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Effect of Planting Dates and Potassium Application on Wheat Tolerance to Irrigation with Saline Water

Zahra Ahmad Hassan1, Abdul Kareem Hassan Odhafa2, Nabil Raheem Lahmod3

1,2 Department of Soil Sciences and Water Resources, College of Agriculture, University of Wasit, Iraq
3 Department of Crop Sciences, College of Agriculture, University of Wasit, Iraq

Corresponding author: **zaahmed@uowasit.edu.iq**

Abstract:

The experiment investigated the effects of planting dates, irrigation water quality, and potassium fertilizer levels on wheat growth, yield, and selected soil chemical and physical properties under saline irrigation conditions. The study was conducted during the 2024–2025 agricultural season in Al-Akhd area, Al-Rifai District, Dhi Qar Governorate. The field was prepared using standard plowing and leveling practices, and the experiment was arranged in a Randomized Complete Block Design (RCBD) with a split–split plot arrangement and four replications. Planting dates were assigned to main plots, irrigation water quality (fresh and saline) to subplots, and potassium fertilizer levels (0, 60, and 120 kg ha^{-1} as potassium sulfate) to sub-subplots. Wheat cultivar Nazar was planted on two dates, while recommended nitrogen and phosphorus rates were applied uniformly. Potassium was added according to treatment levels. Results showed that the early planting date (November 1) numerically exceeded the late date in most traits, including number of spikes and grains per spike, although differences were not statistically significant. Planting dates had no significant effect on plant height, 1000-grain weight, or harvest index. Potassium fertilization had a significant positive effect on number of spikes, grain yield, 1000-grain weight, and harvest index, with increases observed as potassium levels increased from K0 to K2. However, the number of grains per spike decreased significantly with higher potassium levels. Fresh irrigation water showed numerical superiority over saline water in most traits, though differences were generally non-significant. The highest grain yield was obtained under early planting with fresh water, while the lowest occurred under late planting with saline water. Overall, potassium fertilization was the most influential factor in improving wheat performance under saline irrigation conditions.

Keywords: *Dates, Potassium, Wheat.*

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تأثير مواعيد الزراعة وتطبيق البوتاسيوم على تحمل القمح للري بمياه مالحة

زهرة أحمد حسن[1] ، عبد الكريم حسن [2] ، نبيل رحيم لحمود[3]

[1,2] قسم علوم التربة والموارد المائية، كلية الزراعة، جامعة واسط، العراق

3 قسم علوم المحاصيل، كلية الزراعة، جامعة واسط، العراق

لخلاصة

ملخص: هدفت هذه التجربة إلى دراسة تأثير مواعيد الزراعة، وجودة مياه الري، ومستويات سماد البوتاسيوم على نمو القمح، وإنتاجيته، وبعض الخصائص الكيميائية والفيزيائية للتربة في ظل ظروف الري بمياه مالحة. أُجريت الدراسة خلال الموسم الزراعي 2024-2025 في منطقة الأخد، مديرية الرفاعي، محافظة ذي قار. تم تجهيز الحقل باستخدام أساليب الحراثة والتسوية القياسية، وصُممت التجربة وفق تصميم القطاعات العشوائية الكاملة (RCBD) مع تصميم القطع الفرعية المتداخلة وأربعة مكررات. خُصصت مواعيد الزراعة للقطع الرئيسية، وجودة مياه الري (عذبة ومالحة) للقطع الفرعية، ومستويات سماد البوتاسيوم (0، 60، و120 كجم/هكتار على شكل كبريتات البوتاسيوم) للقطع الفرعية الثانوية. زُرع صنف القمح "نزار" في موعدين، مع تطبيق معدلات النيتروجين والفوسفور الموصى بها بشكل موحد. أُضيف البوتاسيوم وفقًا لمستويات المعالجة. أظهرت النتائج أن تاريخ الزراعة المبكر (1 نوفمبر) تفوق عدديًا على التاريخ المتأخر في معظم الصفات، بما في ذلك عدد السنابل وعدد الحبوب في السنبلة الواحدة، على الرغم من أن الفروق لم تكن ذات دلالة إحصائية. لم يكن لمواعيد الزراعة تأثير يُذكر على طول النبات، أو وزن الألف حبة، أو مؤشر الحصاد. كان لتسميد البوتاسيوم تأثير إيجابي ملحوظ على عدد السنابل، وإنتاجية الحبوب، ووزن الألف حبة، ومؤشر الحصاد، مع زيادة ملحوظة مع ارتفاع مستويات البوتاسيوم من K0 إلى K2. ومع ذلك، انخفض عدد الحبوب في السنبلة الواحدة بشكل ملحوظ مع ارتفاع مستويات البوتاسيوم. أظهر ماء الري العذب تفوقًا عدديًا على الماء المالح في معظم الصفات، على الرغم من أن الفروق لم تكن ذات دلالة إحصائية بشكل عام. تم الحصول على أعلى إنتاجية للحبوب عند الزراعة المبكرة باستخدام الماء العذب، بينما سُجلت أدنى إنتاجية عند الزراعة المتأخرة باستخدام الماء المالح. بشكل عام، كان تسميد البوتاسيوم هو العامل الأكثر تأثيرًا في تحسين أداء القمح في ظل ظروف الري المالح.

الكلمات المفتاحية: *التمر، البوتاسيوم، القمح.*

1. Introduction

Soil and irrigation water salinity are among the most important environmental stresses that limit the productivity of the wheat crop (Triticum aestivum L.), especially in arid and semi-arid regions, where dissolved ions such as sodium (Na^+) and chloride (Cl^-) disrupt the balance of nutrient elements and plant metabolism, leading to a noticeable decrease in growth and grain production. When wheat is exposed to irrigation with saline water, it faces disturbances in ion balance, an increase in osmotic pressure, and accumulation of reactive oxygen species, which negatively affect physiological processes such as photosynthesis and the absorption of essential elements such as potassium (K^+), which is necessary for regulating osmotic pressure and stomatal opening and closing (Farooq et al., 2024) .

The role of potassium in enhancing plant tolerance to salinity is linked to improving ionic relations, supporting the activity of antioxidant enzymes, and reducing the accumulation of sodium in the vital tissues of plants. Recent studies have shown that the application of potassium, whether through the soil or by foliar spraying, can greatly mitigate the harmful effects of salt stress on wheat by enhancing growth, increasing chlorophyll content, and improving nutrient uptake, thus contributing to increased yield under saline stress conditions (Noor et al., 2025). On the other hand, planting dates represent one of the important management factors that affect the ability of plants to adapt to different environmental conditions, as early or late planting can lead to changes in growth periods and the likelihood of exposure to salinity stress at sensitive stages of the plant life cycle. Recent research indicates that the appropriate timing of planting interacts with the levels of added potassium, which significantly affects the morphological and physiological traits of wheat under saline irrigation conditions, leading to variation in productive response and grain characteristics (Mukhlif et al., 2023). Based on the above, this study aims to analyze the integrated effect of planting dates and potassium treatments on the tolerance of wheat to saline irrigation water, by evaluating plants in terms of plant height (cm), number of spikes (m^2), number of grains per spike, biological yield (ton ha^{-1}), grain yield (ton ha^{-1}), 1000-grain weight (g), and harvest index. The study relies on the latest scientific findings published in this field to provide scientific recommendations supported by data that can help improve crop management in high-salinity environments, thus contributing to enhancing food security in areas affected by salinity stress (Mukhlif et al., 2023).

2. Materials and Methods

2.1.The experimental study

The experiment aimed to study the effect of planting dates, irrigation water quality, and levels of potassium fertilizer addition on the growth and productivity of the wheat crop under saline irrigation conditions. This study was conducted in the field in one of the fields of the Al-Akhd area / Al-Rifai District in Dhi Qar Governorate during the 2024–2025 agricultural season. The field was prepared by carrying out the necessary plowing and smoothing operations, and the experimental units were divided according to a Randomized Complete Block Design (RCBD) with a Split–Split Plot arrangement, where the planting dates represented the main plots, the irrigation water quality (fresh and saline) represented the sub-plots, while the levels of potassium addition (0, 60, 120 kg ha^{-1} in the form of potassium sulfate) occupied the sub-sub plots, with four replicates. Seeds of wheat cultivar Nazar were planted at two different dates, with commitment to the recommended fertilizer rates of nitrogen and phosphorus, and potassium was added according to the treatments, with the role of irrigation water quality emerging as the most influential factor compared to planting date.

2.2.Types of irrigation water

Two types of irrigation water were used, the first fresh with a salinity of 1.5 dS m^{-1}, and the second saline with a salinity of 6 dS m^{-1}, prepared by mixing according to the equation of Ayers and Westcot, and irrigation with saline water began after the establishment irrigation. Soil samples were collected before planting and chemical and physical analyses were performed to determine their basic properties, and irrigation water analyses were also carried out to describe its ionic and salinity characteristics.

2.3.Laboratory measurements

included determining electrical conductivity, soil pH, cation exchange capacity, and organic matter, in addition to estimating dissolved ions and available major nutrient elements in the soil. Physical measurements of the soil were also performed, along with plant measurements that included yield components (grain weight, grain yield, biological yield, harvest index).

2.4.Statistical Analyses

Data were statistically analyzed using analysis of variance (ANOVA) for factorial experiments according to the Split–Split Plot arrangement, and means were compared using the Least Significant Difference test (LSD) at a probability level of 5%, based on Gestate software.

3. Results and Discussion

3.1. Effect of Sowing Dates, Irrigation Water Quality, and Soil Application of Potassium on Plant Height (cm)

The results of Table (1) showed a numerical superiority for the first sowing date (M1) on November 1 in plant height (53.295 cm) compared to the second sowing date (M2) on December 1 (52 cm), however, this superiority was not statistically significant. This is attributed to the similarity of prevailing environmental conditions during the sowing periods, particularly temperature and humidity, which led to a similar vegetative growth response (Alam *et al*., 2022). These results are in agreement with Bahadori *et al*., (2025), who stated that the effect of sowing dates on growth may vary depending on the crop and environmental conditions, and may not appear significant when climatic conditions are similar. Similarly, potassium levels ((K0, K1, and K2)) did not show a significant effect on plant height, with means ranging between 52.44 and 52.94 cm, possibly due to sufficient potassium availability in the soil or because this element was not a limiting factor for longitudinal growth during the study period. Although potassium plays an important physiological role in enhancing photosynthesis and regulating water content, its effect on some vegetative growth traits may be limited depending on stress intensity and experimental conditions (Zhu *et al*., 2025).

Regarding irrigation water quality (Figure 1), plants irrigated with fresh water (S1) recorded a higher average height compared to saline water (S2), without statistical significance, indicating that the salinity level used was not sufficient to produce a clear effect on longitudinal growth, or that the plants possessed relative tolerance under these conditions. These results are consistent with Borres *et al*., (2025), who reported that salinity effects may not be significant for all growth traits at low to moderate levels.

Table 1. Effect of Sowing Dates, Irrigation Water Quality, and Soil Application of Potassium on Plant Height (cm)

Sowing Dates	Potassium Level K0	Potassium Level K1	Potassium Level K2
(M1) 1 November	52.38	53.62	53.88
(M2) 1 December	52.5	52.25	51.25
LSD (0.05)	NS		
Mean of Potassium Levels	52.44	52.935	52.565
LSD	NS		
Water Quality	Water Quality × Potassium levels		
S1 (Fresh Water)	55	56.5	55.5
S2 (Saline Water)	49.88	49.38	49.62
LSD (0.05)	NS		
Water Quality	Water Quality × Sowing Dates		Mean
	First Date (M1)	Second Date (M2)	
S1 (Fresh Water)	56.42	54.92	55.67
S2 (Saline Water)	50.17	49.08	49.625
LSD (0.05)	NS		

Overall Mean of Sowing Dates	53.295	52	
LSD (0.05)	NS		

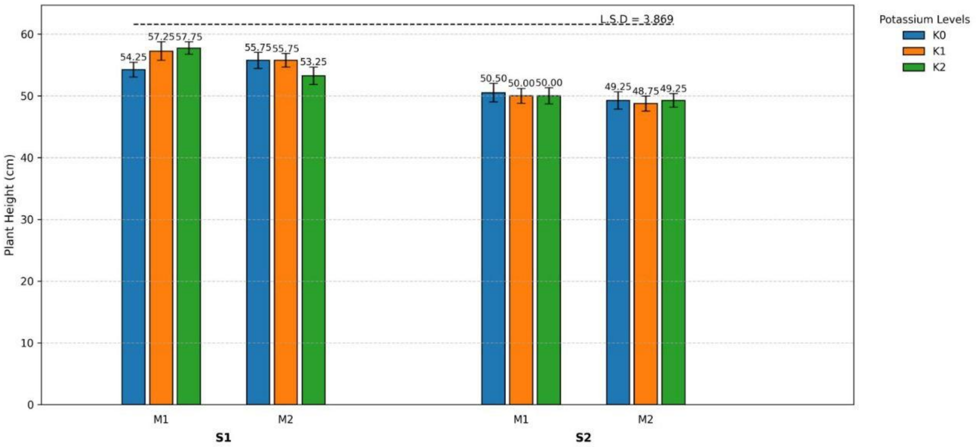

Figure 1: Effect of Sowing Dates, Irrigation Water Quality, and Soil Application of Potassium on Plant Height (cm)

No significant effect was recorded for the two-way interactions between irrigation water quality and potassium levels or sowing dates on plant height, indicating the independence of the studied factors, which agrees with Noor *et al*., (2025).

Overall, the results indicate that plant height was not significantly affected by sowing dates, potassium levels, or irrigation water quality under the conditions of this study.

3.2. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Number of Spikes (m^2).

The results of the study presented in Table (2) showed a numerical superiority of the first sowing date (M1) on 1 November in the mean number of spikes per m² at all potassium levels compared with the second sowing date (M2) on 1 December, with mean values of 275 and 267.5 spikes/m², respectively.

Table 2. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Number of Spikes (m^2).

Sowing Dates	Potassium Level K0	Potassium Level K1	Potassium Level K2
(M1) 1 November	232.5	281.2	311.2
(M2) 1 December	228.8	277.5	296.2
LSD (0.05)	NS		
Mean of Potassium Levels	230.65	279.35	303.7

LSD	17.97		
Water Quality	Water Quality × Potassium levels		
S1 (Fresh Water)	243.8	285	322.5
S2 (Saline Water)	217.5	273.8	285
LSD (0.05)	NS		
Water Quality	Water Quality × Sowing Dates		Mean
	First Date (M1)	Second Date (M2)	
S1 (Fresh Water)	285	282.5	283.75
S2 (Saline Water)	265	252.5	258.75
LSD (0.05)			17.19
Overall Mean of Sowing Dates	275	267.5	
LSD (0.05)	NS		

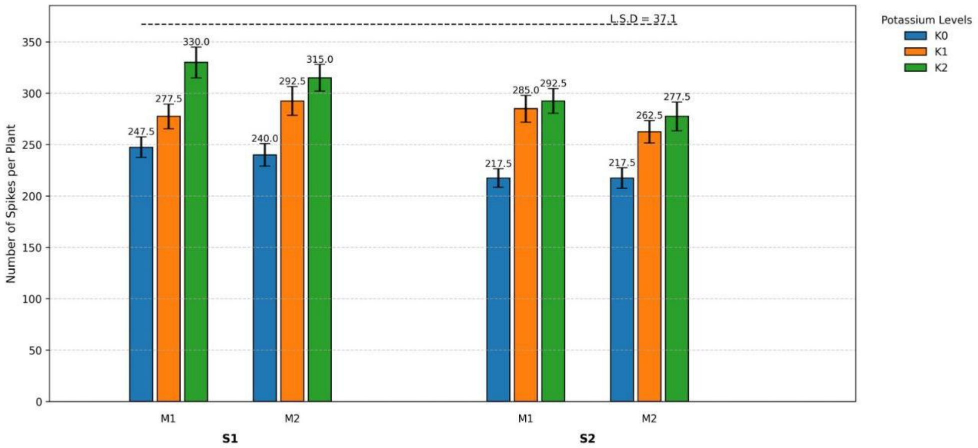

Figure 2. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Number of Spikes (m^2).

However, this superiority was not statistically significant. This may be attributed to the similarity of environmental conditions between the two sowing dates, which limited the effect of delayed planting on the duration of vegetative growth and the number of spikes. These findings are consistent with those reported by Jassim *et al*. (2024), who indicated that the effect of sowing dates on spike number in wheat varies according to prevailing climatic and seasonal conditions. In contrast, potassium levels had a clear and statistically significant effect on the number of spikes, as the mean increased from 230.65 spikes/m² in the control treatment without potassium addition (K0) to 303.7 spikes/m² at the high potassium level (K2). This indicates the effective role of potassium in improving physiological processes associated with the formation of reproductive organs. These results agree with Dennett, (2024), who reported that potassium contributes to enhancing photosynthetic efficiency and the translocation of carbohydrates toward reproductive organs, which positively affects spike number. Regarding irrigation water quality (Figure 2), freshwater (S1) produced higher numbers of spikes than saline water (S2) at all potassium levels, although the differences were not statistically significant. This may be attributed to the salinity level used being within the plant's tolerance limits or to the exposure duration not being sufficient to elicit a clear effect, as indicated by Dieleman, (2023). However, the interaction between sowing dates and irrigation water quality had a significant effect on spike number, with early sowing combined with freshwater recording the highest mean, while late sowing with saline water resulted in the lowest mean. This reflects the sensitivity of spike number to the combined variation of these two factors. These results emphasize the importance of selecting the optimal sowing date and appropriate irrigation water quality to achieve the best productive response, as reported by (Bana *et al*. (2022) ; Malik *et al*. 2021).

3.3. Effect of sowing dates irrigation water quality and soil potassium application on Number of grains per Spike

The study results in Table (3) indicated a slight numerical superiority for the first sowing date (M1) on 1 November in the number of grains per spike compared to the second sowing date (M2) on 1 December at all potassium levels, yet these differences did not reach statistical significance.

Table 3. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Number of Grain per Spike.

Sowing Dates	Potassium Level K0	Potassium Level K1	Potassium Level K2
(M1) 1 November	26.93	26.41	24.28
(M2) 1 December	26.58	25.6	24
LSD (0.05)	NS		
Mean of Potassium Levels	26.755	26.005	24.14
LSD	1.592		
Water Quality	Water Quality × Potassium levels		
S1 (Fresh Water)	28.38	27.75	26.28
S2 (Saline Water)	25.13	24.26	22
LSD (0.05)	NS		
Water Quality	Water Quality × Sowing Dates		Mean
	First Date (M1)	Second Date (M2)	
S1 (Fresh Water)	27.82	27.12	27.47
S2 (Saline Water)	23.93	23.67	23.8
LSD (0.05)			1.518
Overall Mean of Sowing Dates	25.875	25.395	
LSD (0.05)	NS		

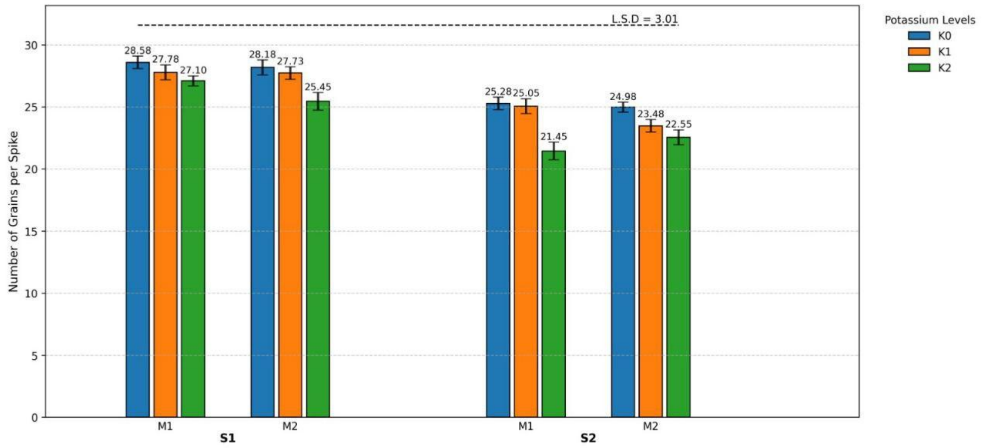

Figure 3. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Number of grains per Spike

This is attributed to the similarity of environmental conditions, especially temperature and humidity, during the grain formation stages in both dates, resulting in similar physiological responses and reflected as numerical homogeneity in the number of grains per spike.

These results agree with Kumar *et al*., (2024) who stated that the effect of sowing dates on grain number is primarily determined by the degree of climatic variation during critical stages, and may be limited when conditions are similar. The results showed that increasing potassium level from K0 to K2 led to a significant decrease in the number of grains per spike, with the mean falling from 26.76 to 24.14 grains. This decrease can be explained by the potential nutritional imbalance between potassium and other elements, particularly nitrogen and phosphorus, or by redirecting photosynthetic products toward vegetative growth or increased metabolic activity at the expense of grain formation. This result agrees with Messaoudi *et al*., (2023) who reported that the response to potassium in grain number per spike may be limited or irregular depending on soil properties, variety, and prevailing environmental conditions. Regarding irrigation water quality, plants irrigated with fresh water (S1) recorded a higher number of grains per spike compared to saline water (S2) across all treatments, though these differences were not statistically significant. This is attributed to the used salinity level being within the plant's tolerance or the exposure duration being insufficient to show a clear significant effect. Recent studies indicated that the effect of salinity stress on grain number per spike is more pronounced at higher salinity levels or longer exposure periods, while it may not be significant at moderate levels (Manhou *et al*., 2024; Patwa *et al*., 2024). The three-way interactions between sowing dates, irrigation water quality, and potassium levels (Figure 3) did not show a significant effect on grain number per spike, indicating that the effects of these factors were independent and limited under the experimental conditions, which is consistent with Soliman and Koubisy, (2025) regarding the limited emergence of significant interactions in some wheat production traits.

3.4 Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Weight of 1000- Grain (g).

Table (4) shows the effect of sowing dates irrigation water quality and levels of soil potassium application and their two-way interactions on 1000 grain weight (g), which is an important indicator of grain quality and filling efficiency. The results showed slight variation in 1000 grain weight between sowing dates, with weight ranging from 48.91–56.2 g in the first date (1 November) and 46.27–55.85 g in the second date (1 December), without statistically significant differences, indicating the limited effect of sowing timing on grain weight under the environmental conditions of the experiment. This agrees with what Chaulagain *et al*., (2024) ; Altai *et al*., (2024) reported, that the effect of sowing dates is less pronounced on grain weight compared to its effect on total yield under similar climatic conditions. In contrast, potassium levels showed a clear significant effect on 1000 grain weight, with the mean increasing from 47.59 g at no application (K0) to 56.03 g at high level (K2). This improvement is attributed to the vital role of potassium in enhancing sugar translocation, regulating osmotic pressure, and improving water use efficiency during grain filling, positively affecting grain weight (Wegner *et al*., 2025).

Table 4. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Weight of 1000- Grain (g).

Sowing Dates	Potassium Level K0	Potassium Level K1	Potassium Level K2
(M1) 1 November	48.91	48.96	56.2
(M2) 1 December	46.27	53.12	55.85
LSD (0.05)	2.663		
Mean of Potassium Levels	47.59	51.04	56.025
LSD	2.094		
Water Quality	Water Quality × Potassium levels		
S1 (Fresh Water)	51.74	55.4	59.14
S2 (Saline Water)	43.45	46.67	52.91
LSD (0.05)	NS		
Water Quality	Water Quality × Sowing Dates		Mean
	First Date (M1)	Second Date (M2)	
S1 (Fresh Water)	55.29	55.56	55.425
S2 (Saline Water)	47.42	47.93	47.675
LSD (0.05)			3.712
Overall Mean of Sowing Dates	51.355	51.745	
LSD (0.05)	NS		

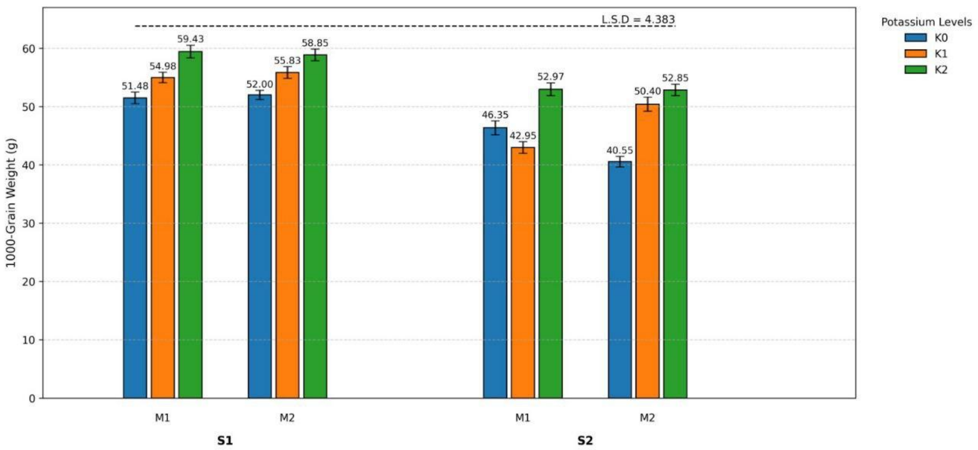

Figure 4. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Weight of 1000- Grain (g).

These results agree with Nawaz *et al*., (2024) regarding the role of potassium in improving plant physiological performance and increasing grain traits, especially under stress conditions. Regarding irrigation water quality (Figure 4), fresh water recorded higher 1000 grain weights compared to saline water at all potassium levels, although these differences were not statistically significant. The relative reduction in grain weight under saline irrigation is attributed to salt stress effects on water and nutrient uptake, consistent with Elhag, (2023) ; Atta *et al*., (2023). The interaction between water quality and potassium levels showed notable improvement in grain weight, especially when using fresh water, confirming the role of potassium in partially mitigating salinity effects by improving ion balance within the plant (Salonia *et al*., 2020). Overall, the results confirm that potassium fertilization is the most influential factor on 1000 grain weight compared to sowing dates and irrigation water quality under the conditions of the experiment (Norouzi and Akbari, 2024).

3.5. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Biological Yield (ton/ha)

The results of Table (5) showed a numerical superiority for the second sowing date (1 December) in biological yield compared to the first date, although this superiority was not statistically significant, which agrees with Kumar *et al*., (2024) that the effect of sowing dates on biological yield may be limited when environmental conditions are similar between dates. Conversely, increasing potassium levels led to a significant increase in biological yield, reflecting the effective role of this element in improving plant physiological processes, especially photosynthesis, carbohydrate transport, and osmotic regulation, which contributes to greater total dry matter accumulation (Al-Taher and Al-Naser, 2021; Sharma *et al*., 2022). As for irrigation water quality, it did not show a significant effect on biological yield, indicating that the salinity level used was within limits that do not cause a clear reduction in biomass, or that the plant possesses initial tolerance mechanisms that limit the negative effect of salinity. These results agree with Farooq *et al*., (2024); Manhou *et al*., (2024) that the effect of salinity is more apparent in grain yield compared to biological yield, especially at high levels or long-term exposure. No significant interaction was recorded between irrigation water quality and potassium levels (Figure 5), indicating the independent effect of each factor under the experimental conditions, which agrees with Soliman and Koubisy, (2025). Meanwhile, the interaction between sowing dates and irrigation water quality showed a significant effect on biological yield, where treatments irrigated with fresh water at both dates outperformed their saline water counterparts, reflecting the interaction of sowing time with water quality. This is attributed to the selection of a climatically suitable sowing date which can mitigate the negative effects of salinity by improving water uptake and biomass accumulation during critical growth stages (Wang *et al*., 2023). The results also showed that the second date (M2) was significantly superior to the first date (M1) in biological yield, confirming the importance of aligning sowing time with optimal climatic conditions to maximize biomass accumulation, which agrees with Ikram *et al*., (2025) in their studies on wheat crop.

Table 5. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Biological Yield (ton/ha).

Sowing Dates	Potassium Level K0	Potassium Level K1	Potassium Level K2

(M1) 1 November	7.59	9.62	9.83
(M2) 1 December	8.87	10	9.88
LSD (0.05)	NS		
Mean of Potassium Levels	8.23	9.81	9.855
LSD	0.974		
Water Quality	Water Quality × Potassium levels		
S1 (Fresh Water)	8.95	10.08	10.39
S2 (Saline Water)	7.51	9.54	9.31
LSD (0.05)	NS		
Water Quality	Water Quality × Sowing Dates		Mean
	First Date (M1)	Second Date (M2)	
S1 (Fresh Water)	9.87	9.75	9.81
S2 (Saline Water)	8.16	9.42	8.79
LSD (0.05)	0.676		0.698
Overall Mean of Sowing Dates	9.015	9.585	
LSD (0.05)	0.445		

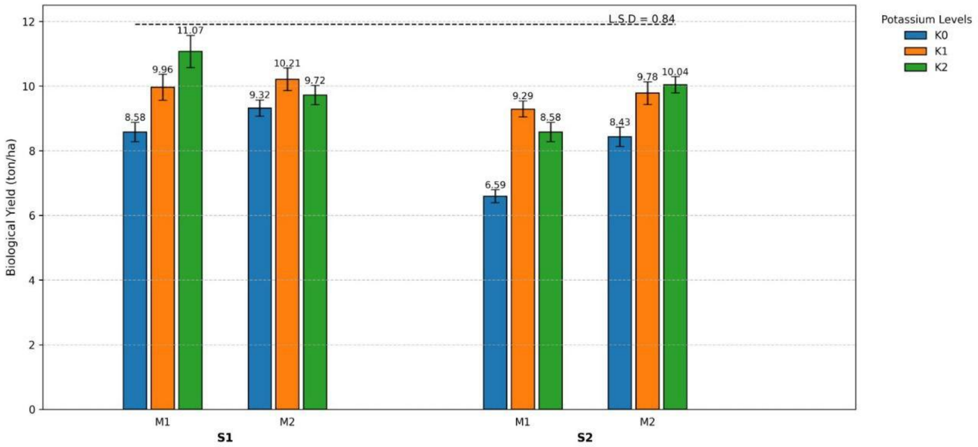

Figure 5. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Biological Yield (ton/ha).

3.6. Effect of Sowing Dates Irrigation Water Quality and Soil Potassium Application on Grain Yield (ton/ha).

Table (6) shows the effect of sowing dates, irrigation water quality, soil potassium levels, and their two-way interactions on grain yield (ton/ha), where the results revealed a clear variation in wheat response to these factors. The results of Figure 6 indicated a numerical superiority of the first sowing date (1 November) in grain yield compared to the second date (1 December), with an average yield of 3.69 versus 3.57 ton/ha, yet this superiority was not statistically significant. This trend is attributed to the early sowing providing a longer growth period and better alignment with thermal conditions during sensitive phenological stages, particularly flowering and grain filling, as noted by Liu et al., 2023. In contrast, potassium levels showed a clear significant effect on grain yield, with the mean increasing from 2.98 ton/ha without application (K0) to 4.17 ton/ha at high level (K2), which is attributed to the physiological role of potassium in regulating osmotic pressure, activating enzymes, improving water use efficiency, and translocating photosynthetic products toward grains, positively affecting grain weight and number. These results agree with Damalas and Koutroubas, 2024, on the importance of adequate potassium supply in enhancing cereal crop productivity under environmental stress. The interaction of sowing dates with irrigation water quality (Figure 6) showed a significant effect on grain yield, with the highest yield achieved under early sowing with fresh irrigation water (4.32 ton/ha), while the negative effect of saline water was more pronounced at late sowing. This is attributed to early sowing enhancing root and shoot growth before exposure to salt stress at later growth stages. Overall, the results confirm that integrated management of sowing dates, irrigation water quality, and potassium fertilization is a critical factor in improving grain yield, with potassium fertilization emerging as one of the key production determinants, especially when good-quality irrigation water is available (Farouk *et al*., 2024)

Table 6. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Grain Yield (ton/ha).

Sowing Dates	Potassium Level K0	Potassium Level K1	Potassium Level K2
(M1) 1 November	3.099	3.644	4.32
(M2) 1 December	2.864	3.807	4.026
LSD (0.05)	NS		
Mean of Potassium Levels	2.9815	3.7255	4.173
LSD	0.3954		
Water Quality	Water Quality × Potassium levels		
S1 (Fresh Water)	3.584	4.362	5.015
S2 (Saline Water)	2.378	3.089	3.331
LSD (0.05)	NS		
Water Quality	Water Quality × Sowing Dates		Mean
	First Date (M1)	Second Date (M2)	
S1 (Fresh Water)	4.39	4.251	4.3205
S2 (Saline Water)	2.985	2.88	2.9325
LSD (0.05)			0.179
Overall Mean of Sowing Dates	3.6875	3.5655	
LSD (0.05)	NS		

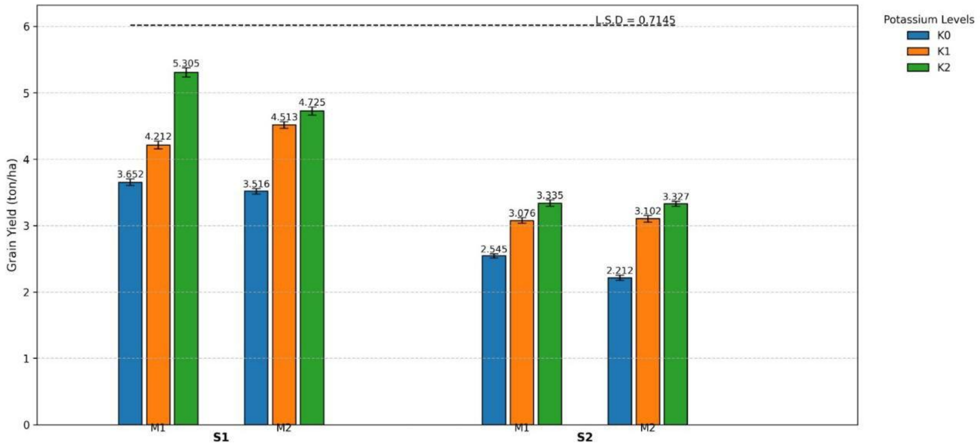

Figure 6. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on Grain Yield (ton/ha).

3.7. Effect of Sowing Dates Irrigation Water Quality and Soil Potassium Application on harvest index (%).

Table (7) shows the effect of sowing dates irrigation water quality potassium levels and their two- way interactions on the harvest index (%) of wheat, which is an indicator reflecting the plant's ability to convert biomass into economic yield and grain filling. The results showed the superiority of the first sowing date (1 November) over the second date (1 December) with a mean of 40.875 versus 37.105, without statistical significance, which is attributed to early sowing providing the plant a longer period for vegetative and root growth before grain formation stages, thus enhancing grain filling and quality (An *et al*., 2025). Furthermore, increasing potassium levels from K0 to K2 showed a significant increase in harvest index from 36.505 to 42.23, as potassium plays a pivotal role in sugar transport to grains and improving grain density and filling, which raises the harvest index, consistent with (Wang *et al*., 2025). Regarding irrigation water quality, fresh water (S1) recorded higher values than saline water (S2) across all levels, with harvest index ranging from 40.54 to 48.47 versus 32.47–35.99, despite the lack of statistical significance, attributed to salinity's effect on water and nutrient uptake and ionic stress on the plant (Atta *et al*., 2023). Moreover, the interaction between irrigation water quality and potassium levels (Figure 7) showed the highest harvest index at S1×K2 = 48.47, while the lowest value was at S2×K0 = 32.47, indicating potassium's ability to partially mitigate salinity effects by improving ion balance and reducing sodium accumulation (Noor *et al*., 2025). When sowing dates were combined with irrigation water, early sowing with fresh water recorded the highest value (44.22) versus the lowest for late sowing with saline water (33.76), highlighting the importance of integrated management of sowing timing and water quality to achieve higher grain quality and yield (Chen *et al*., 2025).

Table 7. Effect of Sowing Dates Irrigation Water Quality and Soil Potassium Application on harvest index (%).

Sowing Dates	Potassium Level K0	Potassium Level K1	Potassium Level K2
(M1) 1 November	40.9	38.27	43.44
(M2) 1 December	32.11	38.19	41.02

LSD (0.05)	NS		
Mean of Potassium Levels	36.505	38.23	42.23
LSD	3.873		
Water Quality	Water Quality × Potassium levels		
S1 (Fresh Water)	40.54	43.64	48.47
S2 (Saline Water)	32.47	32.82	35.99
LSD (0.05)	NS		
Water Quality	Water Quality × Sowing Dates		Mean
	First Date (M1)	Second Date (M2)	
S1 (Fresh Water)	44.63	43.81	44.22
S2 (Saline Water)	37.12	30.4	33.76
LSD (0.05)	NS		4.808
Overall Mean of Sowing Dates	40.875	37.105	
LSD (0.05)	NS		

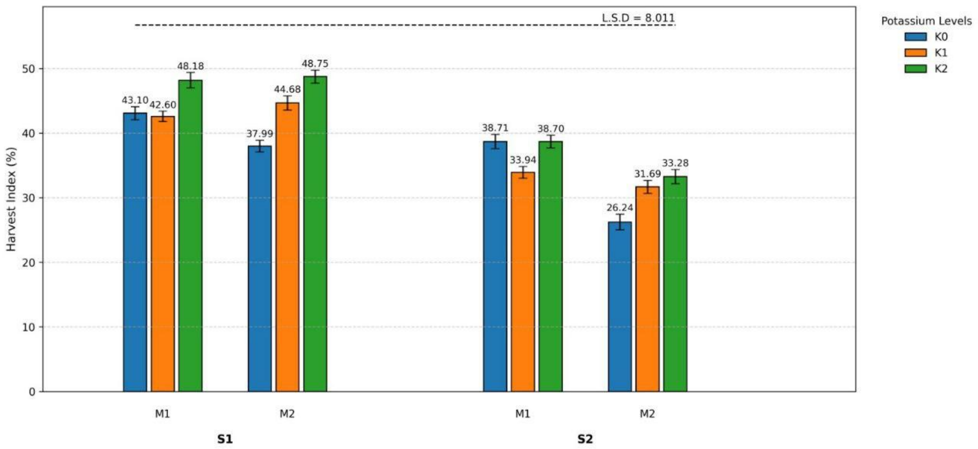

Figure 7. Effect of Sowing Dates, Irrigation Water Quality, and Soil Potassium Application on harvest index (%).

Conclusion

We conclude from the study that early sowing enhances wheat growth under saline irrigation conditions, especially if combined with potassium application at appropriate levels, which reflects in improved grain yield, 1000-grain weight, and harvest index. This indicates the necessity of integrated management of agronomic factors as a strategy to maintain crop productivity when forced to irrigate with saline water under freshwater scarcity.

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