbohydrate production, which directly affect the final yield. The results showed that the autumn season exhibited higher stay-green values than the spring season across all salicylic acid concentrations. The overall mean number of stay green in autumn at the highest concentration (450 mg L^{-1}) reached 14.02 leaves per plant, compared to 12.69 leaves per plant during spring at the same concentration (Table 2). This suggests improved leaf growth during the autumn season, possibly due to more favourable climatic conditions such as temperature and moisture distribution, which enhanced physiological activity, leading to prolonged leaf viability.

The number of stay green varied with salicylic acid concentrations. In the spring season, leaf numbers gradually increased from 11.80 at 0 mg L^{-1} (SA_0) to 12.69 at 450 mg L^{-1} (SA_3). Similarly, in autumn, the mean rose from 12.64 (SA_0) to 14.02 (SA_3). This trend indicates that foliar application of salicylic acid has a stimulatory effect on stay green growth, especially at higher concentrations. This effect is attributed to salicylic acid's physiological role in enhancing photosynthetic efficiency, delaying leaf senescence and improving resistance to environmental stress. These findings align with those reported previously (13–15). Genotypes showed varying responses to the treatments. In spring, the Rabee genotype led with a mean of 13.06 leaves per plant, followed by Bohooth 5012 (13.00) and Al-Maha (12.83), while Bohooth 5018 recorded the lowest mean (11.04). In autumn, Rabee again showed the highest leaf number (14.08), followed by Al-Maha (14.00) and Bohooth 5012 (13.86), with Safa having the lowest mean (12.56). These differences suggest that genetic variation among genotypes plays a critical role in their capacity to respond to foliar treatments and achieve superior vegetative growth. Rabee and Al-Maha exhibited higher physiological capacity to maintain green leaf area under varying conditions. These results are consistent with findings of earlier researchers (16, 17). The interaction between genotypes and salicylic acid concentrations revealed clear variability, particularly in autumn, where differences were more pronounced. The highest value was recorded for Rabee at 450 mg L^{-1} (14.75 leaves per plant), followed by Al-Maha (14.70) and Bohooth 5012 (14.40), while Bohooth 5018 at SA_0 showed the lowest number (11.45). In spring, Rabee at SA_3 had the highest leaf number (13.55), whereas Bohooth 5018 at SA_0 and SA_1 showed the lowest values (10.80). This interaction illustrates that genotype responses to salicylic acid concentrations are not uniform but depend on genetic makeup and seasonal conditions. The highest concentration (450 mg L^{-1}) was the most effective in increasing stay green number, especially in genotypes with strong genetic potential. The results clearly indicate that foliar application of salicylic acid, particularly at 450 mg L^{-1}, contributed to increasing the number of stay green. The genotypes Rabee and Al-Maha demonstrated clear genetic superiority, qualifying them for inclusion in breeding programs aimed at enhancing maize physiological performance under Iraqi environmental conditions. The study recommends, using higher concentrations of salicylic acid for genotypes with good responsiveness to promote vegetative growth and achieve higher yield.

Leaf area

The results presented in Table 3 show the statistically significant difference in plant response to the growing seasons concerning leaf area, with the autumn season outperforming the spring season in most treatments. The overall mean leaf area in autumn at the highest concentration of salicylic acid (SA_3 = 450 mg L^{-1}) reached 0.504 m^2, compared to 0.501 m^2 in spring, indicating a slight numerical difference between the two

Table 2. Effect of salicylic acid concentrations, genotypes and their interaction on the mean number of stay green per plant

Varieties	Season	Salicylic acid concentration (mg L^{-1}) 0	150	300	450	Season mean
Bohooth 5012	Spring	12.50	12.70	13.20	13.45	13.00
	Fall	12.95	13.90	14.20	14.40	13.86
Bohooth 5018	Spring	10.80	10.80	11.10	11.45	11.04
	Fall	11.45	12.00	13.25	13.50	12.55
Safa	Spring	11.00	11.25	11.65	11.85	11.44
	Fall	12.05	12.60	12.75	12.85	12.56
Rabee	Spring	12.70	12.80	13.20	13.55	13.06
	Fall	13.40	13.75	14.40	14.75	14.08
Al-Maha	Spring	12.40	12.60	12.90	13.45	12.83
	Fall	13.35	13.60	14.35	14.70	14.00
Bohooth 106	Spring	11.20	11.50	11.40	12.15	11.56
	Fall	12.50	12.70	13.60	13.70	13.13
Mean SA (Spring)		11.80	11.97	12.27	12.69	
Mean SA (Fall)		12.64	13.19	13.78	14.02	
L.S.D 5 % (Spring)		V	SA	V × SA		
		1.10	0.87	1.21		
L.S.D 5 % (Fall)		V	SA	V × SA		
		0.98	1.33	1.97		

Table 3. Effect of salicylic acid concentrations, genotypes and their interaction on the mean leaf area (m^2)

Varieties	Season	Salicylic acid concentration (mg L^{-1})				Season mean
		0	150	300	450	
Bohooth 5012	Spring	0.451	0.479	0.512	0.536	0.495
	Fall	0.478	0.492	0.501	0.538	0.502
Bohooth 5018	Spring	0.378	0.398	0.402	0.462	0.410
	Fall	0.384	0.439	0.441	0.423	0.422
Safa	Spring	0.367	0.381	0.426	0.461	0.409
	Fall	0.345	0.373	0.443	0.446	0.402
Rabee	Spring	0.454	0.477	0.524	0.542	0.499
	Fall	0.468	0.478	0.502	0.571	0.505
Al-Maha	Spring	0.417	0.456	0.513	0.532	0.480
	Fall	0.457	0.459	0.500	0.589	0.501
Bohooth 106	Spring	0.394	0.410	0.416	0.474	0.424
	Fall	0.451	0.479	0.512	0.536	0.495
Mean SA (Spring)		0.410	0.434	0.466	0.501	
Mean SA (Fall)		0.424	0.442	0.467	0.504	
L.S.D 5 % (Spring)		V	SA	V × SA		
		0.047	0.082	0.095		
L.S.D 5 % (Fall)		V	SA	V × SA		
		0.052	0.073	0.105		

seasons. This modest increase in the autumn season is attributed to the moderate temperatures and well-distributed atmospheric moisture during the vegetative growth stage, which promote cell expansion and delay leaf senescence, thereby directly enhancing the effective leaf area.

The mean values indicate a gradual stimulatory effect of increasing salicylic acid concentration on leaf area. In spring, leaf area increased from 0.410 m^2 at zero concentration (SA_0) to 0.501 m^2 at the highest concentration (SA_3). Similarly, in autumn, leaf area rose from 0.424 m^2 to 0.504 m^2 following the same pattern. This trend suggests that salicylic acid effectively improves vegetative growth by stimulating cell division and expansion in leaves, as well as activating chloroplast formation and enhancing photosynthetic rates, which collectively contribute to the development of larger and more efficient leaves. These findings are consistent with earlier reports (18, 19).

The results also showed clear variation among genotypes in leaf area, indicating the influence of genetic traits. In the spring season, the genotype Rabee exhibited the highest mean leaf area (0.499 m^2), followed by Bohooth 5012 (0.495 m^2) and Al-Maha (0.480 m^2). In contrast, Safa and Bohooth 5018 recorded the lowest values (0.409 and 0.410 m^2, respectively). During autumn, Rabee again achieved the highest mean leaf area (0.505 m^2), followed by Bohooth 5012 (0.502 m^2) and Al-Maha (0.501 m^2), while Safa showed the lowest value (0.402 m^2). These results indicate that certain genotypes possess higher genetic potential in producing leaves with greater surface area, especially when interacting with growth regulators, which positively impacts the overall physiological performance of the plant. This aligns with findings reported in previous studies (20–22).

The interaction effects between genotypes and salicylic acid concentrations revealed significant differences in leaf area. In spring, the highest leaf area was observed in Rabee at SA_3 (0.542 m^2), followed by Bohooth 5012 at SA_3 (0.536 m^2). In autumn, the interaction of Al-Maha × SA_3 resulted in the greatest leaf area (0.589 m^2), followed by Rabee × SA_3 (0.571 m^2), while Safa × SA_0 recorded the lowest value (0.345 m^2). These data indicate that genotypic response to salicylic acid varies according to genetic composition and that the concentration of 450 mg L^{-1} was the most effective in improving leaf area across most genotypes. The results clearly demonstrate that foliar application of salicylic acid has a significant positive effect on increasing maize leaf area, particularly at the highest concentration (450 mg L^{-1}). The genotypes Rabee, Al-Maha and Bohooth 5012 were the most efficient in utilising this growth regulator and exhibited superior physiological responses compared to other genotypes. Therefore, it is recommended to use moderate to high concentrations of salicylic acid in integrated crop management programs, especially when cultivating genotypes with good genetic potential for vegetative growth, aiming to maximise plant productivity.

Number of grains per row

The results presented in Table 4 showed a significant variation in the number of grains per row between the two seasons. The fall season outperformed the spring season in most treatments. The overall mean number of grains per row in the spring season at the highest salicylic acid concentration (450 mg L^{-1}) was 31.75 grains per row. In the fall season, the number reached 32.57 grains per row at the same concentration. This clear superiority is attributed to improved environmental conditions such as moderate temperatures and longer photoperiods, which contributed to better pollination and fertilisation, thereby increasing the number of grains formed. Different salicylic acid treatments showed an increasing trend in the number of grains per row, confirming the role of this growth regulator in enhancing the physiological fertility of female flowers and improving the efficiency of grain setting. In the spring season, the numbers were 26.67, 27.96, 30.47 and 31.75 grains per row at concentrations of 0, 150, 300 and 450 mg L^{-1}, respectively. Similarly, in the fall season, the values were 27.32, 28.24, 30.18 and 32.57 grains per row for the same concentrations.

The highest concentration of 450 mg L^{-1}produced the greatest number of grains, indicating that the higher dose of salicylic acid stimulated vital processes responsible for flowering and fertilisation either by improving the plant's stress response or by increasing the activity of enzymes associated with pollen growth and fruit setting. This aligns with findings from previous studies (23). The tested varieties showed clear differences in grain number per row. In the spring season, the variety Rabee recorded the highest grain count with 33.75 grains per row, followed by Al-Maha with 32.63 and Bohooth 5012 with 31.74. In the fall season, Rabee maintained its lead with 34.73 grains per row, followed by Al-Maha with 33.55 and Bohooth 5012 with 32.59. Conversely, the varieties Bohooth 5018 and Bohooth 106 recorded the lowest values in both seasons, reflecting genetic variability among the varieties in their ability to utilise the regulatory effects of salicylic

Table 4. The effect of salicylic acid concentrations, varieties and their interaction on the mean number of grains per row

Varieties	Season	Salicylic acid concentration (mg L-1)				Season mean
		0	150	300	450	
Bohooth 5012	Spring	28.10	29.45	32.80	34.60	31.74
	Fall	30.20	31.15	32.10	36.90	32.59
Bohooth 5018	Spring	23.50	24.80	26.90	26.10	25.33
	Fall	22.90	23.80	24.70	24.20	23.90
Safa	Spring	25.20	24.50	27.10	29.40	26.55
	Fall	26.80	25.90	26.10	30.80	27.90
Rabee	Spring	29.80	30.90	35.20	37.10	33.75
	Fall	30.90	32.60	35.80	37.60	34.73
Al-Maha	Spring	28.90	31.50	33.50	36.60	32.63
	Fall	28.70	32.90	33.90	36.70	33.55
Bohooth 106	Spring	22.50	24.60	26.30	26.70	25.03
	Fall	24.40	23.10	28.50	27.20	25.30
Mean SA (Spring)		26.67	27.96	30.47	31.75	
Mean SA (Fall)		27.32	28.24	30.18	32.57	
L.S.D 5 % (Spring)		V	SA	V × SA		
		3.21	4.17	6.43		
L.S.D 5 % (Fall)		G	SA	V × SA		
		4.02	5.09	8.05		

acid on flower growth and grain formation. This variation in grain number underscores the importance of selecting genetically superior varieties that efficiently convert vegetative growth into reproductive yield, especially under local environmental conditions. These observations agree with previous research (24, 25). The highest significant interaction effect on grain number per row was observed in the combination of the Rabee variety and the highest salicylic acid concentration (450 mg L^{-1}) during the fall season, where the grain number reached 37.60 grains per row, the highest value recorded in the experiment. It may be stated whether this interaction was statistically significant at $p \leq 0.05$ to clarify the strength of the observed effect. These results confirm that certain varieties, such as Rabee, Al-Maha and Bohooth 5012, possess high genetic responsiveness to salicylic acid stimulation, particularly at high concentrations, which directly enhances grain number per row, an important component of final yield.

Overall, the results demonstrate that foliar application of salicylic acid, especially at 450 mg L^{-1}, significantly increased the number of grains per row across almost all varieties. The Rabee variety showed the highest response, supporting its recommendation for cultivation in similar environments, particularly when growth is supported by growth regulators. The presence of significant differences between varieties and concentrations emphasises the importance of integrating genetic improvement with physiological treatments to achieve optimal production.

Weight of 1000 grains

The results obtained from Table 5 demonstrated a clear effect of the growing season, salicylic acid concentrations, genotypes (varieties) and their interactions on the mean weight of 1000 grains in maize. Regarding the impact of the growing season, the fall season surpassed the spring season at all concentrations, with the overall mean weight of 1000 grains in the fall at the highest concentration (450 mg L^{-1}) reaching 301.3 g compared to 292.88 g in the spring. This superiority can be explained by the lower temperatures during the grain filling period in the fall, which extended the filling duration and improved photosynthesis and the efficiency of assimilate conversion to the grains, thus increasing their weight. Concerning the effect of salicylic acid concentrations, the results showed a clear positive response with increasing concentration, as there was a gradual improvement in the weight of 1000 grains from 0 up to 450 mg L^{-1} in both seasons. In the spring season, the mean increased from 264.95 g in the untreated control to 292.88 g at the highest concentration, while in the fall season it rose from 272.08 to 301.3 g. This increase reflects the active physiological role of salicylic acid in enhancing vital processes within the plant, especially in improving photosynthetic efficiency and reducing the impact of environmental stresses, leading to greater dry matter accumulation in the grains and thus increasing their weight. Regarding the effect of varieties, the genetic compositions showed clear variability in their response to the treatments. The variety Rabee excelled with the highest weight

Table 5. The effect of salicylic acid concentrations, varieties and their interaction on the mean weight of 1000 grains (g)

Varieties	Season	Salicylic acid concentration (mg L-1)				Season mean
		0	150	300	450	
Bohooth 5012	Spring	282.4	287.6	295.3	308.9	293.6
	Fall	289.1	293.2	305.7	319.8	301.9
Bohooth 5018	Spring	254.3	263.5	270.1	278.6	266.6
	Fall	261.2	268.9	275.6	284.7	272.6
Safa	Spring	240.5	248.6	259.2	270.4	254.7
	Fall	247.7	255.3	267.1	279.5	262.4
Rabee	Spring	295.2	300.6	312.8	326.1	308.7
	Fall	301.8	308.2	320.7	336.5	316.8
Al-Maha	Spring	280.6	286.5	298.9	313.2	294.8
	Fall	288.9	294.7	309.1	322.8	303.9
Bohooth 106	Spring	236.7	242.5	250.9	260.1	247.6
	Fall	243.8	249.1	256.7	268.5	254.5
Mean SA (Spring)		264.95	271.55	281.2	292.88	
Mean SA (Fall)		272.08	278.23	289.15	301.3	
L.S.D 5 % (Spring)		V	SA	V × SA		
		22.24	27.83	44.39		
L.S.D 5 % (Fall)		V	SA	V × SA		
		21.18	28.05	42.86		

of 1000 grains in both seasons, recording 308.7 g in spring and 316.8 g in fall, outperforming the other varieties. It was followed by Al-Maha and Bohooth 5012, while varieties such as Bohooth 106 and Safa recorded the lowest values. This variation is attributed to genetic differences among the varieties in their ability to utilise nutrients and growth regulators and convert photosynthetic products into grain weight. The interaction between varieties and salicylic acid concentrations showed a significant effect in both seasons, as indicated by the high values of the least significant difference (LSD) at the 5 % level. The highest individual values were recorded for the variety Rabee at 450 mg L^{-1} concentration, reaching 336.5 g in the fall and 326.1 g in the spring. This indicates that this variety has a high genetic capacity to exploit the effects of salicylic acid, especially under favourable environmental conditions, such as in the fall. Similarly, varieties Al-Maha and Bohooth 5012 showed positive responses at the higher concentration, highlighting the importance of selecting varieties with high conversion efficiency when using growth regulators.

Based on these findings, it is clear that the interaction between genetic composition and concentration plays a crucial role in determining final production efficiency, particularly for traits directly linked to yield such as individual grain weight. This calls for adopting production programs that integrate physiological management practices like salicylic acid application with genetic selection of highly efficient varieties to maximise resource use and achieve the highest possible productivity under local environmental conditions.

Plant yield

The results presented in Table 6 revealed a significant effect of salicylic acid concentrations, the studied genotypes and their interaction on total plant yield. Furthermore, the growing season clearly influenced the plant's response to these factors. Concerning the effect of salicylic acid concentrations on mean total yield per plant, there was a consistent and gradual increase in yield with increasing concentration from 0 to 450 mg L^{-1}. The overall means in the spring season were 4.89, 5.72, 6.98 and 8.69 t ha^{-1} for the concentrations 0,150, 300 and 450 mg L^{-1}, respectively, while in the fall season, the corresponding values were 5.27, 6.03, 7.88 and 9.17 t ha^{-1}. These results indicate that salicylic acid spraying played an active role in enhancing the plant's growth and productivity by improving physiological processes associated with grain number, grain weight and grain filling efficiency. This improvement can be attributed to the compound's ability to reduce the impact of environmental stress, enhance enzymatic activity, increase photosynthesis and elevate chlorophyll content in leaves (26, 27). In terms of the genetic effect of the varieties, clear variation was observed in their response to total yield. The variety Rabee recorded the highest mean yield in both seasons, reaching 8.41 t ha^{-1} in the spring and 9.72 t ha^{-1} in the fall, significantly outperforming the other genotypes. This genetic superiority reflects the efficiency of the Rabee variety in utilising environmental and physiological factors and responding to growth regulators, making it one of the high-yielding genetic lines. The varieties Al-Maha and Bohooth 5012 also showed relatively high means, approaching that of Rabee, whereas varieties such as Safa and Bohooth 5018 recorded the lowest yields, particularly in the spring season. This likely reflects a lower conversion efficiency or greater sensitivity to environmental stresses (28–31). The interactions between salicylic acid concentrations and genotypes (V × SA) showed significant differences in both seasons, indicating that genotypic responses vary depending on the concentration applied. The highest individual total yields were recorded in the interaction of the Rabee variety with the 450 mg L^{-1} concentration, reaching 11.54 t ha^{-1} in the spring and 12.33 t ha^{-1} in the fall, followed by the interaction of Bohooth 5012 at the same concentration with values of 10.73 and 11.22 t ha^{-1}, respectively. In contrast, the lowest value was observed in the interaction of the Safa variety with 0 mg L^{-1} salicylic acid during the spring season, with a mean yield of 3.69 t ha^{-1}. These results highlight the importance of matching concentration levels to specific genotypes to achieve maximum productivity. The agricultural season played a notable role in enhancing the productive performance of nearly all genotypes. Higher mean yields were recorded in the fall season compared to the spring, likely due to the relatively stable climatic conditions during fall, particularly during the critical grain-filling stages. This stability had a positive impact on grain development, thereby increasing total plant yield. The LSD values at the 5 % probability level in both seasons confirmed the existence of significant differences for the effects of variety (V), salicylic acid concentration (SA) and their interaction (V × SA). In the spring season, these values were 0.83, 1.02 and 1.65, respectively, while in the fall they were 0.99, 1.22 and 1.98. This underscores the importance of the interactive factor in determining productivity levels (32, 33).

Table 6. Effect of salicylic acid concentrations, varieties and their interaction on the mean total plant yield (t ha^{-1})

Varieties	Season	Salicylic acid concentration (mg L^{-1})				Season mean
		0	150	300	450	
Bohooth 5012	Spring	5.47	6.81	8.42	10.73	7.86
	Fall	5.85	6.71	9.58	11.22	8.84
Bohooth 5018	Spring	4.20	4.81	5.47	5.83	5.08
	Fall	4.60	4.99	6.05	6.14	5.45
Safa	Spring	3.69	4.35	5.06	6.48	4.89
	Fall	4.08	4.82	5.26	6.80	5.24
Rabee	Spring	5.88	7.03	9.20	11.54	8.41
	Fall	6.00	7.98	10.57	12.33	9.72
Al-Maha	Spring	5.68	6.10	7.69	10.67	7.53
	Fall	5.96	6.69	8.95	11.29	8.72
Bohooth 106	Spring	4.42	5.21	6.02	6.84	5.62
	Fall	5.10	4.96	6.91	7.22	6.05
Mean SA (Spring)		4.89	5.72	6.98	8.69	
Mean SA (Fall)		5.27	6.03	7.88	9.17	
L.S.D 5 % (Spring)		V	SA	V × SA		
		0.83	1.02	1.65		
L.S.D 5 % (Fall)		V	SA	V × SA		
		0.99	1.22	1.98		

Based on these findings, it can be concluded that applying salicylic acid at 450 mg L^{-1} represents the most effective treatment for improving total plant yield, provided it is applied to genetically responsive varieties such as Rabee and Bohooth 5012. Furthermore, the agricultural season emerges as a critical factor in enhancing production efficiency, highlighting the need for a well-balanced integration of genetic selection, physiological treatments and planting time to ensure maximum yield under local environmental conditions.

Conclusion

There is a positive relationship between the stay-green trait (duration of green leaf retention) and the total crop yield. In general, all varieties exhibited improvements in both traits with increasing concentrations of salicylic acid, particularly at the 450 mg L^{-1} level. The data indicate that varieties with a longer stay-green period tend to produce higher total yields. For example, the variety Rabee recorded the highest mean stay-green value (14.08) during the autumn season, along with the highest mean yield of 9.72 t ha^{-1}. This suggests that extending the duration of green leaf activity directly contributes to enhanced photosynthetic efficiency, which in turn increases dry matter accumulation and final crop productivity. Foliar application of salicylic acid improved both the stay-green duration and the total yield, with the most pronounced effects observed at the 450 mg L^{-1} concentration. This concentration consistently yielded the highest values across most varieties, highlighting its role in promoting plant health and enhancing resistance to environmental stressors. Furthermore, overall performance was superior in the autumn season compared to the spring, which may be attributed to more favourable environmental conditions during that period.

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Authors' contributions

AMS, SAA, ZAA, NMA and ASAR wrote and designed the article. All the authors read and approved the final manuscript.

Compliance with ethical standards

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