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Effect of salicylic acid on water stress tolerance of two cultivars of bread wheat (*Triticum aestivum* L.) under two agricultural systems.

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I. Abstract

The field experiment was conducted in Tel Kaif district, Nineveh Governorate Iraq(36.491° N, 43.120° E), located approximately 20 km northeast of Mosul city center , during the 2023–2024 growing season to study the effect of salicylic acid foliar spray on the growth and yield of two bread wheat (*Triticum aestivum* L.) cultivars: Denk and Ozkan, under two farming systems—conservation and conventional agriculture. The experiment followed a Randomized Complete Block Design (RCBD) with three replications, using three spray concentrations of salicylic acid (0, 100, and 200 mg·L^{-1}). The results showed that spraying at a concentration of 200 mg·L^{-1} led to significant increases in grain yield, number of spikes, spike weight, spike length, and 1000-grain weight. Meanwhile, the concentration of 100 mg·L^{-1} gave the highest values for biological yield and number of tillers. The Denk cultivar outperformed in most of the studied traits, particularly in plant height, grain yield, and harvest index, while the Ozkan cultivar showed superiority only in 1000-grain weight. Regarding the farming systems, the conventional system resulted in higher tiller number and biological yield, while conservation agriculture performed better in plant height, spike length, and spike weight. The triple interaction between the Denk cultivar, conservation farming, and 200 mg·L^{-1} salicylic acid achieved the highest grain yield (1483.05 g).

Key words: Salicylic acid, Water stress, Bread wheat, Cultivars.

II. Introduction

Wheat (*Triticum aestivum* L.) is considered one of the most strategic crops in the world, serving as a major source of carbohydrates and playing a significant role in global food security. According to the Food and Agriculture Organization (FAO), global wheat production in 2024 was estimated at around 787 million tons, showing a slight decrease of 0.1% compared to the previous year due to reduced yields in some major producing countries. In Iraq (excluding the Kurdistan region), wheat production for 2024 was estimated at about 5.2 million tons, marking an increase of nearly 20% compared to the five-year average. This rise was attributed to improved rainfall and government support.[1] With the growing impact of climate change—such as drought and rising temperatures—wheat productivity has been negatively affected in many regions, prompting the need to explore ways to enhance production efficiency. In this context, many studies have turned to conservation agriculture, which the FAO (2015) defines as an ecosystem-based approach to agricultural management that aims to improve and sustain productivity while preserving environmental resources. Research indicates that the method of cultivation

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significantly influences wheat productivity. A recent global meta-analysis showed that no-till farming, when combined with cover crops or organic amendments, increased wheat yields by 58% and improved nitrogen use efficiency compared to conventional tillage, especially under low-input conditions.[22] Conservation agriculture is recognized for reducing tillage, increasing soil organic matter, and limiting the degradation of arable land.[23] Field experiments have shown that some traits—such as tiller number and biological yield—tend to be higher under conventional tillage, while other traits like spike number and grain yield are sometimes superior under no-till systems.[9][10][11] The importance of using plant growth regulators has also grown in helping plants cope with environmental stress. Among these, salicylic acid stands out as a phenolic organic compound² extracted from various plant species[8] and derived from the amino acid phenylalanine.[3] It functions as a growth regulator that controls several physiological processes such as growth, germination, and ion uptake,[34] while also contributing to disease resistance and enhancing photosynthesis.[5] Moreover, it improves hormonal balance and helps plants adapt to environmental stress, making it a valuable tool under current climate challenges[2] One study showed that a concentration of 100 mg·L^{-1} of salicylic acid significantly increased grain yield, particularly in the cultivar Sakha 93, which recorded the highest values for grain number, spike weight, and total yield.[19]Another study found that 10 mg·L^{-1} was most effective in improving growth and yield traits such as plant height, grain number, and 1000-grain weight.[20] Choosing the right cultivar is also a key factor in improving productivity and determining a plant's response to environmental conditions and management practices. In an experiment involving 11 local wheat cultivars, IPA-99, Abughraib-3, and Mahwada showed superiority in growth and productivity under semi-arid conditions.[43] In another comparative trial between the Turkish cultivar Adana-99 and the local Ebba-99, grain yields were similar, but Ebba-99 was more efficient in utilizing available resources such as water and fertilizers to achieve equivalent yields—a concept known as technical efficiency. Thus, Ebba-99 is considered more suitable for local growing conditions.[44]

The study aims to evaluate different concentrations of salicylic acid on drought stress tolerance of two wheat cultivars (Denk and Ozkan), as well as growth and yield traits under two farming systems: conservation agriculture and conventional agriculture.

III. Materials and Methods

This experiment was conducted in farmers' fields in Tel Kaif district, Mosul, Iraq(36.491° N, 43.120° E), located approximately 20 km northeast of Mosul city center on soft wheat using two cultivars: Ozkan and Denk. The seeding rate was 25 kg.dunum^{-1}, and two cropping systems were applied: conservation agriculture (using a disc seeder) and conventional agriculture. Sowing was carried out in November. Two chemical fertilizers were used: urea (46% nitrogen) at 40 kg.ha^{-1} (18.4 kg.ha^{-1} nitrogen)and diammonium phosphate (DAP) at 80 kg.ha^{-1} (14.4 kg. ha^{-1} nitrogen)(36.8 kg. ha^{-1} P_2O_5). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Each experimental unit covered an area of 9 m². Salicylic acid was applied at two concentrations (100 and 200 mg.L^{-1}), in addition to the control treatment (0 mg.L^{-1}). Spraying was done once on March 4, 2024, during the stem elongation stage. Control plots were sprayed with water only. Vegetative growth traits were measured in April, and yield components were recorded in May after harvest. The studied traits were:

plant height (cm), number of tillers/m², number of spikes/m², spike length (cm), number of grains per spike, spike weight (g), biological yield (g), grain yield (g), harvest index, and 1000-grain weight (g).

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Data were statistically analyzed using SAS software, and means were compared using Duncan's Multiple Range Test at a 0.05 probability level.

IV. Results and Discussion

3.1. Plant Height (cm)

As shown in Table (1), spraying with salicylic acid at 100 mg·L⁻¹ significantly increased plant height to 91.43 cm, compared to the control. This may be due to the hormone-like role of salicylic acid in stimulating cell division and elongation, as well as regulating hormonal balance, thus enhancing vertical growth.[25] These findings are consistent with Al-Hakimi et al.[45], who reported a significant increase in wheat (Triticum aestivum L.) height after salicylic acid application. The Denk cultivar recorded a greater plant height (89.83 cm) than Ozkan, likely due to its stronger vegetative growth, which enabled it to grow taller under the same conditions.[31] This result agrees with Karimi et al.[46], who highlighted genotypic differences in wheat height. Among the farming systems, conservation agriculture resulted in the highest plant height (89.54 cm), possibly due to better soil moisture retention and reduced tillage, which support better root development and shoot elongation.[37] Similar outcomes were noted by Abdelrahman and Ghoneim[47]. As for interaction effects, the Denk cultivar combined with 100 mg·L⁻¹ gave 95.66 cm, and conventional farming with the same concentration reached 99.11 cm. The conservation system combined with Denk recorded 86.35 cm. The highest value (101.63 cm) was observed under the triple interaction of Ozkan + conservation agriculture + 200 mg·L⁻¹ salicylic acid, showing a statistically significant difference from several other treatments.

Table 1. Effect of salicylic acid application on plant height (cm) for two bread wheat (*Triticum aestivum* L.) cultivars under two farming systems.

Farming system	Varieties	Concentration 0 mg·L⁻¹	Concentration 100 mg·L⁻¹	Concentration 200 mg·L⁻¹	Farming system* Varieties	Farming system	
Conservation	Denk	78.00 ab	91.43 a	89.63 ab	86.35 a	89.54 a	
	Ozkan	78.43 ab	99.90a	101.63 a	93.32 a		
Conventional	Denk	64.67 bc	76.07ab	49.93 c	63.55 b	74.95 b	
	Ozkan	76.03 ab	98.33 a	82.93 ab	85.76 a		
Concentrations * Farming system	Conservation	71.33 c	83.75 abc	69.78 c			
	Conventional	77.23 bc	99.11 a	92.28 ab			Effect of varieties
Varieties * Concentrations	Denk	78.21 bc	95.66 a	95.63 a			89.83 a
	Ozkan	70.35 c	87.20 ab	66.43 c			74.66 b
Effect of concentrations		74.28 b	91.43 a	81.03 ab			

3.2. Number of Tillers (tillers.m^{-1})

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Table (2) shows the effect of the studied treatments and their two-way and three-way interactions on the number of tillers per square meter. Regarding the effect of salicylic acid spray, the second concentration (100 mg·L⁻¹) resulted in the highest number of tillers (269.83), significantly surpassing both the control and the third concentration. These findings align with El-Tayeb et al.[48], who noted that spraying wheat with salicylic acid led to a significant increase in the number of tillers. Concerning cultivar effect, Denk outperformed Ozkan in the number of tillers (307.77 tillers.m^{-2}). This significant increase may be due to the genetic traits of the Denk cultivar, which give it a better capacity to produce more tillers thanks to its vigorous growth habit, unlike Ozkan.[32] These results are consistent with Singh et al.[49], who observed that some wheat cultivars demonstrated superiority in tillering ability due to genetic characteristics associated with high branching potential. As for the farming system, conventional agriculture showed superiority with 300.667 tillers.m^{-2}. This significant increase could be attributed to the fact that tilled soil is better aerated and less compacted, encouraging plants to produce more tillers during the early growth stages.[40] This matches the findings of Hussein et al.[50] who stated that conventional tillage produced better tiller numbers in early growth due to improved soil structure and root aeration. Regarding the two-way interactions between salicylic acid concentration and cultivars, the combination of Denk + 200 mg·L⁻¹ produced the highest number of tillers (359.50), significantly outperforming all other interactions. Similarly, the interaction between conventional farming and 200 mg·L⁻¹ spray yielded 357.17 tillers, which was also statistically superior. In the interaction between farming system and cultivar, conservation farming with Denk gave the highest number of tillers (309.00), significantly differing only from conventional farming with Denk. For the three-way interaction, Ozkan + conservation farming + 200 mg·L⁻¹ recorded the highest value (379.33), significantly exceeding most other combinations.

Table 2. Effect of salicylic acid application on number of tillers per m² for two bread wheat cultivars under two farming systems.

Farming system	Varieties	Concentration 0 mg·L⁻¹	Concentration 100 mg·L⁻¹	Concentration 200 mg·L⁻¹	Farming system* Varieties	Farming system	
Conservation	Denk	234.67 e	352.67 ab	339.67 abc	309.00 a	236.61 b	
	Ozkan	231.67 e	308.67 cd	379.33 a	306.56 a		
Conventional	Denk	165.33 f	143.67 f	183.67 f	164.22 b	300.667 a	
	Ozkan	275.00 d	274.33 d	335.00 bc	294.78 a		
Concentrations * Farming system	Conservation	200.00 d	248.17 c	261.67 c			
	Conventional	253.33 c	219.50 b	357.17 a			**Mean of varieties**
Varieties * Concentrations	Denk	233.17 cd	330.67 b	359.50 a			307.77 a
	Ozkan	220.17 d	209.00 d	259.33 c			229.50 b
Effect of concentrations		226.66 c	269.83 b	309.41 c			

3.3. Number of Spikes (spikes.m^{-2})

University of Thi-Qar Journal of agricultural research

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Table (3) illustrates the effect of the studied factors and their two-way and three-way interactions on the number of spikes per square meter. With regard to the effect of salicylic acid spraying, the third concentration (200 mg·L⁻¹) gave the highest spike number, reaching 304.24 spikes.m^{-2}, significantly surpassing both the control and the 100 mg·L⁻¹ treatment. This significant increase may be attributed to salicylic acid's ability to stimulate the development of lateral branches (tillers) by activating growth hormones, which in turn leads to the formation of more spikes.[26] These findings are consistent with those of Jini and Joseph[51], who found that spraying wheat with salicylic acid increased the number of spikes. Regarding the effect of the cultivation system, the conventional system was superior to conservation agriculture, recording 278.28 spikes.m^{-2}. This increase may be due to the fact that conventional tillage supports early formation of fertile tillers, which later develop into a greater number of spikes.[41] This agrees with Hussein et al.[50] , who also indicated that the conventional system encouraged a higher number of spikes due to enhanced early tillering. As for the cultivar effect, Denk outperformed Ozkan in spike number, reaching 299.50 spikes.m^{-2}. This significant increase may be attributed to the greater number of fertile tillers produced by Denk, which translated into more spikes per plant.[33] These findings are in line with Singh et al.[49], who showed that cultivars capable of producing more fertile tillers tend to achieve higher spike numbers per area. For the two-way interactions between salicylic acid and cultivars, the combination of Denk + 200 mg·L⁻¹ yielded the highest spike number (276.50). In the interaction between salicylic acid and farming system, the highest spike number (321.11 spikes.m^{-2}) was observed in the treatment combining conservation agriculture with 200 mg·L⁻¹ salicylic acid, which was significantly superior to all other combinations. In terms of the three-way interaction, the highest number of spikes (321.11 spikes.m^{-2}) was recorded from the treatment combining Denk + conservation farming + 200 mg·L⁻¹ salicylic acid, significantly outperforming all other three-way combinations.

Table 3. Effect of salicylic acid application on number of spikes per m² for two bread wheat cultivars under two farming systems.

Farming system	Varieties	Concentration 0 mg·L⁻¹	Concentration 100 mg·L⁻¹	Concentration 200 mg·L⁻¹	Farming system* Varieties	Farming system	
Conservation	Denk	209.67 cd	314.00 b	439.67 a	321.11 a	240.89 b	
	Ozkan	220.33 cd	300.00 b	313.33 b	277.89 b		
Conventional	Denk	161.67 d	165.67 d	154.67 d	160.67 c	278.28 a	
	Ozkan	267.00 bc	259.00 bc	310.00 b	278.67 b		
Concentrations * Farming system	Conservation	185.67 c	239.83 b	297.17 a			
	Conventional	243.67 b	279.50 ab	311.67 a			Mean of varieties
Varieties * Concentrations	Denk	215.00 c	307.00 b	232.33 c			299.50 a
	Ozkan						219.67 b
Effect of concentrations		214.67 c	259.67 b	304.42 a			

3.4. Spike Length (cm)

University of Thi-Qar Journal of agricultural research

Thi-Qar Journal of agricultural research

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Results for the experimental factors and their two-way and three-way interactions on spike length are presented in table (4). With respect to the main effect of salicylic acid spraying, the concentration of 200 mg·L⁻¹ provided the longest spike length, 10.94 cm, and was significantly higher than any of the other treatments. This increased spike length may be attributed to the involvement of salicylic acid in the elongation of the spike as it influences spike axis cell growth, which results in spike elongation and possibly increases its potential for grain.[27] This is in agreement with Aldesuquy et al.,[54] who observed salicylic acid foliar spraying improved spike length in wheat. When considering cultivar, the Denk cultivar had a spike length of 9.97 cm but was significantly higher than that of Ozkan. This difference may be explained by Denk's structural quality of developing a spike supported by relatively longer stem degrees of freedom compared to Ozkan.[34] The results of this study are in agreement with the findings of Singh et al.[49] who reported significant differences between cultivars in spike length as a function of differences in stem morphology and internode length as a result of genetic differences among the cultivars. With regards to the farming system factor, conservation agriculture had longer spikes than conventional tillage with mean values of 10.23 cm. The increase could be attributed to the improved and consistent soil moisture and soil aeration in conservation agriculture, which could enhance nutrient availability and the pitch of spike development.[38] This corresponds with the findings by Hussein et al.[50], who showed a positive aspect of conservation agriculture on aerial plant parts, including spike elongation. In terms of two way interactions: The treatment Denk + 200 mg·L⁻¹ salicylic acid resulted in the largest spike length (10.96 cm), with the length significantly greater than most of the other treatments. The interaction of 200 mg·L⁻¹ salicylic acid ultimately in conservation farming resulted in the longest spike length from any treatment (11.60 cm) which was significantly longer than all other salicylic acid × farming system treatments. In terms of the two way interaction between farming system and cultivar, the Denk × CF combination resulted in a spike length of 10.57 cm, which was not significantly greater than conservation agriculture with Ozkan. In terms of the three way interaction, the combination of conventional + Denk + 200 mg·L⁻¹ salicylic acid resulted in the longest spike, at 12.86 cm which was statistically significantly greater than all other interaction treatments.

Table 4. Effect of salicylic acid application on average spike length (cm) for two bread wheat cultivars under two farming systems.

Farming system	Varieties	Concentration 0 mg·L⁻¹	Concentration 100 mg·L⁻¹	Concentration 200 mg·L⁻¹	Farming system* Varieties	Farming system	
Conservation	Denk	Concentration 0 mg·L⁻¹	Concentration 100 mg·L⁻¹	Concentration 200 mg·L⁻¹	9.88 b	10.23 a	
	Ozkan	9.16 de	10.16 cd	10.33 c	10.06 ab		
Conventional	Denk	8.46 ef	10.13 cd	11.60 b	10.57 a	9.06 b	
	Ozkan	8.16 efg	10.70 bc	12.86 a	8.06 c		
Concentrations * Farming system	Conservation	7.20 g	8.03 fg	8.96 ef			
	Conventional	8.66 c	10.43 b	11.60 a			Mean of varieties
Varieties * Concentrations	Denk	7.83 d	9.08 c	10.28 b			9.97 a
	Ozkan	8.81 c	10.15 b	10.96 a			9.32 b

University of Thi-Qar Journal of agricultural research

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https://iasj.rdd.edu.iq/journals/journal/issue/20226 https://doi.org/10.54174/utjagr.v13ii 44.

Effect of concentrations		7.68 d	9.36 c	10.91 a		

3.5. Number of Grains per Spike

Table (5) presents the effects of the studied factors and their two-way and three-way interactions on the number of grains per spike. Regarding the individual effect of salicylic acid spraying, there were no significant differences among the concentrations in terms of grain number per spike. Similarly, no significant differences were observed between the conservation and conventional farming systems for this trait. However, regarding cultivar performance, the Denk cultivar significantly outperformed Ozkan, recording an average of 34.62 grains per spike, compared to 29.18 grains for Ozkan. This increase may be due to Denk's longer and more branched spike structure, which allows for the formation of more grains even under similar environmental conditions.[34] These findings agree with Singh et al.[49], who reported that cultivars with longer and more branched spikes tend to carry a greater number of grains. In terms of the two-way interaction between salicylic acid and cultivar, the combination of Denk + 200 mg·L^{-1} salicylic acid resulted in the highest grain number per spike (35.58 grains), which differed significantly only from the combination of Denk + 100 mg·L^{-1}. Regarding the interaction between salicylic acid and farming system, no significant differences were found in grain number per spike. As for the interaction between farming system and cultivar, the combination of conservation agriculture + Denk yielded the highest grain number (35.42 grains), but it did not significantly differ from conservation agriculture + Ozkan. In the three-way interaction, the combination of conservation agriculture + Denk + control treatment (0 mg·L^{-1}) gave the highest grain number per spike, reaching 38.16 grains, and was significantly superior to most other interaction treatments.

Table 5. Effect of salicylic acid application on number of grains per spike for two bread wheat cultivars under two farming systems.

Farming system	Farming system	Varieties	Concentration 0 mg·L^{-1}	Concentration 100 mg·L^{-1}	Concentration 200 mg·L^{-1}	Farming system* Varieties	
Conservation	Denk	38.16 a	32.76 abcd	35.33 abc	35.42 a	32.03 a	
	Ozkan	35.54 abc	29.50 bcd	36.43 ab	33.82 a		
Conventional	Denk	27.20 d	28.70 cd	30.03 bcd	28.64 b	31.77 a	
	Ozkan	28.63 cd	30.70 bcd	29.83 bcd	29.72 b		
Concentrations * Farming system	Conservation	32.68 a	30.73 a	32.68 a			
	Conventional	32.08 a	30.10 a	33.13 a			34.62 a
Varieties * Concentrations	Denk	36.85 a	31.13 b	35.88 a			29.18 b
	Ozkan	27.91 b	29.70 b	29.93 b			34.62 a
Effect of concentrations		32.38 a	30.41 a	32.908 a			

University of Thi-Qar Journal of agricultural research

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3.6. Spike Weight (g)

Table (6) shows the effect of the studied factors and their two-way and three-way interactions on spike weight. Regarding the individual effect of salicylic acid spraying, the concentration of 200 mg·L⁻¹ resulted in the highest spike weight, reaching 442.08 g, and significantly surpassed the 100 mg·L⁻¹ treatment and the control. This increase may be due to the ability of salicylic acid to enhance nutrient uptake and distribution within the spikes, which improves grain filling without necessarily increasing grain number, thereby increasing the spike's dry weight.[29] This finding is supported by Aldesuquy et al.[54], who confirmed that salicylic acid improved grain filling and increased the dry weight of wheat spikes without directly affecting grain count. As for the cultivar effect, no significant difference was observed between Denk and Ozkan in spike weight. Concerning the farming system, conservation agriculture showed superiority over the conventional system, recording 410.28 g compared to 355.56 g. This significant increase may be attributed to the improved soil conditions in conservation systems, which enhance nutrient absorption and grain development inside the spike, due to less soil stress and reduced moisture loss.[60] This agrees with Hussein et al.[50], who stated that conservation agriculture improves soil environment and increases nutrient use efficiency, positively affecting spike weight. In terms of the two-way interaction between salicylic acid and cultivar, the highest spike weight (495.83 g) was recorded from the combination of Denk + 200 mg·L⁻¹ salicylic acid, significantly surpassing all other combinations. For the interaction between farming system and salicylic acid, the conventional system + 200 mg·L⁻¹ salicylic acid recorded the highest value (490.00 g), which was also significantly superior to all other salicylic acid × system combinations. As for the interaction between farming system and cultivar, the highest spike weight (420.00 g) was obtained from conventional agriculture + Ozkan, which differed significantly only from the combination of conventional agriculture + Denk.

Table 6. Effect of salicylic acid application on average spike weight (g) for two bread wheat cultivars under two farming systems.

Farming system	Varieties	**Concentration 0** mg·L⁻¹	**Concentration 100** mg·L⁻¹	**Concentration 200** mg·L⁻¹	**Farming system* Varieties**	**Farming system**	
Conservation	Denk	267.33 d	430.00 abc	486.67 a	394.67 a	355.56 a	
	Ozkan	335.00 cd	361.67 bcd	505.00 a	400.56 a		
Conventional	Denk	334.33 cd	313.33 cd	301.67 d	316.44 b	410.28 b	
	Ozkan	355.00 cd	430.00 abc	475.00 ab	420.00 a		
Concentrations * Farming system	Conservation	300.83 c	371.67 bc	394.17 b			
	Conventional	345.00 bc	359.83 b	490.00 a			Mean **of varieties**
Varieties *	Denk	301.17 c	359.83 b	495.83 a			397.61 a

University of Thi-Qar Journal of agricultural research

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Concentrations	Ozkan	344.67 bc	371.67 bc	388.33 b		368.22 a
Effect of concentrations	Varieties	322.92 c	383.75 b	442.08 a		

3.7. Biological Yield (g)

Table (7) shows the effect of the studied factors and their two-way and three-way interactions on biological yield. The treatment with 100 mg·L⁻¹ of salicylic acid resulted in the highest biological yield, recording 1201.50 g, and significantly surpassed both the control and the 200 mg·L⁻¹ treatment. This finding aligns with El-Tayeb et al.[48], who reported that spraying wheat with salicylic acid increased total biomass. Regarding cultivar performance, the Denk cultivar gave a higher biological yield (1162.39 g) compared to Ozkan (918.72 g). This increase may be attributed to Denk's more vigorous vegetative growth and greater number of tillers, which contributed to a higher total plant mass at harvest.[35] These results are consistent with Singh et al.[49], who highlighted that some cultivars excel in biomass production due to their superior tillering and canopy development. As for the farming system, conventional agriculture resulted in a significantly higher biological yield (1168.00 g) compared to conservation agriculture (913.11 g). This may be due to the denser vegetative growth associated with conventional tillage, where full soil inversion improves aeration and enhances early root and shoot development.[42] The findings of Hussein et al.[50] also support this, showing improved soil characteristics and increased biomass production in wheat under conventional tillage compared to conservation practices.

Table 7. Effect of salicylic acid application on biological yield (g) for two bread wheat cultivars under two farming systems.

Farming system	Varieties	Concentration 0 mg·L⁻¹	Concentration 100 mg·L⁻¹	Concentration	Farming system* Varieties	Farming system	
Conservation	Denk	791.00 e	1272.00 c	1432.33 a	1109.33 b	913.11 b	
	Ozkan	846.67 e	1367.33 b	807.33 e	1215.44 a		
Conventional	Denk	548.33 f	795.00 e	1015.00 d	716.89 c	1168.00 a	
	Ozkan	975.00 d	1371.67 b	1036.17 c	1120.56 b		
Concentrations * Farming system	Conservation	669.67 e	1033.50 c	1223.67 b			
	Conventional	910.83 d	1369.50 a	1348.67 a			Mean of varieties
Varieties * Concentrations	Denk	818.83 d	1319.67 a	911.17 c			1162.39 a
	Ozkan	761.67 e	1083.33 b	1129.92 b			918.72 b
Effect of concentrations		790.25 c	1201.50 a	1265.00 c			

University of Thi-Qar Journal of agricultural research

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Regarding two-way interactions:

- The highest biological yield (1348.67 g) was obtained from the combination of Denk + 100 mg·L⁻¹ salicylic acid, with no significant difference from the combination of the same cultivar with 200 mg·L⁻¹.
- For the interaction between farming system and salicylic acid, the highest biological yield (1369.50 g) was recorded in conventional agriculture + 100 mg·L⁻¹, significantly surpassing all other treatments.
- In the interaction between farming system and cultivar, the highest value (1215.44 g) was obtained from conservation agriculture + Ozkan, significantly higher than other combinations.
- The highest biological yield overall (1432.33 g) was recorded from the three-way interaction of Ozkan + conservation agriculture + 200 mg·L⁻¹ salicylic acid, significantly outperforming all other treatments.

3.8. Grain Yield (g)

Table (8) presents the effect of the studied factors and their two-way and three-way interactions on grain yield. Spraying with 200 mg·L⁻¹ of salicylic acid had a significant positive effect on grain yield, reaching 1053.81 g, surpassing the yield obtained with 100 mg·L⁻¹. This increase may be attributed to the role of salicylic acid in enhancing photosynthetic efficiency and delaying leaf senescence, which prolongs the grain-filling period and increases grain weight, even if the grain number remains unchanged.[30] These results agree with those of El-Tayeb et al.[48], who demonstrated that salicylic acid improved photosynthesis and grain filling, contributing to increased overall grain yield in wheat. Regarding cultivar performance, Denk significantly outperformed Ozkan, recording a grain yield of 3633 g compared to 1898.4 g. This improvement may be due to Denk's superior genetic potential for producing heavier, fuller grains under the same growing conditions.[36] These findings are consistent with Singh et al.[49], who indicated that some wheat cultivars have better grain-filling capacity due to their genetic characteristics, leading to higher yields. As for the farming system, no significant difference was found between conservation and conventional agriculture in grain yield Concerning two-way interactions:The highest grain yield (1435.13 g) was recorded from the combination of Denk + 200 mg·L⁻¹ salicylic acid, significantly outperforming all other cultivar × spray combinations. For the interaction between farming system and salicylic acid, no significant differences were observed. In the interaction between farming system and cultivar, the combination of conservation agriculture + Denk resulted in the highest grain yield (3925.9 g), significantly superior to all other combinations The highest overall grain yield (1483.05 g) was achieved in the three-way interaction of Denk + conservation agriculture + 200 mg·L⁻¹ salicylic acid, significantly exceeding most other treatments.

University of Thi-Qar Journal of agricultural research

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https://iasj.rdd.edu.iq/journals/journal/issue/20226 https://doi.org/10.54174/utjagr.v13ii 44.

Table 8. Effect of salicylic acid application on grain yield (g) for two bread wheat cultivars under two farming systems.

Farming system	Varieties	Concentration 0 mg·L⁻¹	Concentration 100 mg·L⁻¹	Concentration 200 mg·L⁻¹	Farming system* Varieties	Farming system	
Conservation	Denk	338.79 bc	355.92 b	483.05 a	1109.33 b	913.11 b	
	Ozkan	327.71 bcd	281.27 bcd	387.22 ab	1215.44 a		
Conventional	Denk	146.57 ef	121.05 f	115.52 f	716.89 c	1168.00 a	
	Ozkan	295.50 bcd	222.96 de	237.46 cde	1120.56 b		
Concentrations * Farming system	Conservation	242.68 a	238.48 a	299.29 a			
	Conventional	311.60 a	252.12 a	312.34 a			Mean of varieties
Varieties * Concentrations	Denk	333.25 b	318.60 b	435.13 a			362.33 a
	Ozkan	221.03 c	172.01 c	176.49 c			189.84 b
Effect of concentrations		277.14 ab	245.30 b	305.81 a			

3.9. Harvest Index

Table (9) shows the effects of the studied factors and their two-way and three-way interactions on the harvest index. Concerning the individual effect of salicylic acid spraying, there was no significant effect observed on harvest index values among the applied concentrations. Similarly, no significant difference was found between the conservation and conventional farming systems in this trait. However, regarding the cultivar effect, the Denk cultivar recorded a significantly higher harvest index, reaching 3.53, compared to 2.01 for the Ozkan cultivar. This increase may be due to the genetic capacity of Denk to allocate a greater proportion of its total biomass to grain production rather than vegetative parts like leaves and stems, thereby achieving a higher ratio of grain yield to total biomass.[36] These results agree with Singh et al.[49], who indicated that certain wheat cultivars possess a higher harvest index due to their efficient assimilate partitioning toward grain. In terms of the two-way interaction between salicylic acid and cultivar, the combination of Denk + 0 mg·L⁻¹ (control) recorded the highest harvest index, reaching 40.73, significantly surpassing all other interaction treatments. For the interaction between farming system and salicylic acid, the highest value (3.72) was observed in the combination of conservation agriculture + 0 mg·L⁻¹, which did not differ significantly from conventional agriculture + 0 mg·L⁻¹. Regarding the interaction between farming system and

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Thi-Qar Journal of agricultural research

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cultivar, the conservation agriculture + Denk combination achieved the highest harvest index (36.31), significantly outperforming all other two-way interactions in this trait. The highest overall value (4.281) was recorded under the three-way interaction of Denk + conservation agriculture + control treatment (0 mg·L⁻¹), which significantly exceeded most of the other treatments.

Table 9. Effect of salicylic acid application on harvest index for two bread wheat cultivars under two farming systems.

Farming system	Varieties	Concentration 0 mg·L⁻¹	Concentration 100 mg·L⁻¹	Concentration 200 mg·L⁻¹	Farming system* Varieties	Farming system	
Conservation	Denk	42.81 a	27.97 cd	38.16 ab	36.31 a	27.52 a	
	Ozkan	38.651 ab	20.572 def	27.05 cd	28.75 b		
Conventional	Denk	26.64 cd	15.23 ef	14.29 f	18.72 c	26.033 a	
	Ozkan	30.30 bc	16.22 ef	23.39 cde	23.30 c		
Concentrations * Farming system	Conservation	34.728 a	21.60 bc	26.22 b			
	Conventional	34.47 a	18.39 c	25.22 b			Mean of varieties
Varieties * Concentrations	Denk	40.73 a	24.275 cd	32.605 b			32.53 a
	Ozkan	28.47 bc	15.72 e	18.84 de			21.01 b
Effect of concentrations		34.60 a	20.00 c	25.72 b			

3.10. 1000-Grain Weight (g)

Table (10) illustrates the effect of the studied factors and their two-way and three-way interactions on 1000-grain weight. Regarding the individual effect of salicylic acid spraying, the highest value was obtained from the 200 mg·L⁻¹ treatment, although it did not significantly differ from the 100 mg·L⁻¹ treatment. This increase may be attributed to salicylic acid's role in extending the lifespan of leaves and delaying senescence, allowing grains to fill over a longer period and thereby increasing their weight.[25] These findings are consistent with those of Li et al.[66], who showed that salicylic acid enhanced grain filling and raised 1000-grain weight in wheat. As for cultivar performance, the Ozkan cultivar significantly outperformed Denk, recording 35.13 g compared to 28.33 g. This increase may be attributed to the genetic characteristics of Ozkan that enable it to produce larger and heavier grains. With respect to the farming system, no significant difference was observed between conservation and conventional agriculture in this trait. In terms of two-way interactions:The combination of Ozkan + 200 mg·L⁻¹ salicylic acid resulted in the highest 1000-grain weight (39.88 g), although it did not differ significantly from Denk + 100 mg·L⁻¹. For the interaction between farming system and salicylic acid, the highest value (86.48 g) was recorded under conservation agriculture + 200 mg·L⁻¹, which differed significantly from two other treatment combinations. Regarding the interaction between farming system and cultivar, the highest 1000-grain weight (36.77 g) was obtained from conventional agriculture + Denk, significantly surpassing all other combinations. Finally, in the three-

University of Thi-Qar Journal of agricultural research

Thi-Qar Journal of agricultural research

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https://iasj.rdd.edu.iq/journals/journal/issue/20226 https://doi.org/10.54174/utjagr.v13ii 44.

way interaction, the highest 1000-grain weight was recorded under the combination of conventional agriculture + Denk + 200 mg·L^{-1}, which did not differ significantly from the combination involving 100 mg·L^{-1}.

Table 10. Effect of salicylic acid application on 1000-grain weight (g) for two bread wheat (Triticum aestivum L.) cultivars under two farming systems.

Farming system	Varieties	Concentration 0 mg·L^{-1}	Concentration 100 mg·L^{-1}	Concentration 200 mg·L^{-1}	Farming system* Varieties	Farming system	
Conservation	Denk	23.66 e	29.03 cde	32.13 bc	28.27 c	32.528 a	
	Ozkan	23.96 e	31.46 bcd	29.73 cd	28.38 c		
Conventional	Denk	30.00 cd	39.50 a	40.83 a	36.77 a	30.944 a	
	Ozkan	25.90 de	35.66 ab	38.93 a	33.50 b		
Concentrations * Farming system	Conservation	26.83 b	34.26 a	36.48 a			
	Conventional	24.93 b	33.56 a	34.33 a			Effect of varieties
Varieties * Concentrations	Denk	23.81 c	30.25 b	30.93 b			28.33 b
	Ozkan	27.95 b	37.58 a	39.88 a			35.13 a
Effect of concentrations		25.88 b	33.91 a	35.40 a			

Conclusion

Foliar application of salicylic acid at 200 mg·L^{-1} markedly enhanced wheat growth and yield, with the Denk cultivar showing clear genetic superiority. The integration of Denk cultivar, conservation agriculture, and 200 mg·L^{-1} salicylic acid represented the most efficient approach for maximizing grain yield.

Recommendations:

- Apply salicylic acid at 200 mg·L^{-1} to improve wheat growth and yield.
- Focus on the Denk cultivar for its genetic superiority.
- Promote conservation agriculture for its role in enhancing qualitative traits.

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https://iasj.rdd.edu.iq/journals/journal/issue/20226 https://doi.org/10.54174/utjagr.v13ii 44.

Table 11 . Physico-chemical properties of the experimental soil (0–30 cm, Telkaif site)

Property	Value
Sand%	29.45
Silt%	47.40
Clay%	23.15
Texture class	Silty clay loam
Total nitrogen ppm	68.8
Available phosphorus (Olsen) ppm	112.5
Available potassium	2.4
Organic matter%	0.87
pH (1:2.5 soil:water)	7.33
Electrical conductivity (EC) dS m^{-1}	0.13
Calcium carbonate equivalent%	31.5
Chloride meq L^{-1}	0.52

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