



Effects of Irrigation Water Quality on Seed Germination and Early Seedling Growth of Wheat (*Triticum aestivum* L.)



Muhammad Zakir¹

¹Arid University, Pakistan

Email: zakir011@gmail.com

ARTICLE INFO	ABSTRACT
Received: July 28, 2026 Revised: August 26, 2026 Accepted: September 25, 2026 Available Online: October 01, 2026 Keywords: <i>wheat; Triticum aestivum; irrigation water quality; salinity; electrical conductivity; seed germination; seedling growth</i> Corresponding Author: Muhammad Zakir	Irrigation water of poor quality, particularly saline water, is a growing constraint on wheat (<i>Triticum aestivum</i> L.) production, and the germination and early seedling stages are among the most sensitive to salt stress. This study will quantify how irrigation-water quality affects seed germination and early seedling growth of wheat under controlled laboratory conditions. A completely randomised design will compare four treatments: distilled water (control), freshwater, moderately saline water (target electrical conductivity, EC, 6 dS/m), and highly saline water (target EC 12 dS/m), each with six replicates of 50 seeds in Petri dishes incubated at 20 °C. Germination percentage and mean germination time will be calculated from daily counts over eight days, and root length, shoot length, fresh biomass, and dry biomass will be measured on ten seedlings per replicate. Data will be analysed with one-way ANOVA followed by Tukey's post-hoc test when assumptions are met, with Welch's ANOVA and Games-Howell comparisons or Kruskal-Wallis and Dunn's tests as alternatives, and with eta- and omega-squared effect sizes. A planning calculation indicated 80% power to detect a standardised effect of about $f = 0.75$ with six replicates per treatment. The study is intended to provide a reproducible, transparent evaluation of water-quality thresholds for wheat establishment and to inform irrigation management where saline water is used.

Introduction

Wheat is one of the most significant food crops in the world and food security in many regions depends on the production of wheat (Shiferaw et al., 2013). Soil and water salinisation are becoming a growing threat in large parts of irrigated and rain-fed areas, with impacts likely to increase where saline groundwater and low-quality irrigation water is employed (Rengasamy, 2006; Shahid et al., 2018). Irrigation water quality is determined by the amount of salt present in the water (total salt content, usually measured as electrical conductivity, EC), and the type of ions present (Machado and Serralheiro, 2017; Shrivastava and Kumar, 2015).

There are two ways in which salinity has a negative effect on plants: firstly by causing an osmotic effect, which limits water uptake, and secondly by causing an ion-specific effect, caused by the buildup of sodium and chloride ions (Munns & Tester, 2008). Because the imbibing seed requires a favourable water potential and the establishment of the stand will affect the crop performance, germination and early seedling growth are particularly sensitive stages (Bewley et al., 2013). Laboratory experiments have shown that wheat germination and seedling growth is affected by salinity and cultivars vary in response to salinity (Akbarimoghaddam et al., 2011; Datta et al., 2009). Studies may vary, however, in the definition of salinity, in the scoring of germination and in the analysis of the results making it difficult to compare and replicate.

A well-controlled experiment can provide more information about the relationship between irrigation-water quality and wheat establishment with measured EC, a standard germination-testing environment, and pre-specified statistical procedure. This evidence may be helpful in screening water sources and for establishing a baseline for comparing cultivars or amendments. The aim of this study is thus to answer three questions: (1) What is the effect of the quality of the irrigation water (its electrical conductivity, EC) on the germination percentage and mean germination time of wheat? (2) What is the effect of the irrigation water quality (EC) on the length of the roots and shoots and fresh and dry biomass of the wheat's early seedlings? and (3) How big are these effects, and how uncertain are they, with suitable effect sizes and uncertainty? The null hypothesis is that there are no differences between the mean values of each response variable between the four water treatments. The other hypothesis supported by osmotic and ionic effects of the salts is that as EC rises the germination and seedling growth will decrease and the time of germination will increase.

Literature Review

Salinity is among the most important abiotic stresses for crops and its impact is typically characterized as an osmotic phase and an ionic phase. The osmotic phase starts the moment the salt concentration in the medium decreases the water potential and makes it unavailable to the roots or seeds, the ionic phase starts when the concentration of sodium ions and chloride ions in the tissues reaches toxic levels (Munns & Tester, 2008). Soils with an electrical conductivity of approximately 4 dS/m (or about 40 mM sodium chloride) are considered saline, and they have an osmotic pressure of the order of 0.2 MPa (Munns & Tester, 2008). Wheat is considered as moderately tolerant to salinity and tolerance is different across the genotype and growth stages.

Salts cause germination delays and/or inhibitions due to their effect on water uptake and ion-specific toxicity to the embryo and the relative importance of these impacts varies across species (Gul et al., 2013). The seed physiology literature defines germination as taking place when the embryo takes up water, and finishing when the radicle emerges, and any decrease in external water potential will delay or inhibit the completion of germination (Bewley et al., 2013). Since a delay in germination might be as significant as a smaller final germination percentage, researchers suggest reporting the time and rate of germination as well as final germination percentages and have developed formulas for mean germination time, rate, and other measures (Ranal & Santana, 2006; Ranal et al., 2009).

These relationships have been studied under controlled conditions with wheat. Several wheat cultivars were also tested at a laboratory level, with an impact of salt stress on germination and seedling traits and genotypic variation in the cultivars tested also reported (Datta et al., 2009), and a study of bread wheat cultivars reported significant effects of salinity on germination and seedling growth and genotypic variation (Akbarimoghaddam et al., 2011). The results of these tests suggest that the characteristics of seedlings could serve as useful indicators of salinity responses and that responses would vary depending on the salinity stress. Meanwhile, many treatments are often formulated with a single salt, and the water used as the control is not always described, nor is the method of EC determination. Concurrently, the water used as the control and the method of verifying EC are not always provided and therefore limit the extent to which results can be applied to irrigation water in the field.

There is a basis for improvements in comparability through standardised germination-testing procedures. International Seed Testing Association (ISTA) has published rules for substrates, temperatures, test duration and evaluation of wheat seedlings, in addition to other agricultural species (ISTA, 2024). In addition to design and measurement standards, there is a need to report on statistics. Assumptions of classical one way ANOVA (OWA) (normality and homogeneity of variance) should be examined, not assumed (Ghasemi & Zahediasl, 2012); there are robust alternatives available when variances are unequal (welch's F test) (Delacre et al., 2019); and there are also non-parametric pairwise comparisons available when parametric assumptions fail (dunn's test) (Dinno, 2015). Using confidence intervals to report effect sizes enables readers to determine the practical significance of a difference that is not statistically significant (Lakens, 2013). The present study utilizes these standards to design, measure and analyze a 4-level irrigation-water experiment involving wheat, which can be repeated and expanded.

Materials and Methods

Experimental Design and Experimental Location

A single factor (irrigation-water treatment) laboratory experiment was conducted in a completely randomized design (CRD) with 24 experimental units, 6 replicates per irrigation-water treatment. The experimental unit in this experiment was the Petri dish with 50 seeds and all statistics were calculated on the mean of the dishes to prevent pseudoreplication of data on individual seeds and seedlings. Irrigation-water quality (four levels, according to measured EC) was the independent variable. Germination percentage, mean germination time, root length, shoot length, fresh biomass and dry biomass were the dependent variables. The experiment was carried out in a germination incubator in the plant physiology laboratory of [institution], and

the dates were [start date] to [end date]. Dish positions in the incubator were randomized by selection using random number generation and shifted on a daily basis to minimize the effects of dish position.

Irrigation-Water Treatments

There were four treatments (Table 1). The control used was distilled water. The freshwater treatment was dechlorinated tap water or well water representative of local irrigation water, and was characterized by measuring major ions (Na^+ , Ca^{2+} , Mg^{2+} , Cl^- , HCO_3^-), EC and pH before use (where facilities allowed). Analytical grade sodium chloride was dissolved in distilled water and the solution conductivity measured at 25 °C using a calibrated conductivity meter to adjust the solution to the desired EC, which was the saline treatments. The treatment levels for the moderately saline and highly saline treatments were set at 6 and 12 dS/m, respectively. The 6 dS/m level was beyond the typical saline condition threshold of 4 dS/m (Munns & Tester, 2008), and would be considered a stress level for a moderately tolerant crop, whereas the 12 dS/m level would be considered severe salinity that would strongly limit germination. These were roughly proportional to the osmotic pressure associated with 4 dS/m (Munns & Tester, 2008) and were easily confirmed using an osmometer if available. The values were design values that were based on the literature and practical considerations, and were to be confirmed in a pilot test; the measured EC of each batch, not the target, was to be reported. Water containing mixed ions was not used as a control or an interpretative sample, only sodium chloride.

Table 1

Irrigation-Water Treatments

Treatment	Preparation	Target EC (dS/m)	Measured (dS/m)	EC	Measured pH
T1 Control	Distilled water	≤ 0.05	0.03		6.8
T2 Freshwater	Dechlorinated tap or well water (local irrigation supply)	Record actual (expected < 1.0)	0.62		7.3
T3 Moderately saline	NaCl in distilled water	6.0 ± 0.2	6.08		6.9
T4 Highly saline	NaCl in distilled water	12.0 ± 0.3	12.14		6.8

Note. They are included only to demonstrate reporting format and must be replaced with actual laboratory measurements. EC = electrical conductivity, measured at 25 °C with a calibrated meter. Freshwater EC depends on the local source.

Replication and Sample-Size Rationale

The number of replicates was increased from the minimum to 4 to provide greater sensitivity. The planning calculation for a one-way ANOVA with four groups, $\alpha = .05$, and the noncentral F indicated that the number of replications for an approximate power of 80% to detect an effect of approximately 0.75 (Cohen's f) was six, versus five and four replications for an effect of approximately 0.84 and 0.98, respectively (Table 2). As salinity effects on germination and growth are typically large relative to the variation within treatments, six replications were deemed to be a reasonable compromise based on this assumption, which needed to be verified with the pilot variance. The experiment consisted of 300 seeds per treatment and 1200 seeds altogether with 50 seeds per replicate. Germination data was taken for each of the 50 seeds and the measurements of the seedlings taken for 10 randomly selected normal seedlings per dish.

Table 2

Power of One-Way ANOVA (Four Groups, $\alpha = .05$) by Replicates per Treatment

Replicates per treatment	$f = 0.6$	$f = 0.8$	$f = 1.0$	Smallest f with 80% power
4	.38	.62	.82	0.98
5	.49	.76	.93	0.84
6	.60	.86	.97	0.75

Note. Computed from the noncentral F distribution. f = Cohen's effect size for ANOVA. Estimates assumed equal group sizes and homogeneous variances.

Seed Material and Surface Sterilisation

Since there was no genetic or seed-quality variation, certified seed of a single cultivar and seed lot of bread wheat (cultivar, source, seed lot number, harvest year) was used. The initial moisture content and standard germination in distilled water was determined using ISTA procedures (ISTA, 2024), and the lot was only used if sufficiently high. Seeds were removed if they were broken or discoloured and uniform-sized seeds were retained. Fungi have been a potential contaminant and were reduced by surface sterilisation to avoid a treatment effect. The seeds were soaked in 1% sodium hypochlorite for 3 min, washed 3 times with distilled water and patted dry. All treatments were carried out in the same way and the time of the treatment was monitored in a pilot to rule out that the treatment itself would affect germination. Chemical seed treatment was recorded if the seed was treated.

Experimental Setup, Temperature and Light

All experimental units were 150 mm sterile Petri dishes that were sealed with two layers of germination filter paper. The seeds were distributed in the dish, with the embryo end facing the same direction and at equal distances. Embryo end was oriented in uniform direction and the seeds were arranged in the dish at regular intervals so that 50 were in the dish. Like wheat, dishes were incubated at 20 ± 1 °C and temperature was recorded for the duration of incubation (ISTA, 2024). The 12 h light/12 h dark incubator was provided with cool-white fluorescent lamps and the irradiation was measured and reported at the dish level. Dishes were covered in clear polyethylene bags to reduce evaporation and cross-contamination and the locations of the dishes were randomly placed and rotated each day.

At the beginning of the experiment 20 mL of each treatment solution was applied to the dishes, enough to wet the paper, but not enough to drench the seeds. The amounts of water lost were replaced by fresh treatment solution to the original amount and volume every day to maintain the moisture in dishes and prevent accumulation of salt by evaporation, and the volume added was recorded. Stock solutions were used to make new solutions and their EC was re-determined at the beginning. The sowing to final count in wheat was the longest period (8 days) specified in the ISTA rules (ISTA, 2024) for wheat and the experiment was conducted over this period. To record exposure, the EC of the paper leachate was measured at the end of the experiment in a subset of dishes.

Germination was recorded hourly for 8 days after which a seed was considered germinated when the radicle grew at least 2 mm in length. The variables and how they are calculated are summarised in Table 3. The percentage of germination was determined by dividing the number of germinated seeds by the number sown and multiplying by 100. To calculate mean germination time, one should use the sum of the products of the number of seeds newly germinated on each day and the day of count, divided by the total number of germinated seeds (Ranal & Santana, 2006; Ranal et al., 2009), which resulted in the mean germination rate being the reciprocal. On day 8, 10 normal seedlings were randomly taken from each dish. The length of roots (longest seminal root) and shoots (from seed base to end of longest leaf) was measured using a ruler to the nearest mm or from calibrated digital images. Seedling mass (fresh biomass) was measured after gently drying with a paper towel on an analytical balance, and dry biomass was measured after drying in an oven at 70 °C until constant mass. Dish mean per seedling was reported as measurements. When possible, observers were blinded to treatment by using coded dish labels.

Table 3

Response Variables and Calculation Methods

Variable	Definition or formula	Unit
Germination percentage (GP)	$GP = (G / N) \times 100$, where G = seeds germinated, N = seeds sown	%
Mean germination time (MGT)	$MGT = \Sigma(n_i \times t_i) / \Sigma n_i$, where n_i = seeds newly germinated on day t_i	days
Root length	Longest seminal root, mean of 10 seedlings per dish	cm
Shoot length	Seed base to tip of longest leaf, mean of 10 seedlings per dish	cm
Fresh biomass	Mass of seedlings after blotting, per seedling	mg
Dry biomass	Mass after drying at 70 °C to constant mass, per seedling	mg

Note. Formulas for GP and MGT follow Ranal and Santana (2006) and Ranal et al. (2009). Each dish contributed one value per variable.

Statistical Analysis

Analyses were performed in R (R Core Team, 2024) at $\alpha = .05$. For each treatment descriptive statistics of mean, standard deviation and of range of dish means were reported. A one-way ANOVA due to the treatment as a fixed factor was performed for each response variable. Normality of residuals was tested using the Shapiro–Wilk test in conjunction with Q–Q plots (which have limited power at small sample sizes; Ghasemi & Zahediasl, 2012) and homogeneity of variance was tested using Levene's or Brown–Forsythe test, as well as residual versus fitted plots. Randomisation of dish position was a factor that facilitated independence. If the assumptions were met, significant ANOVA results were followed by Tukey's honestly significant difference test for all comparisons between pairs. Welch's ANOVA with Games–Howell comparisons was performed when variances were unequal (Delacre et al., 2019). In cases of violation of normality or data ceilinging, such as germination percentages of 100% in the control, the Kruskal–Wallis test with Dunn's test and Holm adjustment was applied (Dinno, 2015), or a binomial GLM on seed counts was applied. Transformations (e.g., arcsine square root of proportions) were considered but warranted by diagnostic evidence. Effect sizes were reported as eta-squared and the less biased omega-squared with 95% confidence intervals, and pairwise differences as Hedges' g (Lakens, 2013). Scatter plots of the results were also presented as a percentage of the control for ease of interpretation. Responses were regressed on measured EC in an exploratory analysis for the purpose of describing the dose–response relationship. All analysis scripts and raw dish level data to be archived.

Concerns in the laboratory and in the environment.

Sodium chloride was not hazardous, but sodium hypochlorite was corrosive and an irritant: it was handled with gloves and eye protection and was handled in a well-ventilated space and never mixed with acids. Chemical treated seeds were treated with gloves. Standard lab practices were used such as safety data sheets and an institutional risk assessment. Saline solutions and used filter paper were not released to soil, to drains to the environment, nor to compost because salts may have a negative effect on soil and aquatic systems. Dried plant material was considered non-hazardous waste. No hazardous biological agents or protected organisms were employed as part of the experiment, nor was it undertaken for ethical reasons for work on humans or animals; however, approval of the experiment was required in its institutional laboratory.

Reproducibility

The study was to report the cultivar, the seed source and lot, the method used for making up treatments, the actual EC and pH of each batch of solutions used, the models of instruments used, the calibration performed, the temperature of the incubator, the light supplied, the randomisation procedure used, the dates of the experiment and the versions of software used. Any dish excluded and the reasons were to be recorded, and any variance from this protocol. Raw dish-level and seed-level data and analysis code was to be deposited in a public repository and a complete record of the experiment kept in a laboratory notebook. Experiment could be repeated in time to verify findings were not specific to a single experiment.

Results

Water Characterisation and Assumption Checks

The average values of the EC for the control, freshwater, moderately saline and highly saline treatments were 0.03, 0.62, 6.08 and 12.14 dS/m respectively as show in Table 1. Incubator temperature averaged 20.1 °C (range 19.4–20.8 °C). Growth variables, except for germination percentage, which was non-significant Shapiro–Wilk tests for residuals ($W = .94$, $p = .16$); and MGT ($W = .96$, $p = .42$); were non-significant. Growth variables, except for germination percentage (which was non-significant Shapiro–Wilk tests for residuals ($W = .94$, $p = .16$); and MGT ($W = .96$, $p = .42$); were also non-significant. Levene's test was non-significant for germination percentage ($F(3, 20) = 1.12$, $p = .37$), MGT ($F(3, 20) = 1.46$, $p = .25$), root length ($F(3, 20) = 1.31$, $p = .30$), shoot length ($F(3, 20) = 1.28$, $p = .31$), fresh biomass ($F(3, 20) = 1.52$, $p = .24$), and dry biomass ($F(3, 20) = 1.37$, $p = .28$). Therefore, the illustrative comparisons were made using one-way ANOVA and Tukey's honestly significant difference test. These are diagnostic statistics that have been fictionalised and should be changed with actual test results.

Effects on Germination and Seedling Growth

Table 4

Effects of Irrigation-Water Quality on Germination and Seedling Traits

Variable	Control	Fresh	Moderate	High	F	p	ω^2
Germination (%)	98.3 $\pm$ 4.1 ^a	96.7 $\pm$ 5.2 ^a	78.0 $\pm$ 8.3 ^b	42.3 $\pm$ 10.1 ^c	66.20	< .001	.89
MGT (days)	1.55 $\pm$ 0.12 ^a	1.68 $\pm$ 0.15 ^a	2.35 $\pm$ 0.28 ^b	3.10 $\pm$ 0.35 ^c	25.70	< .001	.76
Root length (cm)	12.4 $\pm$ 1.0 ^a	11.9 $\pm$ 0.9 ^a	8.3 $\pm$ 1.1 ^b	4.2 $\pm$ 0.8 ^c	74.80	< .001	.91
Shoot length (cm)	10.8 $\pm$ 0.8 ^a	10.3 $\pm$ 0.7 ^a	7.5 $\pm$ 0.9 ^b	3.8 $\pm$ 0.7 ^c	79.60	< .001	.92
Fresh biomass (mg)	185 $\pm$ 18 ^a	178 $\pm$ 16 ^a	129 $\pm$ 15 ^b	72 $\pm$ 12 ^c	62.40	< .001	.88
Dry biomass (mg)	42 $\pm$ 4 ^a	40 $\pm$ 3 ^a	31 $\pm$ 4 ^b	19 $\pm$ 3 ^c	45.60	< .001	.85

Note. Values are mean $\pm$ SD of six dish means per treatment. Different superscript letters within a row indicate illustrative significant differences based on Tukey's honestly significant difference test ($p < .05$). ω^2 = omega-squared; MGT = mean germination time. The reported F-statistics and effect sizes are illustrative estimates, not results computed from an actual dataset.

The irrigation-water quality significantly illustrated the germination percentage, $F(3, 20) = 66.20$, $p < .001$, $\omega^2 = .89$ as shown in Table 4. In the treatment with high salinity, the germination rate was 43.0% of that of the control, which is a representative example of a 57.0% reduction. The highly saline treatment had a longer mean germination time (3.10 days) compared to the control (1.55 days). The root length, shoot length, fresh biomass and dry biomass decreased with an increase in EC, especially shoot length and root length under high salinity. The highly saline treatment was significantly different from the control in the germination percentage, as suggested by the results of pairwise comparisons (adjusted $p < .001$; Hedges' g approximately 6.4; 95% CI [4.0, 8.8]). The measured EC was used to plot an illustrative exploratory regression, which yielded a negative slope of -4.65 percentage points in germination per dS/m ($R^2 = .91$). The figures in this paragraph are all inflammatory and should be reworked based on the actual facts.

Additional Germination and Seedling Growth Results

Table 5

Percentage Reduction in Germination and Seedling Growth Relative to the Control

Variable	Freshwater (%)	Moderate Salinity (%)	High Salinity (%)
Germination percentage	1.6	20.7	57.0
Root length	4.0	33.1	66.1
Shoot length	4.6	30.6	64.8
Fresh biomass	3.8	30.3	61.1
Dry biomass	4.8	26.2	54.8

Note. Values represent percentage reductions relative to the distilled-water control. Mean germination time is excluded because an increase in germination time represents a delay rather than a reduction in growth.

The data in Table 5 indicate the relative sensitivity of germination and early seedling growth of wheat to irrigation-water salinity. Reductions for fresh water were relatively small and reductions for moderate and high salinity were progressively increased. Root length had an illustrative decrease of 66.1% under high salinity followed by shoot length (64.8%) and fresh

biomass (61.1%). The following examples illustrate how percentage changes can be used in conjunction with the treatment comparisons presented in Table 4; they also quantify the level of response in relation to the control.

Table 6

Relationship Between Irrigation-Water Electrical Conductivity and Wheat Germination and Growth

Response variable	Regression coefficient (β)	R ²	p-value
Germination percentage	-4.65	.91	< .001
Root length	-0.68	.94	< .001
Shoot length	-0.56	.93	< .001
Fresh biomass	-9.20	.90	< .001
Dry biomass	-1.83	.88	< .001

Note. β represents the estimated change in each response variable per 1 dS/m increase in measured EC. The regression models and p-values must be recalculated using the actual dish-level observations.

Table 6 describes the inverse relationship of electrical conductivity with wheat germination and growth of seedlings. The regression coefficients for all five response variables were negative (diminishing) when salinity was increased, indicating that germination percentages decreased, along with the root and shoot lengths and the amount of biomass. Coefficients of determination ranged from .88 to .94 which represented strong illustrative association between the EC and the respective outcomes. The values, however, do not indicate whether or not there is a real statistical significance or cause and effect, and should be changed to values based on the completed experiment.

Discussion

The results showed that wheat (*Triticum aestivum* L.) seed germination and early seedling growth were affected by salinity of the irrigation water. Generally, the germination percentage decreased, while the root length, shoot length and seedling biomass decreased as salinity increased, and mean germination time increased with salinity. The results of these tests indicated that higher salinities had an adverse effect on both initiation of germination and seedling development. The moderate improvement for the distilled and freshwater treatments suggests that establishment of wheat was more favourable at the lower salinity levels.

This saline stress-induced decrease in germination might be attributed to the effects of osmotic stress and ion toxicity. High levels of dissolved salts reduce water potential of the environment around the seeds and affect the ability of the seeds to absorb water. Water uptake is vital to activate metabolic processes, mobilise stored food reserves and start growth of the embryo. These processes can be interrupted or slowed down when seeds are under the effect of osmotic stress, leading to slower and less uniform germination. This was confirmed by the observed increase in mean germination time with increasing salinity.

Increased salinity seemed to have a greater effect on root growth. Roots come in direct contact with the growth medium around them, and thus are subject to changes in the osmotic potential and ion concentrations. If there are too many sodium and chloride ions, they may disrupt nutrient absorption, cellular processes, and proper ionic balance. These impacts can limit plant growth, especially root development, and hinder seedling water and nutrient uptake. Limited root growth could then cause growth of the shoots to be restricted by reduced resources for above ground growth.

In addition, shoot length decreased with increased salinity, suggesting that salinity stress impacted seedling development outside of the root zone. Salt can slow cell growth, disrupt nutrient supply and interfere with physiological processes associated with plant growth. These effects can also impact photosynthetic activity and structural biomass under chronic or extreme stress. Physiological processes such as photosynthesis, accumulation of ions and enzyme activity were not directly measured in this experiment and are therefore considered as possible explanations for the results and not as proven causes.

The biomass reductions observed for both fresh and dry biomass further suggested that salinity may be limiting early seedling establishment. The fresh biomass includes both biomass growth and water content while dry biomass gives a better idea of plant material accumulated. A reduction in fresh biomass can partially be attributed to reduced water uptake and a reduction in dry biomass can be attributed to reduced growth and biomass accumulation. Combined, these responses illustrate how

germination percentage alone might not be a robust indication of salinity tolerance. Root length, shoot length and biomass are also measured and provide more information about the ability of seedlings to grow under salinity.

The differences between the freshwater and saline treatments also highlight the importance of irrigation water quality in wheat production. Wheat is moderately tolerant in comparison to other crops, but its tolerance is dependent on cultivar, developmental stage of wheat, duration of salinity exposure, and environmental conditions. Seedlings may be especially sensitive during early growth, due to their restricted root systems and their ability to absorb water and nutrients for growth. Thus, irrigation water of high salinity can impact vigour of seedlings and crop establishment under poor environmental conditions.

There are some limitations to this study that need to be taken into account when interpreting the results. The experiment was carried out to study the early germination and seedling growth under controlled environment with specified salinity treatments. These conditions are not a true reflection of field conditions and soil texture, drainage, temperature, irrigation frequency, and accumulation of salts may affect plant responses in the field. In addition, the application of sodium chloride solutions is only one type of salinity and does not account for all the chemical complexities of the irrigation water in agricultural situations. Further varieties of wheat would give a fuller picture of the effects of salinity; longer growing seasons would also allow a better picture to be obtained; and field observations would be useful.

The results indicated that, as a general rule, the salinity of irrigation water may have a detrimental effect on wheat germination, lag germination and early seedling growth. The responses highlight the need to assess the water quality of irrigation water when growing wheat in salinity affected areas. More studies are needed to examine cultivar-specific tolerance, physiological responses and early seedling performance and its relationship to crop productivity. This evidence may be useful for developing better irrigation management practices and enhance wheat establishment in saline condition.

Conclusion

This study was designed to investigate the effect of salinity of irrigation water on germination and early growth of wheat (*Triticum aestivum* L.). The results showed a decline in germination percentage, root elongation, shoot elongation and seedling biomass and an increase in mean germination time with an increase in salinity. The responses indicate that high salinity levels may affect water uptake and may limit early growth events for successful establishment of seedlings.

The results emphasize the significance of irrigation water quality for wheat production especially in regions where saline water is being utilized for crop culture. Water salinity can affect crop establishment under salt stress, and their effects could be minimized by monitoring water salinity and applying irrigation management practices. Future research needs to examine plant responses to various wheat cultivars, incorporate a wider salt stress range and examine plant performance in the field. Physiological and biochemical responses in addition to germination and growth parameters would also give a more complete picture of wheat salinity tolerance.

Finally, it may be concluded that irrigation water salinity is an important factor affecting the early growth of wheat. Knowing how to respond to its impact can help to enhance water management strategies and develop more saline wheat production systems. The final conclusions should be verified with experimental data from the study.

References

1. Akbarimoghaddam, H., Galavi, M., Ghanbari, A., & Panjehkeh, N. (2011). Salinity effects on seed germination and seedling growth of bread wheat cultivars. *Trakia Journal of Sciences*, 9(1), 43–50.
2. Bewley, J. D., Bradford, K. J., Hilhorst, H. W. M., & Nonogaki, H. (2013). *Seeds: Physiology of development, germination and dormancy* (3rd ed.). Springer. <https://doi.org/10.1007/978-1-4614-4693-4>
3. Datta, J. K., Nag, S., Banerjee, A., & Mondal, N. K. (2009). Impact of salt stress on five varieties of wheat (*Triticum aestivum* L.) cultivars under laboratory condition. *Journal of Applied Sciences and Environmental Management*, 13(3), 93–97.
4. Delacre, M., Leys, C., Mora, Y. L., & Lakens, D. (2019). Taking parametric assumptions seriously: Arguments for the use of Welch's F-test instead of the classical F-test in one-way ANOVA. *International Review of Social Psychology*, 32(1), Article 13. <https://doi.org/10.5334/irsp.198>
5. Dinno, A. (2015). Nonparametric pairwise multiple comparisons in independent groups using Dunn's test. *The Stata Journal*, 15(1), 292–300. <https://doi.org/10.1177/1536867X1501500117>

6. Ghasemi, A., & Zahediasl, S. (2012). Normality tests for statistical analysis: A guide for non-statisticians. *International Journal of Endocrinology and Metabolism*, 10(2), 486–489. <https://doi.org/10.5812/ijem.3505>
7. Gul, B., Ansari, R., Flowers, T. J., & Khan, M. A. (2013). Germination strategies of halophyte seeds under salinity. *Environmental and Experimental Botany*, 92, 4–18. <https://doi.org/10.1016/j.envexpbot.2012.11.006>
8. International Seed Testing Association. (2024). *International rules for seed testing*. ISTA.
9. Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, 4, Article 863. <https://doi.org/10.3389/fpsyg.2013.00863>
10. Machado, R. M. A., & Serralheiro, R. P. (2017). Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae*, 3(2), Article 30. <https://doi.org/10.3390/horticulturae3020030>
11. Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, 59, 651–681. <https://doi.org/10.1146/annurev.arplant.59.032607.092911>
12. R Core Team. (2024). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
13. Ranal, M. A., & Santana, D. G. de. (2006). How and why to measure the germination process? *Revista Brasileira de Botânica*, 29(1), 1–11. <https://doi.org/10.1590/S0100-84042006000100002>
14. Ranal, M. A., Santana, D. G. de, Ferreira, W. R., & Mendes-Rodrigues, C. (2009). Calculating germination measurements and organizing spreadsheets. *Revista Brasileira de Botânica*, 32(4), 849–855. <https://doi.org/10.1590/S0100-84042009000400022>
15. Rengasamy, P. (2006). World salinization with emphasis on Australia. *Journal of Experimental Botany*, 57(5), 1017–1023. <https://doi.org/10.1093/jxb/erj108>
16. Shahid, S. A., Zaman, M., & Heng, L. (2018). Soil salinity: Historical perspectives and a world overview of the problem. In M. Zaman, S. A. Shahid, & L. Heng (Eds.), *Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques* (pp. 43–53). Springer. https://doi.org/10.1007/978-3-319-96190-3_2
17. Shiferaw, B., Smale, M., Braun, H.-J., Duveiller, E., Reynolds, M., & Muricho, G. (2013). Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. *Food Security*, 5(3), 291–317. <https://doi.org/10.1007/s12571-013-0263-y>
18. Shrivastava, P., & Kumar, R. (2015). Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences*, 22(2), 123–131. <https://doi.org/10.1016/j.sjbs.2014.12.001>