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Enhancing Oat Yield and Yield components by Salicylic Acid in Different agro-ecosystem

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ABSTRACT

Climate elements including temperature, humidity, and precipitation all are effects on crop growth and development especially in the arid and semi-arid areas of Northern parts of Iraq. Recently, the stresses of global climate change appear as an effective challenge, so, this study was carried out at two different locations in the Northern part of Iraq; Koya/Erbil and Altun Kopru/Kirkuk to study the effects of salicylic acid (SA) (0, 100, 200, and 300 ppm) twice as foliar spraying on five oat varieties. Results indicate that the Koya district environment significantly improved most studied characteristics, except for panicle number, compared to Altun Kopru. Except the harvest index (HI) which was non-significant, 100 and 200 ppm of SA improved significantly all studied characteristics compared to the control and 300 ppm of SA. Kangaroo, ICARDA Short, and ICARDA Tall varieties were the tallest plants (85.969, 83.469, and 82.833 cm) respectively. Each of Possum and ICARDA Short varieties were superior in panicle number, seed yield, biological yield, and straw yield. Kangaroo variety has the lowest harvest index (42.695%)significantly compared to all other varieties, whereas ICARDA Short variety was the lowest in panicle grain weight(0.898 g/panicle^{-1}).

Index Terms: *Avena sativa* L., Arid and Semiarid Area, Climate Change, Eco-Physiology, Salicylic Acid, Phytohormones.

1. INTRODUCTION

Oat (*Avena sativa* L.),is a small but important grain cereal and forage crop, ranked sixth in grain production after maize, rice, wheat, barley, and sorghum [1]. However, it is consider as one of the important grain crops, which its importance is coming from its multiple uses, where it is consumed by human and as feed for livestock, where it is rich in starch, glucan, protein, antioxidants, and fat [2]. Iraq, especially the Northern part is considered as semiarid area [3] and it depends on rainfall for irrigation which is the main factor for decreasing grain production in the Northern part of Iraq, so, any fluctuations in the ecological characteristics especially temperature and misdistribution of precipitation affects grain production. More warmer climate shortens crop growth including the grain filling period and decreases the photosynthesize accumulation, enhancing leaves senescence and increase plant respiration [4], [5]. For each Celsius degree rise in mean air temperature global is linked to an average drop of at least 3.1% in global yields of major crops [6].

Consequently, to decrease the adverse effects of stress on plants, many strategies were applied including genetically modified plants or varieties, in addition to the use of salicylic acid (SA) to increase yield and yield component [7]–[9]. SA is a safe phenolic compound for human health and it is an endogenous plant hormone it is produced normally in very small quantities. SA regulates many biochemical and physiological processes in plants such as seed germination,

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growth of plants, flower induction, uptake of nutrients, membrane permeability, transport, plant-water relations, stomatal conduction, photosynthesis, and enzyme activities [10]. Several researches have reported that foliar application of SA results in a significant effect on plant adaptation to stress factors, as SA actions as a natural signaling particle targeting different plant species to increase their tolerance to abiotic pressures, and in plant response to environmental stress [11], [12].

High oat crop production due to good varieties, intensive cultural management practices, and relatively good weather conditions [13]–[17].

While previous studies have explored the effects of SA on crop yields, few have focused on its application in arid and semi-arid regions, particularly for oat varieties, so the aim of this study is an attempt to investigate the effects of two different ecological conditions on yield and yield components of five varieties of oat under SA application and the possibility of exploiting low-rainfall lands for grain production and providing cheap food for humans and animals. We hypothesized that SA application would significantly improve oat yield components, particularly under the stress conditions of arid and semi-arid environments.

2. MATERIALS AND METHODS

2.1. Study Area

The study area is demonstrated in the Fig. 1 a which shows the locations of each of Koya in Erbil governorate, Iraq (latitude 36.1° N and Longitude 44.6°, Elevation 560 msal), and Altun Kopru in Kirkuk governorate Iraq (latitude 35.8° N and Longitude 44.2°, Elevation 285 msal), while Fig. 1b provides a detailed map of the study sites.

2.2. Plant Materials, Cultivation, and Treatments

A Field experiment was carried out in the winter season of 2019–2020 at two different locations; the fields of the agricultural research station at Koya/Erbil (latitude 36.1° N and Longitude 44.6°, Elevation 560 msal), and a private field at Altun Kopru/Kirkuk (latitude 35.8° N and Longitude 44.2°, 285 msal) to study the effects of four concentrations of SA (0, 100, 200, and 300 ppm) mentioned as SA0, SA100, SA200, and SA300, these concentrations of SA were selected based on previous studies showing optimal yield improvements at these levels ,where one gram of SA was added to one liter of water and mix well to get the concentration 1000 ppm (stock solution). One part of the stock solution added to nine parts of water to get 100 ppm, we take two part of stock solution add to eight parts of water to get 200 ppm, and so on three part of the stock solution added to seven parts of water to get 300 ppm. The solutions applied twice as foliar spraying until a complete wetting, first spray was applied at tillering stage, and the second at flowering stage, 0.1% detergent was added to the treatment solutions as a surfactant chemical. Five oat varieties obtained from College of Agriculture, Tikrit University were used in the study, three Australian varieties; Kangaroo, Mitika, Possums, and two varieties from ICARDA, which were ICARDA Short and ICARDA Tall.

The experimental design was a randomized complete block in split-split plots. Main plots consisted of two locations (Altun Kopru and Koya), subplots consisted of SA concentration and sub-subplots consisted of varieties; the soil was plowed and smoothed then, the planting was carried out on lines with a distance between one line and another is 20 cm. Crop services including fertilization and weed control were carried out as needed. The seeds were cultivated at 15 and 17 December 2019 in both locations, respectively, and the plants were harvested on the 20 and 22 of June 2020 after reaching the stage of full maturity in both locations, respectively.

2.3. Studied Characteristics

During the physiological maturity plants height was measured from the soil surface to the plant panicle base to calculate the average height in cm for twenty plants, and the number of panicles per square meter of midline from each experimental unit where measured by calculating the total effective spikes [18].

At the day of harvesting, yield and yield components were evaluated as it mentioned by Al-Jobouri [19] which included; panicle grain yield (g/panicle^{-1}) which was measured from one-meter length of one midline from each experimental unit, grain yield (ton/hectare) was calculated from the yield of the harvested area of one-meter length of midline from each experimental unit and converted to ton/hectare, biological yield (ton/hectare) was calculated from the weight of the entire dry plants harvested above soil and for an area of 1 m length of midline and then converted to ton/hectare. Straw yield is the biological yield without grain yield. The percent of the harvest index (HI) denotes the ratio of economic yield to biological yield and It was calculated from the following equation:

Harvest index = (grain yield/Biological yield) × 100 [20]

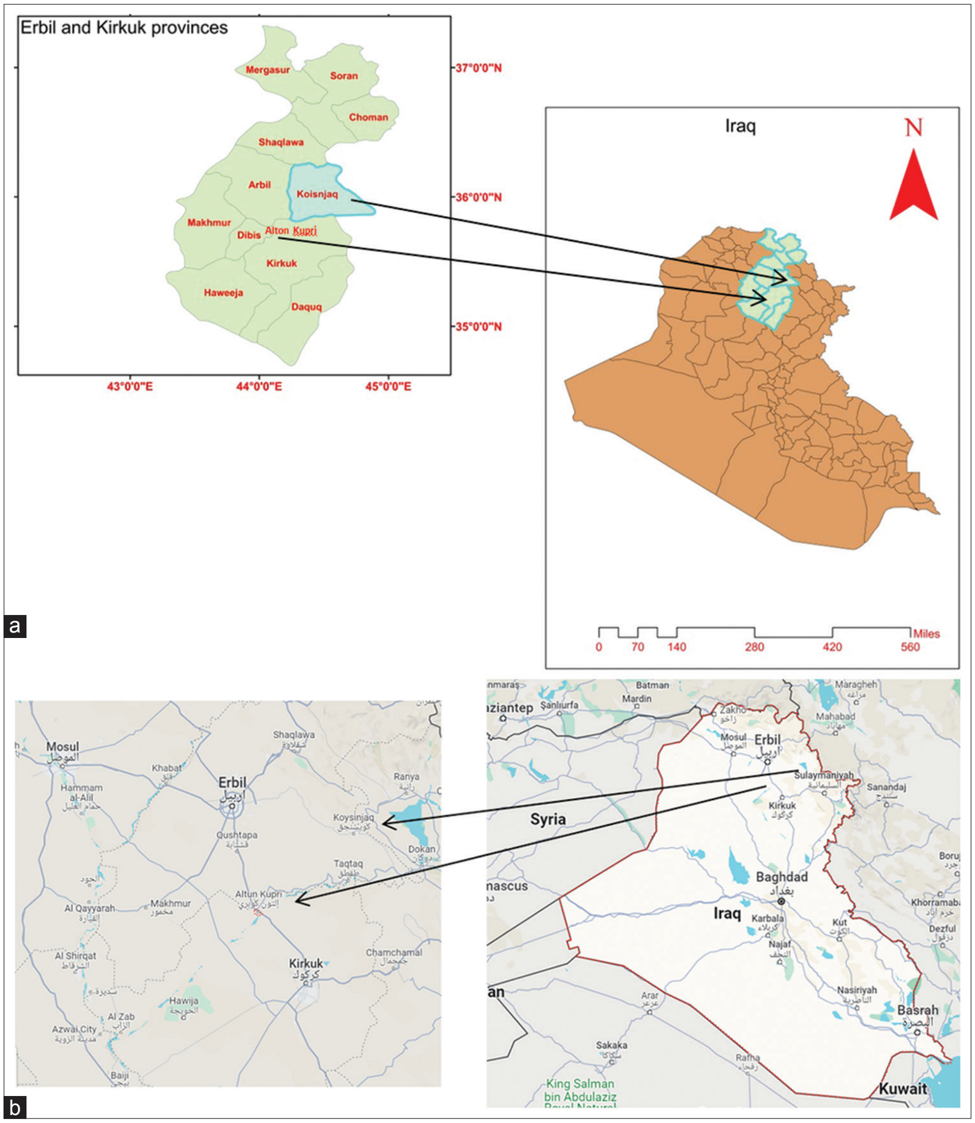

Fig. 1. (a) The areas of the study, (b) detailed map of the study sites.

2.4. Soil Characteristics and Meteorological Data

Table 1 shows some physical and chemical characteristics of the study area soils, whereas Fig. 2 shows some meteorological data of the study locations during the study period.

Soil analysis was done in the Kirkuk Agricultural Directorate in Soil Department Laboratory

2.5. Statistical Analysis and Experimental Design

Data were submitted for analysis of variance, the mean separation among treatment means for locations, SA concentration, and varieties by using Duncan's Multiple Range test at a probability level of %5 was used for comparing between experiment means using the SAS program version 9.4 [21].

3. RESULTS AND DISCUSSION

Results revealed that locations and their ecological contributions significantly affect on all studied characteristics except the straw yield. Koya district environment condition was more favorable for the plant growth and development excluding panicle number, compared to Altun Kopru district.

Regarding plant height, plant growth was better and plant height increased significantly in Koya district (74.898 cm)

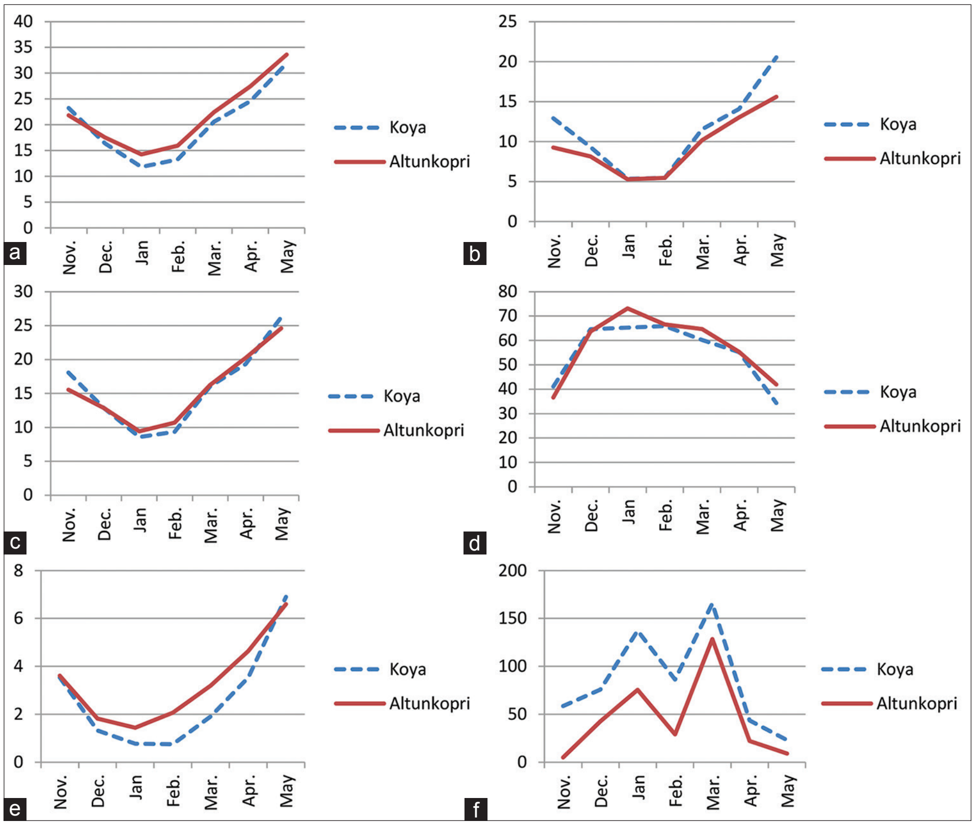

Fig. 2. Meteorological data of the study locations; Koya- Erbil, and Altun Kopru- Kirkuk During November 2019–May 2020. (a) Maximum temperature (◦C), (b) minimum temperature (◦C), (c) temperature average (◦C), (d) relative humidity (%), (e) evaporation (mm), (f) Precipitation (mm).

TABLE 1: Physical and chemical analysis for the study soils during winter season

Physical soil properties	pH	Ec (ms.cm^{-1})	O. M (%)	N (ppm)	P (ppm)	K (ppm)	Sand (%)	Silt (%)	Clay (%)	Texture
Koya	7.6	0.30	1.20	1200	8.80	120	18.3	41.1	40.6	Silty clay
Altun Kopru	6.8	0.12	0.62	350	1.26	106	66.0	16.0	18.0	Sandy loam

compared to Altun Kopru (70.646 cm)as it shown in table 2. The variety Kangaroo(85.969 cm) with ICARDA Short (83.469 cm) and Tall (82.833 cm)varieties gave highest plants significantly compared to other two Australian varieties Mitika(53.531 cm) , Possum (58.058 cm). Salicylic acid application had a significant effect in increasing plant height especially the low concentration 100 ppm which reached (75.522 cm), whereas increasing the concentration to 200 and 300 ppm which reached (73.800 ,70.875 cm) respectively led to non-significant effects compared to the control treatment (70.892 cm).Kangaroo variety regardless SA concentration gave the highest plants, and to some extend plants of each of ICARDA Short, ICARDA Tall compared to Mitika and Possum varieties.

In this study, it was shown that the number of branches was equal to the panicle number for all experimental units, so it was excluded from the result and we depend on panicle number only. Table 3 shows that the panicle number for Altun Kopru plants increased significantly to 85.033 panicle/m^{-1} compared to Koya district (79.45 panicle/m^{-1}). The Australian variety Possum, with ICARDA Short, gave the highest panicle number reached 94.313 and 90.396 panicle/m^{-1} significantly compared to all other varieties, whereas the lowest number recorded for the Kangaroo variety (68.646 panicle/m^{-1}). The application of SA regardless the concentration increased panicle number significantly compared to the control treatment which recorded the lowest value (76.367 panicle/m^{-1}), whereas the SA at 200 ppm increased them to 86.55 panicle/m^{-1} significantly compared to the concentration of 300 ppm SA.

Panicle number in the variety Possum increased significantly to 104.25 panicle/m^{-1} where they received SA at 200 and 300 ppm, whereas the variety Kangaroo that didn`t receive SA gave the lowest panicle number (59.583 panicle/m^{-1}).

As it reported in Table 3 the panicle number in the Koya district was less than Altun Kopru, which led to distribute the photosynthetase to the lowest number of panicles, as a result to increase the weight of panicles grain weight of plants grown in Koya district to 1.174 g/panicle^{-1} compared to ALtun Kopru (0.857 g/panicle^{-1}) (this effect was followed by other yield components), this effect was continue for the varsities, Possum and ICARDA Short where they gave the highest panicle number and the lowest panicle yield (Table 4) whereas the highest panicle grain yield recorded for other varieties, especially the Kangaroo

TABLE 2: Effect of SA concentrations, oat varieties, and their interactions on plant height (cm) at Koya and Altun Kopru

Varieties	SA (ppm)				Varieties means
	0	100	200	300	
Kangaroo	83.500[a-d]*	87.500[a,b]	88.500[a]	84.375[a-c]	85.969[a]
Mitika	50.875[g]	55.625[f,g]	52.375[f,g]	55.250[f,g]	53.531[c]
Possum	54.375[f,g]	62.608[e]	59.000[e,f]	56.250[e-g]	58.058[b]
ICARDA short	84.750[a-c]	83.250[a-d]	89.125[a]	76.750[d]	83.469[a]
ICARDA tall	80.958[b-d]	88.625[a]	80.000[c,d]	81.750[a-d]	82.833[a]
SA Mean	70.892[b]	75.522[a]	73.800[a,b]	70.875[b]	
Locations mean					
Koya			Altun Kopru		
74.898[a]			70.646[b]		

*Means followed by the same letters for factors and their interactions are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test and vice versa. SA: Salicylic acid.

TABLE 3: Effect of SA concentrations, oat varieties, and their interactions on panicles number (panicle/m^{-1}) at Koya and Altun Kopru

Varieties	SA (ppm)				Varieties means
	0	100	200	300	
Kangaroo	59.583[j]*	77.500[e-h]	65.000[i,j]	72.500[f-i]	68.646[d]
Mitika	66.500[h-j]	78.750[d-g]	83.500[c-f]	70.750[g-j]	74.875[c]
Possum	82.500[c-g]	86.250[c-e]	104.250[a]	104.250[a]	94.313[a]
ICARDA short	90.083[b-d]	99.750[a,b]	94.500[a-c]	77.250[e-h]	90.396[a]
ICARDA tall	83.167[c-f]	80.500[d-g]	85.500[c-e]	82.750[c-g]	82.979[b]
SA Mean	76.367[c]	84.550[a,b]	86.550[a]	81.500[b]	
Locations mean					
Koya				Altun Kopru	
79.450[b]				85.033[a]	

*Means followed by same letters for factors and their interactions are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test and vice versa. SA: Salicylic acid

TABLE 4: Effect of SA concentrations, oat varieties and their interactions on panicle grain weight (g/panicle^{-1}) at Koya and Altun Kopru

Varieties	SA (ppm)				Varieties means
	0	100	200	300	
Kangaroo	1.066[a-e]*	1.015[a-e]	1.176[a-c]	1.062[a-e]	1.080[a]
Mitika	1.129[a-d]	0.939[b-e]	1.207[a,b]	1.022[a-e]	1.074[a]
Possum	0.895[c-e]	1.096[a-e]	0.928[b-e]	0.925[b-e]	0.961[a,b]
ICARDA short	0.976[a-e]	0.975[a-e]	0.844[d, e]	0.798[e]	0.898[b]
ICARDA tall	1.129[a-d]	1.247[a]	1.045[a-e]	0.826[d,e]	1.062[a]
SA mean	1.039[a,b]	1.054[a]	1.040[a,b]	0.926[b]	
Locations mean					
Koya			Altun Kopru		
1.174[a]			0.857[b]		

*Means followed by same letters for factors and their interactions are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test and vice versa. SA: Salicylic acid variety (1.08 g/panicle^{-1}). Increasing SA increased the panicle yield but non-significantly compared to the control treatment, whereas increasing the concentration to 300 ppm decreased it to 0.926 g/panicle^{-1} significantly compared to 100 ppm treatment (1.054 g/panicle^{-1}).

Each of seed yield, biological yield, and HI increased significantly in the Koya district compared to Altun Kopru, where environmental differences between them such as maximum temperature during the study period was less compared to Altun Kopru (Fig. 1), in addition, the minimum temperature in the beginning of crop establishment branching stages was higher in Koya district compared to Altun Kopru, although the average temperature was approximately similar for both districts (Fig. 1), where this different, especially in the plants' establishment was clear in the different in panicles number (Table 3).

Increasing precipitation amount and decreasing evaporation in the Koya district might be in the interest of increasing the yield and its components compared to the Altun Kopru environment. The great effects of thermal factor and precipitation on the growth and development of oat crop was also studied by [22], [23] also found that climate change in the semi-arid region leads to a negative effect on oats growth, and a reduction in oats production. Our findings are consistent with those of [24], who reported that SA application improved plant tolerance to abiotic stress.

Regarding the variety, although of their significantly low panicle seed weight (Table 4) the varieties Possum and ICARDA Short record the highest values of different yield components: Seed yield (ton/hectare), biological yield (ton/hectare), and straw yield, this increment may due to the increasing of panicle number in these varieties compared to others, which reflects on yield components. The straw yield was reflected by plant high, where the Mitika variety records significant low plant high and significant low straw yield compared to other treatments. The superior performance of Possum and ICARDA Short may be attributed to their genetic tolerance to drought and heat stress.

Increased HI has been one of the principal factors contributing to genetic yield improvements in oat (*A. sativa* L.). Although high HI demonstrates high-yielding ability when cultivars are compared, it can also indicate challenges to yield formation when comparisons are made across differing growing conditions. From this study it is clear that yield component increased in that treatments with high harvest index (Table 7) regarding the locations ecosystems, whereas, it doesn't regarding the genotypes (varieties), which is not agrees with [25] results of their study which carried out in southern Finland and reported that HI was associated with short plant stature in the studied cereal species (wheat oat, barley), and grain yield was associated closely with HI for 10 oat cultivars. However, high HI didn't indicate the degree of success in yield determination when environments are compared, which reflects the difference in environmental conditions between Finland and the Northern part of Iraq.

Most characteristics show a superior effect of SA at low (100 ppm) and moderate (200 ppm) concentrations in increasing plants growth and yield components (Tables 2-6 and 8), where in latest decades, many studies have reported that using SA as the foliar application had a significant effect on plant adaptation to stress factors, as SA actions as a natural signaling particle targeting different plant species to increase their tolerance to biotic and abiotic pressures [10]. The use of SA at 100-200 ppm could be recommended for oat cultivation in similar environments to mitigate the effects of climate stress.

TABLE 5: Effect of SA concentrations, oat varieties and their interactions on grain yield (ton/ha) at Koya and Altun Kopru

Varieties	SA (ppm)				Varieties means
	0	100	200	300	
Kangaroo	2.911^{g}*	3.638^{d-g}	3.762^{d-g}	3.292$^{f, g}$	3.400^{c}
Mitika	2.877^{g}	3.899^{c-g}	3.465^{e-g}	2.817^{g}	3.265^{c}
Possum	4.959^{a-d}	5.330^{a,b}	5.493^{a}	4.317^{a-f}	5.025^{a}
ICARDA short	4.764^{a-e}	5.097^{a-c}	5.558^{a}	4.137^{b-g}	4.889^{a}
ICARDA tall	3.709^{d-g}	4.444^{a-f}	4.043^{b-g}	3.799^{c-g}	3.999^{b}
SA mean	3.844^{b}	4.481^{a}	4.464^{a}	3.672^{b}	
Locations Mean					
Koya				Altun Kopru	
4.571^{a}				3.659^{b}	

*Means followed by same letters for factors and their interactions are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test and vice versa. SA: Salicylic acid

TABLE 6: Effect of SA concentrations, oat varieties and their interactions on biological yield (ton/ha) at Koya and Altun Kopru

Varieties	SA (ppm)				Varieties means
	0	100	200	300	
Kangaroo	6.667^{f-i}*	8.938^{a-g}	8.813^{a-g}	7.688^{c-g}	8.026^{b}
Mitika	$5.188^{i, h}$	7.438^{c-h}	6.625^{g-i}	5.125^{i}	6.094^{c}
Possum	9.188^{a-e}	9.813^{a-c}	$10.25^{a,b}$	8.188^{b-g}	9.360^{a}
ICARDA short	9.063^{a-f}	9.521^{a-d}	10.813^{a}	7.875^{b-g}	9.318^{a}
ICARDA tall	7.084^{e-i}	8.875^{a-g}	7.688^{c-g}	7.313^{d-i}	7.740^{b}
SA mean	7.438^{b}	8.917^{a}	8.838^{a}	7.234^{b}	
Locations mean					
Koya			Altun Kopru		
8.434^{a}			7.782^{b}		

*Means followed by same letters for factors and their interactions are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test and vice versa. SA: Salicylic acid

TABLE 7: Effect of SA concentrations, oat varieties and their interactions on harvest index (%) at Koya and Altun Kopru

Varieties	SA (ppm)				Varieties means
	0	100	200	300	
Kangaroo	44.072^{b}*	41.264^{b}	43.047^{b}	42.395^{b}	42.695^{b}
Mitika	55.240^{a}	52.443^{a}	52.410^{a}	54.827^{a}	53.730^{a}
Possum	51.312^{a}	54.571^{a}	53.297^{a}	52.740^{a}	52.980^{a}
ICARDA short	52.165^{a}	54.883^{a}	51.599^{a}	53.860^{a}	53.127^{a}
ICARDA tall	52.070^{a}	49.637^{a}	51.664^{a}	51.456^{a}	51.206^{a}
SA Mean	50.972^{a}	50.559^{a}	50.403^{a}	51.056^{a}	
Locations mean					
Koya				Altun Kopru	
54.015^{a}				47.480^{b}	

*Means followed by same letters for factors and their interactions are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test and vice versa. SA: Salicylic acid

TABLE 8: Effect of SA concentrations, oat varieties and their interactions on straw yield (ton/ha) at Koya and Altun Kopru

Varieties	SA (ppm)				Varieties means
	0	100	200	300	
Kangaroo	3.756^{c-e}*	5.300^{a}	$5.052^{a,b}$	4.396^{a-e}	4.626^{a}
Mitika	2.312^{f}	3.539^{c-e}	$3.160^{e,f}$	2.309^{f}	2.830^{c}
Possum	4.229^{a-e}	4.483^{a-d}	4.758^{a-c}	3.872^{b-e}	4.335^{a}
ICARDA short	4.299^{a-e}	4.425^{a-d}	5.255^{a}	3.739^{c-e}	4.429^{a}
ICARDA tall	3.374^{d-f}	4.432^{a-d}	3.645^{c-e}	3.514^{c-e}	3.741^{b}
SA mean	3.594^{b}	4.435^{a}	4.374^{a}	3.566^{b}	
Locations mean					
Koya			Altun Kopru		
3.862^{a}			4.122^{a}		

*Means followed by same letters for factors and their interactions are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test and vice versa. SA: Salicylic acid

Panicle grain weight, biological yield, and straw yield decreased by increasing SA concentration to 300 ppm, which may be due to decreasing physiological reactions, such as photosynthesis, transpiration, and respiration as a result to increasing ABA hormone, [26] which leads to decreasing stomata conductance, It has recently been found that SA treatment caused both ABA and proline accumulation in wheat and increased resistance to salinity [27]. Furthermore, [26] reported that SA treatment increased ABA content in the leaves of the studied oat genotypes. An increase of proline level was observed only in *Hordeum spontaneum*. The obtained results suggest that ABA and proline can contribute to the development of anti-stress reactions induced by SA. The results of this study also agree with [28] where exogenous

SA reduced transpiration and increased nitrate reductase activity, as well as the yield of some plants, also agrees with [9] where SA reduces the inhibitory effects of cadmium stress by improving the performance of root, chlorophyll a, peroxidase, catalase, proline, and total carbohydrates in lettuce (*Lactuca sativa* L.) leaves.

4. CONCLUSION AND RECOMMENDATIONS

Based on our results, we recommend the application of SA at 100-200 ppm to improve oat yields in arid and semi-arid regions, particularly for varieties such as Possum and ICARDA Short, and it reduce the inhibitory effects of the stress of ecological changed especially temperature and precipitation. Our study demonstrates that SA application significantly improves oat yield components under stress conditions, highlighting its potential as a sustainable strategy for climate-resilient agriculture. From the result of soil analysis, it appears that Koya district soil is more fertile, and all the soil parameters are more favorable for plant growth, yield, and yield components than Altun Kopru soil, which reflects clearly in the growth, and yield components.

Further studies are recommended to increase crops yield in areas suffering environmental stresses, in addition to concentrate on local and wild genotyped to achieve these goals. Also studies should explore the long-term effects of SA application on soil health and crop rotation systems in arid regions.

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