Research Article

Effect of Exogenous Salicylic Acid Foliar Spray on Growth, Yield and Chemical Content of Sesame Crop (Sesamum *Indicum L.*) Under Drought Stress

Nask Jawher Ahmed and Kawa A. Ali*

Department of Field Crops and Medicinal Plants, College of Agricultural Engineering Sciences,Salahaddin University, Erbil, Iraq.

Abstract | Drought is an environmental constraint on plant optimum growth and development, which adversely affects yield of all crop. Salicylic acid (SA) induces the responses to biotic and abiotic stresses. A field experiment was designed in Randomized Complete Block having three replications to determine the effect of foliar application of (SA) on sesame plant vegetative parts under drought with focusing observation on morphological and physiological traits of sesame. The study was consisted in two different environments. Treatments were irrigation based on principal development stages according to the general BBCH (Biologische Bundesanstalt, und Chemische Industrie) scale, with three levels of water regimes: (a) control (full irrigations), (b) No further irrigation after flowering (65BBCH), and (c) No further irrigation after seed development (79 BBCH) stages of the crop. There were four concentrations of foliar applied salicylic acid: (a) Control (only water spray) and (b)100ppm, (c) 200ppm, and (d) 300ppm SA spray. Yield traits were observed including (plant height (cm), capsules (plant^{-1}), seed (capsule^{-1}), seed yield (kg d^{-1}), thousand seeds weight (g), biological yield (kg d^{-1}) and harvest index (%), along with some chemical components (oil (%), nitrogen (%), phosphorus (%), potassium (%), carbohydrate (%) and proline content(ppm). The results showed that adding SA has a significant impact on seed yield during drought in both locations, with the highest values recorded (320.47 kg d^{-1}) and (327.56 kg.d^{-1}) at 300 ppm of SA. In both locations, stopping irrigation after flowering (65BBCH) has a higher negative impact on seed yield than stopping irrigation after seed development (79 BBCH). The seed yield in Erbil was 231.53 kg d^{-1} and in Kifri was 353.38 kg d^{-1}, indicating the adverse effects of drought, which were more clearly observed in the Erbil location than the Kifri location. The application of SA with a concentration of 300 ppm has enhanced seed yield with better adaptation of plants exhibiting drought at flowering and seed development in the plant life cycle.

Received | November 02, 2023; **Accepted** | March 21, 2024; **Published** | July 06, 2024
***Correspondence** | Nask Jawher Ahmed, Department of Field Crops and Medicinal Plants, College of Agricultural Engineering Sciences,Salahaddin University, Erbil, Iraq; **Email:** nask.ahmed@student.su.edu.krd
Citation | Ahmed, N.J. and K.A. Ali. 2024. Effect of exogenous salicylic acid foliar spray on growth, yield and chemical content of sesame crop (Sesamum *Indicum L.*) under drought stress. *Sarhad Journal of Agriculture,* 40(3): 702-712.
DOI | https://dx.doi.org/10.17582/journal.sja/2024/40.3.702.712
Keywords | Sesame indicum, Drought stress, Salicylic acid (SA) concentration, Plant growth, Oil, Proline

Introduction

Sesame (*Sesamum indicum* L.) is widely cultivated crop for oil extraction, which plays a substantial role in global economy (Zhang *et al*., 2021). This particular oilseed crop is considered to be among the earliest cultivated species globally (Jat *et al*., 2020). The plant under consideration has exerted a noteworthy influence on human health owing to its substantial oil content ranging (47-52%) with ability to promote favorable levels of cholesterol and antioxidants (Gharby *et al*., 2017). The growth period of sesame ranges from 75 to 150 days, with an average of 100 to 110 days. As plant develops, leaves and the stems turned yellow. Plants has to harvest when all capsules are mature to avoid loss due to shattering (Bedigian and Harlan, 1986). Sesame plants growth and yield hampered with drought (Ayoubizadeh *et al*., 2018). Soil moisture content before planting and during flowering have a significant impact on yield and yield component (Hussein *et al*., 2015). Nevertheless, it is important to identify the most critical stages of crop that may adversely affects by insufficient water supply, as well as their future breeding program for better resistant under drought (Richards, 2006). Salicylic acid (SA) is a phenolic compound that is naturally occurring in plant and identified for its role as a good phytohormone. It serves as a promising non-enzymatic antioxidant and plant growth regulator, which exerts significant impact on regulation of various plant physiological processes. These processes included but not limited to photosynthesis, growth, nitrate metabolism, flowering, seed germination, maturity, and response to stress (Joseph *et al*., 2010). According to a study conducted by Aldesuquy and Ghanem (2015), SA exerts a notable influence on both membrane structure and photosynthetic system. Athari and Talebi (2014) found significant effects of drought stress on various characteristics of plants, including height, number of capsules, number of seeds in capsule, unit seed weight, harvest index and seed yield, these characteristics have also exhibited a decline when the crop transitions from a normal irrigation to a drought condition. Kazemi (2014) reported that use of SA on sesame plants has experiencing with drought has resulted in an enhance in plant growth and seed yield, hence enabling plants to endure with adverse effect of drought. Khatiby *et al*. (2017) have reported an increase in seed number, seed weight and seed yield, when compared with normal irrigation (control) or drought stress during seed development stages, all recorded traits were more severe to drought during flowering stage. According to findings of Waseem *et al*. (2006b), utilization of SA has enhanced plant development and increased seed yield with mitigating adverse impacts of drought stress. Water deficiency is a key environmental constraint on economic development worldwide, particularly in arid and semiarid regions (Kadkhodaie *et al*., 2014). Drought is a significant determinant on sesame seeds composition for protein content, seed weight seed quality (You *et al*., 2019). Afshari *et al*. (2013) have studied the application of SA concentration (300 M) and observed better effects on plants as compared to other concentration. Drought has increased proline with improved morphological and physiological traits adding SA. Drought has increased proline content significantly as an avoidance-mechanism to counteract decreasing pressure potential in several plants due to deficiency of water (Ahmed and Ali, 2015). Proline has been found to have significant effects on scavenging of free radicals and stabilization of biological membranes (Verbruggen and Hermans, 2008), which helps to control cell metabolism and development drought. Bagheri *et al*. (2013) observed SA utilization had a favorable and statistically significant impact on yield. Notably, the highest yield recorded when SA applied. This study aimed to investigate the impact of four concentrations of (SA) foliar spray at three different levels of drought imposed to sesame on yield and chemical constituent grown in two different environments in Iraqi Kurdistan region.

Materials and Methods

The study was conducted during the period between 1st of May 2021 to 10th of September 2021 at the experimental farm in two different environments; Grdarasha field of Erbil Research Directorate, located at 36° 11' 3" N and 44° 1' 48" Elevation, 415m above sea level and in kifri county (Garmean district) located at 34° 40' 48" N and: 44° 59' 3" Elevation, 219m above sea level. It is worth mentioning that the distance between both locations were about 222 km. Some soil physiochemical properties of both locations are shown in Table 1. Meteorological data of season 2021-2022 is also shown in Table 2. Sesame seeds were received from Anbar Research Directorate sesame (Cv. Somar). A factorial experimental were set in completely randomized block design having three replications. Each plot was 2 x 3 m keeping 50 cm

Table 1: *Some of soil physiochemical properties for both study locations.*

Soil sample	EC ds/m	pH	N %	P %	K ppm	O.M %	Classification USDA			Soil texture
							Clay	Silt	Sand	
Grdarasha field	0.3	7.63	0.11	8.32	120.6	0.96	48.4	43.3	8.3	Silty clay
Kifri field	1.8	7.82	0.11	6	144	1.1	33.3	30	36.7	Clay laom

Table 2: *Meteorological data for both study locations during study Season 2021.*

Location	Grdarasha field 2021				Kifri field 2021			
Month	AirTC max	Air TC Min	Rain mm	Avg RH%	AirTC max	Air TC Min	Rain mm	Avg RH%
May	43	18.1	15.2	17.3	31.48	30.05	0	16.08
June	46.7	20.1	0	13.5	35.00	33.57	0	10.51
July	47.8	25.1	0	14.2	39.27	37.71	0	9.57
August	46.2	23.9	0	14.3	39.50	37.98	0	11.66
September	44.7	16.3	0	19.4	38.23	34.81	0	13.16

within plots and 100 cm between blocks spacing. Each plot consisted of 5 rows with 40cm distances, and 20cm within plants. The first factor was irrigation levels: control (S_0) normal irrigation i.e. irrigate on alternate day for 30min (6 L m^{-2}) from sowing until maturity, (S_1) drought imposition by no irrigation at flowering (65BBCH) i.e. from on 10th of July 2021 and (S_2) drought imposition by no further irrigation at seed production (79 BBCH) i.e. from 1st of August 2021. The second factor was four levels of Salicylic acid 0 ppm (sprayed with only water as control), 100, 200, and 300 ppm SA). Sesame plants were sprayed three time (36, 46, and 56) after sowing with 2 L knapsack sprayer which was calibrated to insure complete wetting of plant surface. Spray was conducted in evening to avoid the effect of high temperatures or excessive light. For the study, plots were plowed by two crossed plowing, land was levelled, then rows were established with chisel plow. Sowing was made on 1st of May 2021 at the Research center nurseries, then homogenized seedlings were transplanted on 24th May 2021 at kifri site and on 26th May at Grdarasha site. Nitrogen fertilizer was applied in two splits (80 kg ha^{-1}): First at seedlings transplanting and second 45 days from the first application. Phosphorus fertilizer was applied (80 kg d^{-1}) with seedlings planting. Hand weeding was conducted each 20 days after transplanting. Observation were made on plant height (cm), number of capsules per plant (capsule $plant^{-1}$), number of seeds per capsule (seed $capsule^{-1}$), weight of thousand seeds (g), seed yield (g d^{-1}), plant dry weight (g d^{-1}), biological yield (g d^{-1}), harvest index(%), nitrogen percentage by kjeldahl method (Saez-Plaza *et al.*, 2013), phosphorus (%), and potassium percentage (Allen *et al.*, 1974), carbohydrate percentage (%) (Hedge and Hofreiter, 1962), proline (ppm) (Bates *et al.*, 1973) and oil content (%) (Paquot, 2013) accordingly in laboratories of the Collage of Agricultural Engineering Sciences of Salahaddin university, and laboratories of the Ministry of Science and Technology, department of environment and water in Baghdad.

Statistical analysis

All recorded data were subjected to standard analysis of variance techniques and means were compared using Duncan Multiple Range Test (DMRT) at 5% of probability using SPSS computer analysis according to Field (2005) and Weinberg and Abramowitz, (2008).

Results and Discussion

Influence of salicylic acid (SA) and drought stress on yield (Location Erbil)

Results indicated that salicylic acid caused significant influence on plant height, number of capsules per plant, number of seed capsules per plant, plant dry weight, seed yields, 1000 seed weight, harvest index, and biological yield in (Table 3), where the highest data of plant height was (119.14 cm) registered in concentration of 100 ppm of SA. but the lowest value was (115.60 cm) recorded in (0 ppm) of SA. The highest readings of number of capsules (77.48 $plant^{-1}$), number of seeds capsule (57.77 $capsule^{-1}$) and seed yield (320.47 kg d^{-1}) were recorded in 300 ppm of SA, but the lowest readings of number of capsules $plant^{-1}$, number of seed $capsules^{-1}$, and seed yield were

Table 3: *Influence of salicylic acid (SA) and drought stress on crop yield (Erbil location).*

Treatment	Plant high (cm)	Capsules plant^{-1}	Seed capsule^{-1}	1000 seed weight (g)	Plant dry weight (kg.d^{-1})	Seed yield (kg d^{-1})	Biological yield (kg d^{-1})	HI%
Concentration of SA								
0ppm	115.60 b	62.89 c	54.85 b	3.47 b	1707.86 c	288.36 c	1996.22 c	14.44 b
100ppm	119.14 a	73.18 b	54.87 b	3.46 b	1942.7 a	300.06 b	2242.77 a	13.33 c
200ppm	115.75 b	74.48 b	56.82 ab	3.56 a	1607.16 d	318.17 a	1925.33 d	16.42 a
300ppm	118.79 a	77.48 a	57.77 a	3.43b	1833.33 b	320.47 a	2153.80 b	14.84 b
Drought stress								
S0(Control)	122.59 a	87.58 a	62.95 a	3.69 a	1805.99 b	338.85 b	2144.84 b	15.97 a
S_1(65BBH)	105.96 b	55.71 c	49.11 c	3.10 b	1506.51 c	231.53 c	1738.04 c	13.41 c
S_2(79BBH)	123.40 a	72.72 b	56.17 b	3.65 a	2005.80 a	349.91 a	2355.71 a	14.90 b
Concentration* drought stress								
C0 × S0	121.41 c	71.47 c	59.46 bc	3.71 ab	1796.87cd	330.19 c	2127.06de	15.53 b
C1 × S0	131.83 a	93.03 a	61.82 ab	3.57 c	2161.45 a	331.20 c	2492.66 b	13.29 e
C2 × S0	121.83 c	94.93 a	65.07 a	3.82 a	1588.54 f	328.72 c	1917.26 g	17.15 a
C3 × S0	115.32 d	90.90 a	65.46 a	3.67 bc	1677.08 ef	365.30 b	2042.39 ef	17.92 a
C0 × S1	103.31 e	52.70 e	52.87 e	3.12 d	1338.54 g	218.05 f	1556.59 i	14.03 c-e
C1 × S1	103.83 e	53.49 e	47.06 f	3.05 d	1718.75de	241.68 e	1960.43 fg	12.33 f
C2 × S1	102.76 e	53.37 e	48.55 f	3.15 d	1395.83 g	245.56 e	1641.40 i	14.97 bc
C3 × S1	113.96 d	63.29 d	47.94 f	3.08 d	1572.91 f	220.85 f	1793.76 h	12.31 f
C0 × S2	122.08 c	64.51 d	52.21 e	3.57 c	1988.16 b	316.83 d	2305.00 c	13.76 de
C1 × S2	121.77 c	73.00 c	55.73 de	3.75 ab	1947.91 b	327.31 c	2275.23 c	14.38 cd
C2 × S2	122.67 c	75.13 ab	56.84 cd	3.73 ab	1837.12 c	380.23 a	2217.35cd	17.16 a
C3 × S2	127.10 b	78.25 b	59.91 bc	3.54 c	2250.00 a	375.25 a	2625.25 a	14.31d

Within the individual factor or their interaction, the values that share the alphabet do not differ significantly according to the DMRT, 1955 at α 5%.

(62.89, 54.85 and 288.36), respectively, recorded in 0 ppm of SA. The highest value of 1000 seed weight was (3.56g) at a concentration of 200 ppm of SA, while the lowest value was (3.43g) at a concentration of 300 ppm of SA. The highest data of plant dry weight and biological yield were (1942.7 kg d^{-1} and 2242.77 kg d^{-1}), respectively, observed at concentrations of 100 ppm of SA, but the lowest data were (1607.16 kg d^{-1} and 1925.33 kg d^{-1}) at concentrations of 200 ppm of SA. The maximum reading of harvest index was 16.42% recorded at 200 ppm of SA, but the minimum data was 13.33% recorded at 100 ppm of SA. Severe drought cause stops plants from growing by changing activities like respiration, photosynthesis process, the translocation process, ion uptake, carbohydrates, nutrient metabolism, and growth regulators (Farooq *et al*., 2009).The result in table 3 illustrated that the drought stress caused a significant effect on plant height (cm), number capsule plant^{-1}, number seed capsule^{-1}, seed yield (kg d^{-1}), plant dry weight (kg d^{-1}), biological yield (kg d^{-1}), harvest index (%), and 1000 seed weight (g), of which the highest readings were (123.40, 87.58, 62.95, 2005.80, 349.91, 3.65, 2355.71, and 15.97), respectively. The number of capsules plant^{-1}, number of seeds capsule^{-1}, weight of 1000 seeds, and harvest index were recorded at full irrigation (control) treatment, while plant height, yield weight, weight of dry plants, and biological yield were recorded on irrigation stops at seed production (79BBCH). However, the lowest values of all parameters were (105.96, 55.71, 49.11, 1506.51, 231.53, 3.10, 1738.04, and 13.41) individually registered on irrigation stops at flowering (65BBCH). Soil moisture content during flowering stage have a significant impact on yield and yield component (Hussein *et al*., 2015). The interaction between salicylic acid concentration and drought stress caused significant differences in plant height, number of capsules per plant, number of seeds per capsule, weight of the dry plant, seed yield, weight of 1000 seeds, biological yield, and harvest index in Table 3 whereas the highest value of plant height (131.83 cm) was measured at concentrations of 100 ppm of SA and at full irrigations (control), but the lowest value was (103.31 cm) recorded at 0 ppm of

SA, and irrigation stops at flowering (65 BBCH). The highest values of number of capsules for a plant, and 1000 seed weight were (94.93 capsules plant^{-1}, and 3.82 g), respectively, recorded at concentrations of 200 ppm of SA under full irrigation (control) but for number of seeds per a capsule the data was 65.46 seeds capsule^{-1} registered with spraying of 300ppm SA and full irrigation. While the lowest value of number capsules per a plant was (52.70 capsules plant^{-1}) recorded at 0 ppm of SA and an irrigation stop at flowering (65BBCH), the highest value of number of seeds was (48.55 seeds capsule^{-1}) recorded at concentrations of 200 ppm of SA and an irrigation stop at flowering (65BBCH), and the weight of 1000 seeds was (3.05g) observed at concentrations of 100 ppm of SA and an irrigation stop at flowering (65BBCH). The highest values of weight of plant dry weight and biological yield were (2250 kgd^{-1} and 2625.25 kg d^{-1}) measured at concentrations of 300 ppm of SA and irrigation stop at seed production (79 BBCH); however, the lowest values were (1338.54 kg d^{-1} and 1556.59 kg d^{-1}) measured at concentrations of 0 ppm of SA and irrigation stop at flowering (65BBCH). The maximum reading of seed yield was (380.23 kg d^{-1}) measured at concentrations of 200 ppm of SA and an irrigation stop at seed production (79 BBCH), but the minimum data was (218.05 kg d^{-1}) recorded at concentrations of 200 ppm of SA and an irrigation stop at seed production (79BBCH). The highest harvest index reading (17.92%) was recorded at concentrations of 300 ppm of SA and in full irrigation (control). Application of salicylic acid increased the yield and mitigated the drought stress, so SA foliar spray may reduce water loss, enhance photosynthesis, regulate osmotic balance, and improve crop yield. The effectiveness of salicylic acid may depend on several factors, such as the concentration and timing of application, the severity and duration of drought stress, and the specific variety of sesame plant being grown. Our results, similar to those founded by Athari and Talebi (2014), Najafabadi and Ehsanzadeh (2017), and Kazemi (2014).

Influence of salicylic acid (SA) and drought stress on crop yield (Kifri Location)

Table 4 illustrates the significant differences between concentrations of salicylic acid on plant height, seed yield per a donum area (kg d^{-1}), weight of 1000 number

Table 4: *Influence of salicylic acid (SA) and drought stress on crop yield (Kifri location).*

Treatment	Plant height (cm)	Capsule plant^{-1}	Seed capsule^{-1}	Plant dry weight (kg d^{-1})	Seed yield (kg d^{-1})	1000 seed weight (g)	Biological yield (kg d^{-1})	HI %
Concentration								
0ppm	147.13a	142.73a	53.81ab	2907.98a	412.02a	3.33a	3320.01a	12.56c
100ppm	131.39c	134.16b	56.29a	2306.94c	380.25a	3.40a	2687.19c	14.83b
200ppm	129.18c	100.30d	56.50a	1809.03d	369.88b	3.32a	2178.91d	17.55a
300ppm	135.66b	114.57c	52.01b	2529.86b	327.56c	3.11b	2857.42b	12.05c
Drought stress								
S_0(control)	153.03a	155.21a	59.20a	2669.27a	407.79a	3.54a	3077.06a	13.71b
S_1 (65BBCH)	117.42c	72.47c	52.09c	1729.16b	353.38b	3.17b	2082.55b	17.45a
S_2 (79BBCH)	137.07b	141.14b	52.67b	2766.92a	356.11b	3.17b	3123.04a	11.59c
Concentration* drought stress								
C0 × S0	174.23a	199.3a	53.02de	3651.04a	483.45a	3.45a-c	4134.49a	11.71e
C1 × S0	145.97c	181.00b	61.54ab	2864.58c	438.42ab	3.64a	3303.00c	13.26de
C2 × S0	134.40d	111.35e	64.79a	1697.92f	354.44c-e	3.56ab	2052.35gh	17.3bc
C3 × S0	157.50b	129.20d	57.44b-d	2463.54de	354.84c-e	3.49a-c	2818.38ef	12.56e
C0 × S1	123.46e	90.09f	49.32ef	2260.41e	359.26c-e	3.28a-d	2619.68f	13.73de
C1 × S1	113.77f	74.97g	54.52c-e	1400.00g	322.72de	3.24b-d	1722.72i	18.73b
C2 × S1	110.21f	52.93h	52.75de	1437.5g	408.10 bc	3.3a-d	1845.60hi	22.19a
C3 × S1	122.26e	71.89g	51.76d-f	1818.75f	323.45de	2.86e	2142.20g	15.16cd
C0 × S2	143.70c	138.78cd	59.09bc	2812.50c	393.35bc	3.27a-d	3205.85cd	12.25e
C1 × S2	134.45d	146.52c	52.80de	2656.25cd	379.6b-d	3.32a-d	3035.85de	12.49e
C2 × S2	142.93c	136.63cd	51.96d-f	2291.67e	347.09c-e	3.11c-e	2638.76f	13.17de
C3 × S2	127.21e	142.63cd	46.82 f	3307.29b	304.40e	2.99de	3611.69b	8.44f

of capsules per plant, number of seed per a capsules, dry weight of a plant per donum area (kg d^{-1}), seeds (g), biological yield per donum area (kg d^{-1}), and harvest index (%). The highest value of plant height was 147.13cm recorded at a concentration of 0 ppm of SA, but the lowest value was 129.18 cm recorded at a concentration of 200 ppm of SA. The maximum data for the number of capsules per a plant was (142.73 capsules $plant^{-1}$) measured at a concentration of 0 ppm of SA, but the minimum data was (100.30 capsules $plant^{-1}$) measured at a concentration of 200 ppm of SA. However, the highest data on the number of seeds was (56.50 seeds $capsules^{-1}$) recorded at 0 ppm of SA; on the other side, the lowest data was (52.01 seeds $capsules^{-1}$) recorded at 200 ppm of SA. Additionally, the highest values of weight of dry plant and biological yield were (2907.98 k d^{-1} and 3320.01 kg d^{-1}) observed at 0 ppm of SA, but the lowest values were (1809.03 kg d^{-1} and 2178.91 kg d^{-1}) recorded at 200 ppm of SA. The highest data of seed yield and weight of 1000 seeds were (412.02 kg. d^{-1} and 3.40g), respectively recorded at a concentration of 0ppm and 100 ppm of SA, while the lowest data were (327.56 kg d^{-1} and 3.11g) recorded at a concentration of 300 ppm of SA. As well as the maximum data for harvest index was (17.55%) observed in 200 ppm of SA, the lowest data was (12.05%) recorded in concentration 300 ppm of SA. Salicylic acid at different concentrations doesn't directly increase yield but improves the adaptation of crops to drought stress. The effect of different concentrations of salicylic acid on several parameters was discovered, it may depend on the soil's composition, climate conditions, time of application, and plant variety. According to the result in Table 4, it was clearly observed that drought has a significant influence on all parameters, where the maximum data for all parameters were (153.03cm, 155.21 capsules $plant^{-1}$, 59.20 seeds $capsule^{-1}$, 407.79 kg d^{-1}, 3.54g, and 17.45%) respectively measured in full irrigation (control) treatments, except weight dry plant (2766.92 kg d^{-1}) and biological yield (3123 kg d^{-1}) were measured in irrigation stop at seed production (79BBCH) and harvest index, which was in irrigation stop at (65BBCH). The minimum values were (117.42cm, 72.47 capsules $plant^{-1}$, 52.09 seeds $capsules^{-1}$, 1729.16 kg d^{-1}, 353.38 kg d^{-1}, 3.17 g, 2082.55 kg d^{-1}, and 11.59%), respectively, measured in the irrigation stop at flowering (65BBCH), except harvest index was imposed in the irrigation stop at seed production (79BBCH). The negative effects of water deficiency are more pronounced during the flowering stage and post-flowering period compared to the vegetative stage, the results presented here align with the research conducted by (Rafiei and Asgharipur, 2009). Waseem *et al.* (2006) indicated that exogenous application of SA mitigated the drought stress at both studied stages, while different concentrations of SA enhanced the growth of sesame plants grown under drought stress at vegetative stages, so (SA) applications reduced the negative effect of drought and improved or increased sesame growth and yield. The interaction between both studied factors imposed significant differences within plant height, number of capsules per plant, number of seed per capsule, weight of dry plant, seed yield, weight of 1000 seeds, biological yield, and harvest index, of which the highest data were (174.23cm, 199.30 capsules $plant^{-1}$, 64.79 seeds $capsules^{-1}$, 3651.04 kg d^{-1}, 483.45 kg d^{-1}, 3.64 g, 4134.49kg d^{-1}, and 22.19 %), respectively, all parameters recorded in full irrigations (control) and concentration (0 ppm) of SA, except the number of seed capsules and weight of 1000 seeds, which were registered in concentration (100 ppm and 200 ppm) of SA and harvest index in the concentration 200 ppm of SA, and in irrigation stop at flowering (65 BBCH). The lowest values of plant height, number of capsules per plant were (110.21cm and 52.93capsules $plant^{-1}$) recorded in concentration of (200ppm) of SA, and irrigation stop at flowering stage (65BBCH), for the number of seed per capsule, seed yield and harvest index were (46.82 seeds $capsules^{-1}$, 304.4 kg d^{-1} and 8.44%) recorded at concentration of 300 ppm of SA, and irrigation stop at the seed production (79BBCH) while for weight of dry plant and biological yield were (1400 kg.d^{-1} and1722.72 kg d^{-1}) measured in concentration of (100ppm) of SA, and irrigation stop at flowering stage (65BBCH) but weight of 1000 seed was(2.86g) measured in concentration of (300ppm) of SA, and irrigation stop at flowering stage (65BBCH). As the water content of the soil decreases, plant roots signal air glands to increase resistance, in dry conditions air glands reduce transpiration and preserve leaf moisture, limiting growth (Masinde *et al.*, 2006).

Within the individual factor or their interaction, the values that share the alphabet do not differ significantly according to the DMRT, 1955 at α 5%

Influence of salicylic acid (SA) and drought stress on chemical contents (Erbil location)

The results in Table 5 indicated that salicylic acid

(SA) has a big impact on the chemical content at four different concentrations. The highest amounts of oil content, nitrogen content, phosphor content, potassium content, and carbohydrate content were found at 300 ppm of SA (51.50%,2.70%,6.82%,3.92%, and 25.36%), respectively, except for proline content was (28.75pppm) at concentration of 100 ppm of SA. Under drought-stress conditions, SA application increased the oil content, nitrogen, phosphorus, potassium, carbohydrate, and proline content of the sesame plants. Salicylic acid has a beneficial effect on plant growth and development, including the ability to enhance plant resistance to abiotic stresses such as drought stress (Dianat *et al*., 2016). Concentrations of 100 and 200 ppm of SA recorded the lowest data for amounts of oil content, nitrogen content, phosphor content, potassium content, and carbohydrate content were (51.12%, 2.63%, 6.74%, 3.885, and 25.26%), respectively, while concentrations of 300 ppm of SA recorded (28.24ppm) for proline content. Table 5 illustrate the significant differences between chemical constituent and drought stress, whereas the highest percentage of (oil content, nitrogen, phosphorus, potassium and carbohydrate were (51.805%, 2.685%, 6.865%, 3.94% and 25.37%) respectively recorded in full irrigation plots. Proline content was (28.72ppm) recorded at irrigation stop at flowering (65BBCH). The minimum data were (50.64%, 2.6355, 6.73%, 3.855 and 25.30%) respectively registered in irrigation stop at flowering (65BBCH) but proline (28.42ppm) was recorded in irrigation stop at seed production (79 BBCH). Accumulation of large amounts of proline is an adaptive response of plants exposed to stressful environments (Afshari *et al*., 2013). The interaction between salicylic acid concentration and drought stress caused significant differences within chemical plant constituents. The highest percentage of (oil content, nitrogen, phosphor, potassium and carbohydrate were (60.47%, 3.36%, 7.65%, 4.77% and 26.46%), respectively recorded in (100ppm) of SA, and full irrigations(control) but proline (30.16ppm) was recorded in concentration (200ppm) of SA, and irrigation stop at seed production (79 BBCH). Foliar spray of 300ppm SA resulted in the greatest proline concentration, on other hand the lowest percentage of (oil content, nitrogen, phosphor, potassium and carbohydrate (43.30%,1.95 %, 6.03 %, 3.15 %, and 24.16 %) respectively were recorded in (200ppm) of SA and irrigation stop at seed production (79 BBCH). Proline content was (27.03ppm) when recorded in concentration 300ppm of SA sprayed in irrigation stop at seed production (79 BBCH). The chemical content, in addition to their genetic characteristics, is influenced by some factors such as the environment factor, nutrition factors, planting date, harvest date, and the amount of moisture, results in table 5 agree with (Athari and Talebi, 2014; Ahmed and Ali, 2015; Khatiby *et al*., 2017; Abdulqader and Ali, 2021).

Table 5: *Influence of salicylic acid and drought stress on chemical content (Erbil location).*

Treatment	Oil content %	N %	P %	K %	CHO %	Proline (ppm)
Concentration						
0ppm	51.37 b	2.67b	6.81a	3.90ab	25.37a	28.68 b
100ppm	51.12 c	2.63c	6.79b	3.88 b	25.34a	28.75 a
200ppm	51.38 b	2.63c	6.74c	3.88 b	25.26b	28.74 a
300ppm	51.50 a	2.70a	6.82a	3.92 a	25.36a	28.24 c
Drought stress						
S_0(control)	51.80 a	2.68a	6.86a	3.94 a	25.37a	28.66 b
S_1 (65BBCH)	50.64 c	2.63b	6.73c	3.85 c	25.30b	28.72 a
S_2 (79BBCH)	51.61 b	2.67a	6.79b	3.90 b	25.33b	28.42 c
Concentration* Drought stress						
C0 × S0	45.85 j	2.21j	6.38j	3.35 j	24.62j	29.76 c
C1 × S0	60.47 a	3.36a	7.65a	4.77 a	26.46a	27.38 k
C2 × S0	53.92 e	2.81e	6.95e	4.13 e	25.55e	28.25 h
C3 × S0	46.95 i	2.35i	6.46i	3.53 i	24.85i	29.27 d
C0 × S1	49.74 g	2.55g	6.64g	3.83 g	25.26g	28.64 f
C1 × S1	44.17 k	2.10k	6.18k	3.25k	24.50k	30.02 b
C2 × S1	56.93 c	3.13 c	7.24c	4.36 c	26.06c	27.81 i
C3 × S1	51.71 f	2.73 f	6.86f	3.96 f	25.38 f	28.43 g
C0 × S2	58.54b	3.25b	7.43b	4.53b	26.23b	27.64 j
C1 × S2	48.73 h	2.44h	6.55h	3.64 h	25.07h	28.86 e
C2 × S2	43.30 l	1.95 l	6.03 l	3.15 l	24.16 l	30.16 a
C3 × S2	55.86d	3.03d	7.14d	4.27 d	25.85d	27.03 l

Within the individual factor or their interaction, the values that share the alphabet do not differ significantly according to the DMRT,1995 at α 5%

Influence of salicylic acid and drought stress on chemical contents in (Kifri location)

Table 6 observed that significant differences within the four concentration levels of salicylic acid on chemical content. The highest percentages of oil content, nitrogen, and phosphorus were (53.83%, 2.83%, and 7.21%), respectively, recorded in concentration 0ppm of SA. While the maximum percentages for carbohydrate and potassium were (25.80% and 4.40%), respectively, recorded in concentration of 300 ppm of SA. For the proline content the highest value was (28.03ppm) observed in 200 ppm of SA.

The lowest percentages of oil content, phosphorus, potassium, and carbohydrate were (53.44%, 7.145%, 4.40% and 25.73%), respectively recorded in concentration 100ppm of SA, and for proline, it was (27.75ppm) recorded in 100 ppm of SA, except the nitrogen percentage was (2.75%) recorded in 200 ppm of SA. According to the result in Table 6 illustrated drought stress has a significant influence on chemical content whereas the highest percentages of oil content, nitrogen, phosphorus, potassium, and carbohydrate (54.07 %, 2.83 %, 7.20 %, 4.38 %, and 25.82%), respectively, were recorded in full irrigation (control) except for proline content, which was (28.03 ppm) recorded in irrigation stop at flowering stage (65BBCH). Proline accumulation is a potential response to stress conditions, such as drought. It has been utilized as an indicator for selecting plants with high-stress tolerance (Chutipaijit *et al*., 2008). However, the lowest percentages of oil content, nitrogen, phosphorus, potassium, and carbohydrate were (53.06 %, 2.75%, 7.11%, 4.27%, and 25.68%), respectively recorded in irrigation stop at flowering (65BBCH), but for proline content was (27.59 ppm) in (full irrigation) plots. The interaction between salicylic acid concentration and drought stress caused significant differences within chemical constituents. The highest percentages of seed content of oil content, nitrogen, phosphorus, potassium, and carbohydrate were (63.86 %, 3.58 %, 8.15 %, 5.33 %, and 27.05%), respectively, documented with 100 ppm of SA in full irrigation (control) plots, but for proline content, it was (29.79 ppm) recorded in 200 ppm of SA. and irrigation stop at the seed production (79 BBCH). The lowest percentages of oil content, nitrogen, phosphorus, potassium, and carbohydrate were (45.755, 2.07%, 6.23%, 3.25%, and 24.56%), respectively, recorded in concentration of 200 ppm of SA, and irrigation stop at seed production (79 BBCH), however, for proline content was (25.15ppm) in concentration of 100 ppm of SA and full irrigation (control) treatments, this results was supported by other researchers, who found that drought stress had a significant effect to increasing the amount of proline in the leaves. Proline accumulation is a potential response to stress conditions, such as drought. It has been utilized as an indicator for selecting plants with high-stress tolerance (Chutipaijit *et al*., 2008). This amino acid builds up as a general way for plants to adapt to osmotic stress, results in table 5, 6 clearly indicated almost similar to the results of some researchers, Kadkhodaie *et al*. (2014), Afshari *et al*. (2013), and Khatiby *et al*. (2017).

Table 6: *Influence of salicylic acid and drought stress on chemical contents (Kifri location).*

Treatment	Oil content %	N %	P %	K %	CHO %	Proline (ppm)
Concentration						
0ppm	53.83a	2.83a	7.21a	4.33b	25.78a	27.85b
100ppm	53.44d	2.77b	7.14c	4.27c	25.73b	27.57c
200ppm	53.72b	2.75b	7.15bc	4.31b	25.74b	28.03a
300ppm	53.55c	2.82 a	7.16b	4.40 a	25.8a	27.86b
Drought stress						
S_0(control)	54.07a	2.83a	7.2a	4.38a	25.82a	27.59c
S_1 (65BBCH)	53.06c	2.75c	7.11c	4.27c	25.68c	27.98a
S_2 (79BBCH)	53.77b	2.80b	7.18b	4.33b	25.79b	27.9b
Concentration* Drought stress						
C0 × S0	47.81j	2.33j	6.58j	3.66j	24.95j	29.15c
C1 × S0	63.86a	3.58a	8.15a	5.33a	27.05a	25.15 l
C2 × S0	55.71e	2.94e	7.34e	4.65e	26.13e	27.45h
C3 × S0	48.91i	2.46i	6.76i	3.88i	25.17i	28.63d
C0 × S1	52.40g	2.72g	7.04g	4.16g	25.56g	28.03f
C1 × S1	46.32k	2.16k	6.37k	3.44k	24.77k	29.33b
C2 × S1	59.71c	3.26c	7.87c	5.05c	26.55c	26.86j
C3 × S1	53.82f	2.87f	7.16f	4.45f	25.86f	27.72g
C0 × S2	61.28b	3.45b	8.03b	5.17b	26.84b	26.36k
C1 × S2	50.13h	2.57h	6.89h	4.03h	25.37h	28.25e
C2 × S2	45.75 l	2.07 l	6.23 l	3.25 l	24.56 l	29.79a
C3 × S2	57.91d	3.14d	7.57d	4.86d	26.39d	27.22i

Within the individual factor or their interaction, the values that share the alphabet do not differ significantly according to the DMRT,1995 at α 5%.

General discussion

Water stress causes a reduction in nutrient uptake in sesame plants due to minimizing the process of nutrient translocation from the roots to the shoot parts, which may lead to a reduction of important elements, when shows the result in Tables 5 and 6 similar to result was founded by (Najafabadi and Ehsanzadeh, 2017b). The presence of water deficiency during the vegetative stage of plant growth has been found to have detrimental effects on grain yields, which stress leads to a reduction in plant size, leaf area, and root growth. Additionally, it causes inadequate growth and dry matter in the capsule and ultimately results in an inadequate yield index. The data in tables 3 and 4 show that research has shown that the negative effects of water scarcity are more pronounced during the flowering stage and post-flowering period compared to the vegetative stage.

The results presented here align with the research conducted by (Rafiei and Asgharipur, 2009). Salicylic acid can enhance root development and improve water uptake efficiency, allowing plants to access and absorb water more effectively even under water-limited conditions. This can help maintain proper plant hydration and reduce the negative impacts of water stress on growth and yield. This hormonal crosstalk and regulation contribute to better stress adaptation and ultimately higher yield. It's important to note that the effects of salicylic acid on sesame plants may vary depending on the concentration of SA, timing, and application method of the treatment, as well as the specific environmental conditions. Salicylic acid acts as a signaling molecule that can trigger the expression of various stress-responsive genes. All attributes were more intense during the flowering stage of drought stress compared to seed production, the control stage, and normal watering (Waseem *et al*., 2006a). However, there were three primary mechanisms reduce crop yield due to insufficient soil-moisture: (i) decline canopy absorption of photo synthetically active radiation; (ii) decline radiation use efficiency, (iii) decline harvest index (Farooq *et al*., 2009). During drought stress, plants accumulate proline to increase their internal solute concentration, which helps retain water within the cells.

Conclusions and Recommendations

It was concluded that lack of water during sesame crop flowering and the seed production stages affected plant development and crop yield, while the influence of drought stress on all measured parameters was more significant when irrigation stops at the flowering (65BBCH) compared to irrigation stops at the seed production (79BBCH). Utilizing salicylic acid at a concentration of 300 ppm shows potential for improving the productivity of plants in normal and drought conditions. An increased amount of salicylic acid has been found to improve seed production and increase the ability of plants to adapt in response to drought stress.

AcknowledgmentS

Authors would like to thank the staff of the both researching fields (Erbil Agricultural Research Directorate), kifri filed (Garmian), with special thanks for Al-Anbar Research directorate for providing us with Sesame crop seeds.

Novelty Statement

This study aimed to investigate the impact of Salicylic acid foliar application and drought stress on sesame crop yield and chemical constituent grown in two different environments in Iraqi Kurdistan region.

Author's Contribution

Nask Jawher Ahmed: Conductor of the experiments and wrote the manuscript.
Kawa A. Ali: Supervised the study.

Conflict of interest
The authors have declared no conflict of interest.

References

Abdul-Qader, N.F. and K.A. Ali. 2021. Effect of different fertilizers and sowing date on growth, yield, and yield components of Sesame (Sesame *indicum L*.). Zanco J. Pure Appl. Sci., 33: 1-11. https://doi.org/10.21271/ZJPAS.33.3.1

Afshari, M., F. Shekari, R. Azimkhani, H. Habibi and M. Fotokian. 2013. Effects of foliar application of salicylic acid on growth and physiological attributes of cowpea under water stress conditions. Iran Agric. Res., 32: 55-70.

Ahmed, N.J. and K.A. Ali. 2015. Influence of different levels of water stress on some physiological traits of five wheat (*Triticum* spp.) cultivars. Garmian Univ. J., 1: 436-455.

Ajithkumar, I.P. and R. Panneerselvam. 2013. Osmolyte accumulation, photosynthetic pigment and growth of *Setaria italica* (L.) P. Beauv. under drought stress. Asian Pac. J. Reprod., 2: 220-224. https://doi.org/10.1016/S2305-0500(13)60151-7

Aldesuquy, H. and H. Ghanem. 2015. Exogenous salicylic acid and trehalose ameliorate short term drought stress in wheat cultivars by up-regulating membrane characteristics and antioxidant defense system. J. Hortic., 2(139): 2376-0354. https://doi.org/10.4172/2376-0354.1000139

Allen, S.E., H.M. Grimshaw, J.A. Parkinson and C. Quarmby. 1974. Chemical analysis of ecological materials, Blackwell Scientific Publications.

Allison, P.D., 2010. Survival analysis using SAS: A practical guide, Sas Institute.

Athari, S.N. and R. Talebi. 2014. Effect of exogenous foliar salicylic acid application on sesame (*Sesamum indicum L.*) morphological characters, seed yield and oil content under different irrigation regimes. Int. J. Biosci., 5: 70-74. https://doi.org/10.12692/ijb/5.9.70-74

Ayoubizadeh, N., G. Laei, M.A. Dehaghi, J.M. Sinaki and S. Rezvan. 2018. Seed yield and fatty acids composition of sesame genotypes as affected by foliar application of iron nano-chelate and fulvic acid under drought stress. Appl. Ecol. Environ. Res., 16: 7585-7604. https://doi.org/10.15666/aeer/1606_75857604

Bagheri, E., S.J. Masood, F.M. Baradaran and E.M. Abedini. 2013. Evaluation of salicylic acid foliar application and drought stress on the physiological traits of sesame (*Sesamum indicum*) cultivars.

Bates, L., R.A. Waldren and I. Teare. 1973. Rapid determination of free proline for water-stress studies. Plant Soil, 39: 205-207. https://doi.org/10.1007/BF00018060

Bedigian, D. and J.R. Harlan. 1986. Evidence for cultivation of sesame in the ancient world. Econ. Bot., 40: 137-154. https://doi.org/10.1007/BF02859136

Chutipaijit, S., S. Chaum and K. Sompornpailin. 2008. Influence of drought stress on proline and anthocyanin accumulations in indica rice cultivars. KMITL Sci. J., 82(B): 8.

Sepeardaiizadeh, R., 1999. Effect of harvest time on seed yield and quality and storability of different cultivars of canola. M. Sc. thesis. The University of Guilan. pp. 479. (In Persian).

Shamrad, H.Y. and K.A. Shakir. 2019. Sesame oil extraction and antioxidant activity of lignans from locally cultivated sesame seeds (*Sesamum indicum* L.). Iraqi J. Agric. Sci., 50(1): 382-389.

Dianat, M., M.J. Saharkhiz and I. Tavassolian. 2016. Salicylic acid mitigates drought stress in *Lippia citriodora* L.: Effects on biochemical traits and essential oil yield. Biocatal. Agric. Biotechnol., 8: 286-293. https://doi.org/10.1016/j.bcab.2016.10.010

Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S. Basra. 2009. Plant drought stress: Effects, mechanisms and management. Sustain. Agric., pp. 153-188. https://doi.org/10.1007/978-90-481-2666-8_12

Gharby, S., H. Harhar, Z. Bouzoubaa, A. Asdadi, A. El-Yadini and Z. Charrouf. 2017. Chemical characterization and oxidative stability of seeds and oil of sesame grown in Morocco. J. Saudi Soc. Agric. Sci., 16: 105-111. https://doi.org/10.1016/j.jssas.2015.03.004

Hedge, J. and B. Hofreiter. 1962. Estimation of carbohydrate. Methods in carbohydrate chemistry. Academic Press, New York. pp. 17-22.

Hussein, Y., G. Amin, A. Azab and H. Gahin. 2015. Induction of drought stress resistance in sesame (*Sesamum indicum* L.) plant by salicylic acid and kinetin. J. Plant Sci., 10: 128. https://doi.org/10.3923/jps.2015.128.141

Hayat, Q., S. Hayat, M. Irfan and A. Ahmad. 2010. Effect of exogenous salicylic acid underchanging environment: A review. Environ. Exp. Bot., 68: 14-25. https://doi.org/10.1016/j.envexpbot.2009.08.005

Jat, M., P. Yadav, R. Singh, A. Tikkoo and R. Dadarwal. 2020. Response of phosphorus in sesame (*Sesamum indicum* L.) on coarsetextured soils of South West Haryana. J. Pharma. Phytochem., 9: 2098-2101.

Joseph, B., D. Jini and S. Sujatha. 2010. Insight into the role of exogenous salicylic acid on. Asian J. Crop Sci., 2: 226-235. https://doi.org/10.3923/ajcs.2010.226.235

Kadkhodaie, A., J. Razmjoo, M. Zahedi and M. Pessarakli. 2014. Oil content and composition of sesame (*Sesamum indicum* L.) genotypes as affected by irrigation regimes. J. Am. Oil Chem. Soc., 91: 1737-1744. https://doi.org/10.1007/s11746-014-2524-0

Kazemi, M., 2014. Effect of foliar application with salicylic acid and methyl jasmonate on growth, flowering, yield and fruit quality of tomato. Bull. Environ. Pharmacol. Life Sci., 3: 154-158.

Khatiby, A., F. Vazin, M. Hassanzadeh and A.A. Shadmehri. 2017. Effect of foliar application with salicylic acid on some morphological and physiological characteristics of sesame (*Sesamum indicum* L.) under drought stress. https://doi.org/10.1515/cerce-2016-0034

Masinde, P.W., H. Stützel, S.G. Agong and A. Fricke. 2006. Plant growth, water relations and transpiration of two species of African nightshade (*Solanum villosum* Mill. ssp. miniatum (Bernh. ex Willd.) Edmonds and S. sarrachoides Sendtn.) under water-limited conditions. Sci. Horticultur., 110(1): 7-15.

Najafabadi, M.Y. and P. Ehsanzadeh. 2017a. Salicylic acid effects on osmoregulation and seed yield in drought-stressed sesame. Agron. J., 109: 1414-1422. https://doi.org/10.2134/agronj2016.11.0655

Najafabadi, Y.M. and P. Ehsanzadeh. 2017b. Photosynthetic and antioxidative upregulation in drought-stressed sesame (*Sesamum indicum* L.) subjected to foliar-applied salicylic acid. Photosynthetica, 55: 611-622. https://doi.org/10.1007/s11099-017-0673-8

O'rourke, N. and L. Hatcher. 2013. A step-by-step approach to using SAS for factor analysis and structural equation modeling, Sas Institute.

Paquot, C., 2013. Standard methods for the analysis of oils, fats and derivatives, Elsevier.

Rafiei, S. and M. Asgharipur. 2009. Yield reaction and morphological characteristics of some mung bean genotypes to drought stress. J. Modern Agr Knowl., 5: 67-76.

Richards, R.A., 2006. Physiological traits used in the breeding of new cultivars for water-scarce environments. Agric. Water Manage., 80: 197-211. https://doi.org/10.1016/j.agwat.2005.07.013

Sáez-Plaza, P.M., J. Navas, S. Wybraniec, T. Michałowski and A.G. Asuero. 2013. An overview of the Kjeldahl method of nitrogen determination. Part II. Sample preparation, working scale, instrumental finish, and quality control. Crit. Rev. Anal. Chem., 43: 224-272.

Verbruggen, N. and C. Hermans. 2008. Proline accumulation in plants: A review. Amino Acids, 35: 753-759. https://doi.org/10.1007/s00726-008-0061-6

Waseem, M., H.H.U.R. Athar and M. Ashraf. 2006. Effect of salicylic acid applied through rooting medium on drought tolerance of wheat. Pak. J. Bot., 38: 1127-1136.

Weinberg, S.L. and S.K. Abramowitz. 2008. Statistics Using SPSS. Cambridge University Press.UK.

You, J., Y. Zhang, A. Liu, D.Li, X. Wang, K. Dossa, R. Zhou, J. Yu, Y. Zhang and L.Wang. 2019. Transcriptomic and metabolomic profiling of drought-tolerant and susceptible sesame genotypes in response to drought stress. BMC Plant Biol., 19: 1-16. https://doi.org/10.1186/s12870-019-1880-1

Zenawi, G. and A. Mizan. 2019. Effect of nitrogen fertilization on the growth and seed yield of sesame (Sesamum *indicum* L.). Int. J. Agron., 2019: 7 pages. https://doi.org/10.1155/2019/5027254

Zhang, H., D.R. Langham and H. Miao. 2021. Economic and academic importance of sesame. Sesame Genome, pp. 1-18. https://doi.org/10.1007/978-3-319-98098-0_1