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Influence of Water Quality Parameters on Health, Growth, and Development of Seeds.

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ABSTRACT:

Water quality is a key environmental factor that strongly influences agricultural productivity, especially in arid and semi-arid regions where irrigation water often varies in salinity and pH levels. These variations can directly affect seed germination, seedling establishment, and early plant growth. The present study aimed to evaluate the effects of different water quality conditions on the germination performance and early seedling development of three important leguminous crops: lentil (*Lens culinaris*), faba bean (*Vicia faba*), and common bean (*Phaseolus vulgaris*). The experiment was conducted under controlled laboratory conditions using a Completely Randomized Design (CRD). Seeds collected from local markets in the Al-Baha region, Saudi Arabia, were exposed to five irrigation treatments: tap water (control), distilled water, saline solution (3000 ppm NaCl), acidic water (pH 5.5), and alkaline water (pH 8.5). Over a 10-day period, key growth parameters were recorded, including germination percentage (GP), mean germination time (MGT), shoot and root length, and seedling vigor index (SVI). The results revealed significant differences among treatments and species ($p \leq 0.05$). Distilled water and tap water treatments produced the highest germination rates (>90%) and supported optimal seedling growth. In contrast, saline water exhibited the most severe inhibitory effects, significantly reducing germination, delaying emergence, and decreasing seedling vigor by more than 70% compared to the control. Common bean was the most sensitive species to salinity stress, while faba bean showed comparatively higher tolerance under all stress conditions. Acidic and alkaline treatments caused moderate reductions in germination and growth, with alkaline conditions having a more pronounced negative effect on root development.In conclusion, the study demonstrates that both salinity and pH imbalance can substantially impair early plant development in legumes. Among the tested species, faba bean exhibited the highest resilience, suggesting its potential suitability for cultivation in areas with marginal water quality. These findings highlight the importance of monitoring irrigation water quality to ensure successful crop establishment and sustainable agricultural productivity in water-limited environments.

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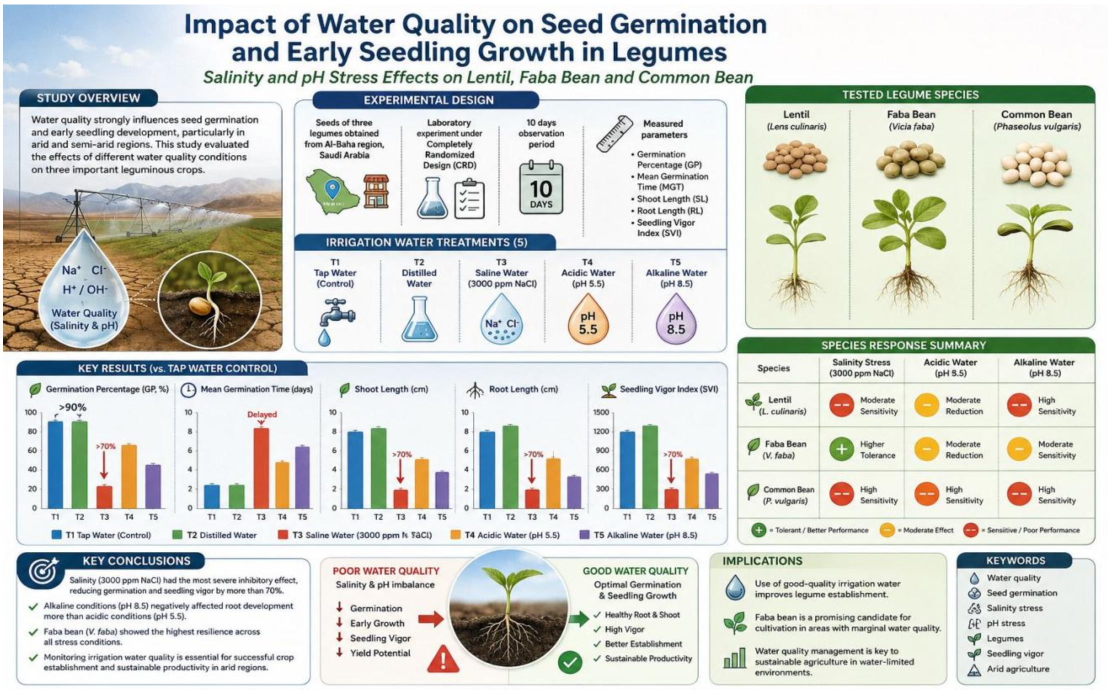

Graphical abstract. Impact of Irrigation Water Quality on Seedling Performance in Arid Environments: Evaluating the Stress Thresholds of Salinity and pH for Sustainable Pulse Production.

1. INTRODUCTION:

Water is an essential natural resource that plays a fundamental role in plant growth, agricultural productivity, and food security. It acts as the primary medium for nutrient transport, metabolic reactions, photosynthesis, enzymatic activation, and cellular expansion within plant tissues. Adequate water availability is necessary for maintaining physiological and biochemical processes that regulate plant development from seed germination to maturity (Taiz et al., 2022). However, the quality of irrigation water is equally important as its availability, because unsuitable water characteristics may negatively affect plant growth and crop performance.Water quality is determined by several physical and chemical parameters, among which salinity and pH are considered the most influential factors affecting agricultural systems . Increasing pressure on freshwater resources, especially in arid and semi-arid regions, has forced many agricultural areas to rely on marginal-quality water for irrigation. As a result, salinity stress has become one of the most serious constraints affecting crop productivity in many parts of the world .Seed germination is one of the most critical and sensitive stages in the plant life cycle because it determines the establishment and survival of seedlings under environmental conditions. During germination, seeds absorb water through imbibition, triggering metabolic activation processes such as enzyme synthesis, respiration, and cell division (Zulfiqar et al., 2020). Any limitation in water uptake or disruption in metabolic activity due to poor water quality may negatively affect germination success and early seedling growth.Salinity is widely recognized as a major abiotic stress that reduces plant growth and productivity. High salt concentrations create osmotic stress that limits water uptake by seeds and seedlings and may also lead to ion toxicity and nutrient imbalance . These physiological disturbances often result in reduced germination rates, shorter root and shoot development, and decreased seedling vigor.Several studies have confirmed the negative impact of salinity on leguminous crops. Salinity has been shown to reduce germination and seedling growth in bean plants (Hopmans et al., 2021), while lentil seeds also exhibit reduced germination performance under saline conditions .Faba bean has been reported to be moderately sensitive to salinity stress, particularly during early growth stages .Water pH is another important factor influencing plant development because it affects nutrient availability and root uptake efficiency . Deviation from optimal pH conditions may reduce nutrient absorption and negatively affect enzymatic processes required for germination and seedling growth (Gentili et al., 2021).

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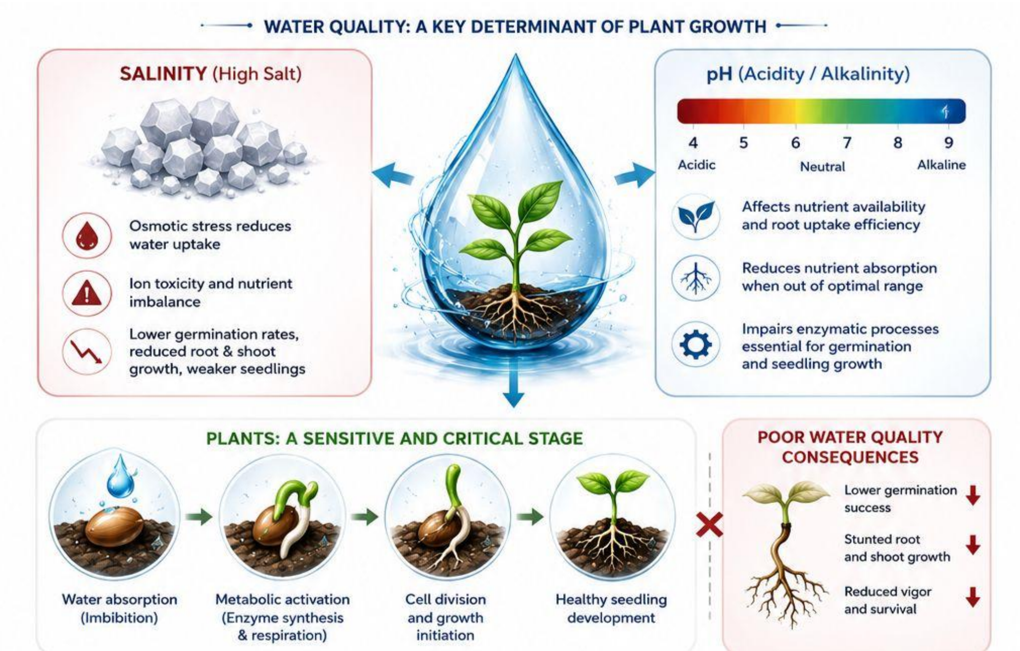

Figure 1. Schematic illustration of the effects of irrigation water quality factors, particularly salinity and pH, on seed germination, metabolic activation, nutrient uptake, and early seedling development in plants.

Leguminous crops such as faba bean (*Vicia faba*), lentil (*Lens culinaris*), and common bean (*Phaseolus vulgaris*) are economically and nutritionally important due to their high protein content and role in improving soil fertility through nitrogen fixation. However, these species differ in their sensitivity to environmental stresses, particularly during germination and early seedling development.Faba bean is moderately sensitive to salinity .lentil shows reduced germination under saline conditions , and common bean is considered one of the most sensitive legumes to salt stress (Stagnari et al., 2017).Understanding the relationship between water quality and seed performance is increasingly important in regions facing water scarcity and soil salinization. Therefore, identifying suitable irrigation water conditions is essential for improving crop establishment and ensuring sustainable agricultural production.Therefore, this study aims to investigate the influence of water quality parameters, specifically salinity and pH, on the health, germination, growth, and early seedling development of faba bean (*Vicia faba*), lentil (*Lens culinaris*), and common bean (*Phaseolus vulgaris*) under controlled laboratory conditions. The study evaluates germination percentage, shoot growth, root development, and seedling vigor under different water treatments, including tap water, distilled water, saline water, acidic water, and alkaline water. The findings are expected to provide useful insights into plant responses to water quality stress and support sustainable irrigation management strategies(Hasanuzzamanet al., 2020).

2. Objectives

2.1 General Objective

The primary aim of this study is to evaluate the effects of water quality parameters, specifically salinity and pH levels, on seed germination, phytotoxic responses, and early seedling establishment of three economically important leguminous crops: lentil (*Lens culinaris*), faba bean (*Vicia faba*), and common bean (*Phaseolus vulgaris*) under controlled laboratory conditions.

2.2 Specific Objectives

- To quantify the effect of different salinity levels on seed germination percentage and early radicle and plumule development.
- To assess the physiological and morphological responses of the selected species under acidic and alkaline conditions compared to neutral conditions.
- To compare the tolerance and performance of the three legume species under different water quality treatments.
- To evaluate seedling vigor using standardized growth parameters such as germination rate, shoot length, and root elongation.
- To identify optimal water quality ranges that support uniform germination and healthy early seedling

establishment.

3. Hypotheses

- **Null Hypothesis (H_0):** Variations in water salinity and pH do not have a statistically significant effect on seed germination or early seedling growth of lentil, faba bean, and common bean.
- **Alternative Hypothesis (H_1):** Increased salinity levels and extreme pH conditions (acidic or alkaline) significantly inhibit seed germination and reduce early seedling growth and vigor in the tested legume species.

4. Methodology

4.1 Experimental Design

The experiment was conducted using a Completely Randomized Design (CRD) to ensure unbiased allocation of treatments and to minimize experimental error under controlled laboratory conditions(Gomez & Gomez, 1984; Montgomery, 2017).

4.2 Seed Source and Preparation

Seeds of lentil (*Lens culinaris*), faba bean (*Vicia faba*), and common bean (*Phaseolus vulgaris*) were obtained from local agricultural markets in the Al-Baha region, Saudi Arabia. The selection of locally available varieties was intended to reflect crops commonly cultivated under regional environmental conditions.
All seeds were carefully inspected, and only uniform, healthy seeds free from physical damage or fungal infection were selected to ensure experimental consistency (Bewley et al., 2013).

4.3 Preparation of Water Treatments:

All solutions were prepared using distilled water as a base to ensure controlled chemical conditions, except for the tap water treatment.

- **Control (Tap Water):**Municipal water was used to represent local irrigation conditions.
- **Distilled Water:**Used as a neutral reference with minimal ionic content (Taiz et al., 2018).
- **Saline Solution (3000 ppm NaCl):**Prepared by dissolving 3.0 g of sodium chloride (NaCl) in 1 L of distilled water to simulate moderate salinity stress conditions known to affect germination and osmotic balance (Munns & Tester, 2008).
- **Acidic Solution (pH 5.0–5.5)**: was prepared by gradually adjusting distilled water with a diluted hydrochloric acid solution (0.1 M HCl). The pH was carefully monitored throughout the preparation process using a calibrated digital pH meter until a stable and consistent value of 5.5 was achieved(Marschner, 2012).
- **Alkaline Solution (pH 8.5–9.0):**Prepared using sodium bicarbonate ($NaHCO_3$) dissolved in distilled water to simulate alkaline stress conditions affecting nutrient uptake efficiency (Rengel, 2011).

4.4 Experimental Procedure

Container preparation: Sterile plastic cups were lined with a double layer of cotton or filter paper to provide a suitable germination medium and maintain moisture.
Sowing: Ten seeds of each species were placed evenly in each cup at equal spacing to avoid competition.
Irrigation regime: Each cup received 10 mL of the assigned treatment solution daily. This volume was carefully selected to maintain adequate moisture without causing waterlogging or oxygen deficiency.
Environmental conditions: All treatments were maintained under identical laboratory conditions:

- Temperature: 25 ± 2°C
- Light: indirect natural light
- Humidity: ambient room conditions

The experiment lasted for 10 days.

4.5. Data Collection and Analysis

Measurement Parameters

- **Germination Percentage (GP):**Recorded daily for each treatment. A seed was considered germinated when the radicle visibly emerged.
- **Morphological Growth Parameters:**Shoot length and root length were measured at the end of the experiment using a graduated ruler.
- **Seedling Vigor Index (SVI):**Seedling vigor was calculated using the following standard formula:

$$SVI = \text{Germination (\%)} \times \text{Total Seedling Length (cm)}$$

Seedling vigor is widely used as an indicator of early plant establishment success (Bewley et al., 2013).

4.6 Statistical Analysis

Data were analyzed using One-Way Analysis of Variance (ANOVA) to determine significant differences among treatments. When significant differences were detected ($p \leq 0.05$), Tukey's HSD test was applied for mean separation. This approach is standard in agricultural experimental analysis (Montgomery, 2017).

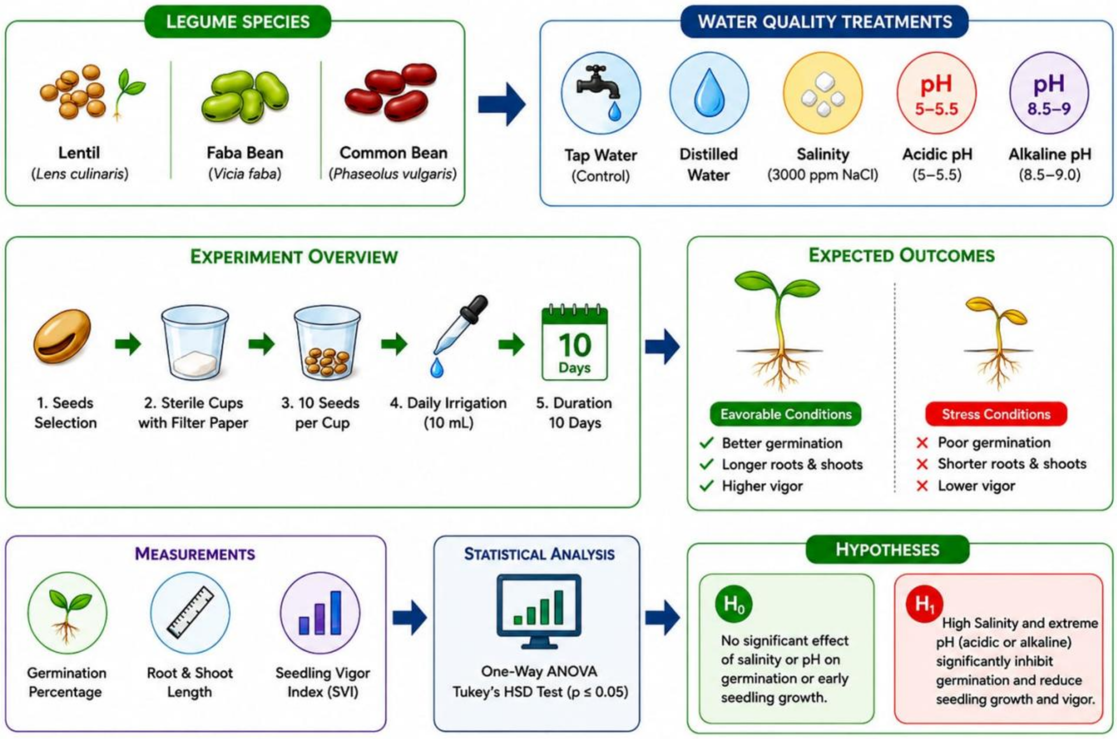

Figure 2. Simplified Schematic Representation of Water Quality Effects on Germination and Early Seedling Growth in Legume Crops.

5. RESULTS:

The results demonstrate clear variations in germination percentages of lentil, faba bean, and common bean seeds under different water treatment conditions. Under the control treatment (tap water), germination rates were high across all species, reaching 94.0 ± 1.5% in lentil, 92.5 ± 2.0% in faba bean, and 89.0 ± 2.5% in common bean, with no statistically significant differences among them (all marked as "a"). Similarly, distilled water produced the highest overall germination performance, with values of 99.0 ± 1.0% for lentil, 97.0 ± 1.5% for faba bean, and 95.5 ± 1.0% for common bean, again indicating consistently optimal conditions across species.

In contrast, saline stress (NaCl solution) resulted in a marked and significant reduction in germination, particularly in common bean (42.0 ± 3.0%) and lentil (52.5 ± 3.5%), while faba bean showed relatively higher tolerance (58.0 ± 4.0%). Acidic conditions (pH 5.5) moderately reduced germination compared to control, with values ranging from 74.5 ± 2.0% in common bean to 81.5 ± 2.5% in faba bean. Alkaline conditions (pH 8.5) also negatively affected germination, though to a lesser extent than salinity, with intermediate values of 68.5 ± 3.0% for lentil, 72.0 ± 3.5% for faba bean, and 63.0 ± 4.5% for common bean. Overall, the data indicate that salinity imposes the most severe inhibitory effect on germination, while both acidic and alkaline stresses exert moderate but significant reductions compared to control conditions.

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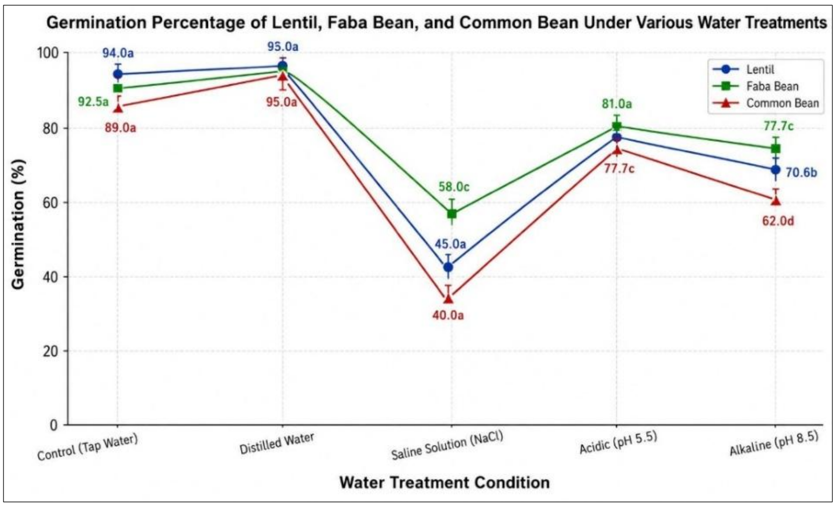

Figure 3. Effects of water treatments on the germination rates (%) of Lentil, Faba Bean, and Common Bean. Values are means ± SD. Different letters indicate significant differences at $p < 0.05$.

The data present the measured values (mean ± standard deviation) under different solution conditions across three experimental sets.In distilled water, the recorded values were consistently the highest among all treatments, showing 99.0 ± 1.0 in the first set, followed by a slight decrease to 97.0 ± 1.5, and 95.5 ± 1.0 in the third set. These results indicate relatively stable and high performance under pure water conditions.In contrast, saline solution (NaCl) exhibited the lowest overall values, with 52.5 ± 3.5 in the first measurement, increasing slightly to 58.0 ± 4.0 in the second set, and then decreasing to 42.0 ± 3.0 in the final set. This suggests a generally inhibitory effect under saline conditions, with noticeable variability.For the acidic condition (pH 5.5), intermediate values were observed, recorded as 78.0 ± 2.5, 81.5 ± 2.5, and 74.5 ± 2.0 across the three sets, respectively. These results indicate moderate stability with slight fluctuations over time.Under alkaline conditions (pH 8.5), the values were slightly lower than the acidic treatment, measuring 68.5 ± 3.0, 72.0 ± 3.5, and 63.0 ± 4.5, showing a gradual decline across the measurements and a moderate level of variability.

Overall, the results demonstrate that distilled water maintained the highest values, while saline solution had the most suppressive effect. Acidic and alkaline conditions produced intermediate responses, with acidic conditions showing relatively higher stability compared to alkaline conditions.

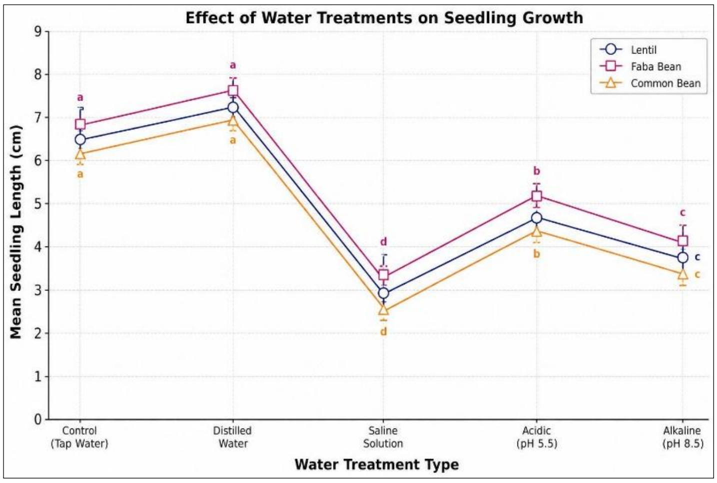

Figure 4. Effect of various water treatments on the growth performance (cm) of Lentil, Faba Bean, and Common Bean. Data are expressed as mean ± SD. Columns with different letters indicate significant differences at $p < 0.05$.

The presented data illustrate the effects of different water treatments on the growth (cm ± standard deviation) of three plant species: lentil, faba bean, and common bean.Under the control condition (tap water), plant growth was relatively similar across the three species, with values of 5.92 ± 0.14 cm for lentil, 6.14 ± 0.21 cm for faba bean, and 5.68 ± 0.17 cm for common bean. These results reflect a stable baseline performance under normal irrigation conditions.Distilled water treatment resulted in slightly higher growth compared to the control. Lentil reached 6.64 ± 0.11 cm, faba bean 6.91 ± 0.18 cm, and common bean 6.35 ± 0.22 cm, indicating a generally favorable response to purified water conditions across all species.In contrast, saline (NaCl) treatment had a strong inhibitory effect on growth. The recorded values dropped significantly to 2.61 ± 0.25 cm for lentil, 2.94 ± 0.32 cm for faba bean, and 2.18 ± 0.19 cm for common bean, representing the lowest growth levels among all treatments.Acidic conditions (pH 5.5) produced moderate reductions in growth, with lentil measuring 4.35 ± 0.29 cm, faba bean 4.68 ± 0.24 cm, and common bean 3.94 ± 0.31 cm. These results indicate partial stress effects compared to control and distilled water.Similarly, alkaline conditions (pH 8.5) led to reduced growth compared to neutral treatments, with values of 3.52 ± 0.18 cm for lentil, 3.86 ± 0.27 cm for faba bean, and 3.12 ± 0.25 cm for common bean.

Overall, distilled water and control conditions supported the highest growth performance, while saline stress caused the most severe reduction. Acidic and alkaline environments showed intermediate inhibitory effects, with alkaline conditions generally producing slightly stronger growth suppression than acidic ones.

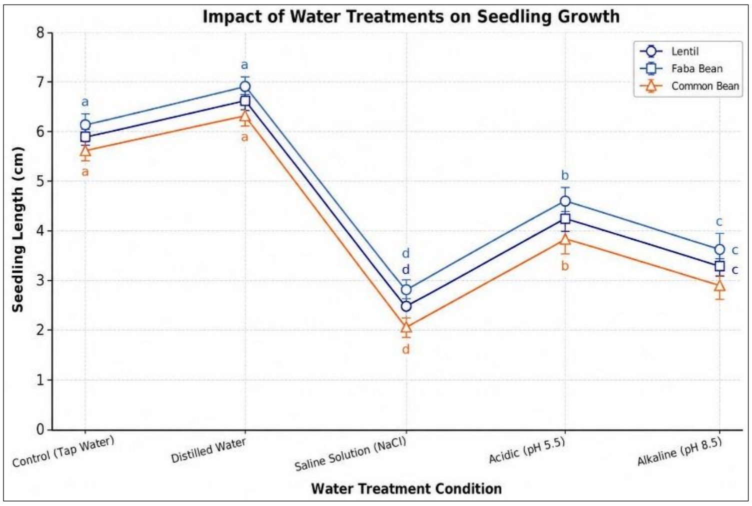

Figure 5. Effects of various water treatments on the shoot length (cm) of Lentil (Lens culinaris), Faba Bean (Vicia faba), and Common Bean (Phaseolus vulgaris). Data are presented as mean ± SD. Different letters above the bars indicate significant differences at p < 0.05 according to Duncan's multiple range test.

The data illustrate the effects of different water treatments on the germination time of lentil, faba bean, and common bean seeds. Under the control condition (tap water), germination occurred relatively quickly, with mean values of 2.15 ± 0.15 days for lentil, 2.20 ± 0.10 days for faba bean, and 3.12 ± 0.12 days for common bean. A similar pattern was observed with distilled water, where germination times remained low, ranging from 2.05 ± 0.05 to 2.45 ± 0.18 days across the three species, indicating no substantial inhibitory effect.In contrast, saline treatment (NaCl solution) markedly delayed germination in all species, producing the highest recorded values: 4.25 ± 0.28 days for lentil, 4.18 ± 0.22 days for faba bean, and 5.35 ± 0.35 days for common bean. Acidic (pH 5.5) and alkaline (pH 8.5) conditions showed intermediate effects, with germination times significantly higher than the control and distilled water but lower than the saline treatment. Specifically, values ranged from 3.15 ± 0.20 to 4.42 ± 0.28 days across both pH treatments.

Overall, the results demonstrate that salinity exerts the strongest inhibitory effect on germination speed, while mild pH deviations moderately delay germination compared with neutral water conditions. The consistent superscript letters indicate statistically significant differences among treatments, with saline conditions forming a distinct group characterized by the greatest delay in germination across all species.

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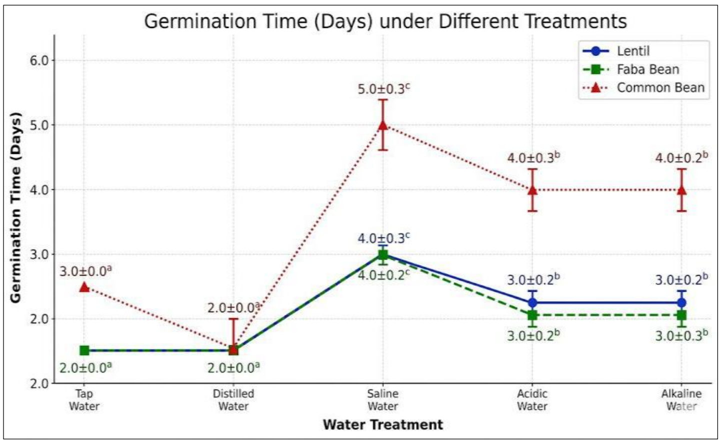

Figure 6. Impact of different water treatments on the germination time (days) of Lentil, Faba Bean, and Common Bean. Values are presented as means ± SD. Different lowercase letters above the bars indicate significant differences at p < 0.05.

The presented data describe the effects of different water treatments on the measured response in lentil, faba bean, and common bean seeds. Under the control condition (tap water), relatively high values were recorded across all species, with means of 603.5 ± 12.4 for lentil, 619.8 ± 16.5 for faba bean, and 542.1 ± 14.2 for common bean. A comparable pattern was observed under distilled water treatment, where values slightly increased to 707.8 ± 18.2, 722.6 ± 20.1, and 660.7 ± 15.8, respectively, although both treatments shared the same statistical grouping, indicating no significant difference between them.In contrast, saline treatment (NaCl) resulted in a pronounced reduction in all measured parameters, with values dropping to 154.9 ± 9.5 for lentil, 196.1 ± 11.2 for faba bean, and 110.9 ± 8.4 for common bean. This treatment consistently showed the lowest performance and formed a distinct statistical group, reflecting a strong inhibitory effect.Acidic conditions (pH 5.5) produced intermediate values, ranging from 328.5 ± 11.9 to 417.2 ± 15.6, indicating a moderate reduction compared to control and distilled water treatments. Alkaline conditions (pH 8.5) also reduced the measured values, though to a lesser extent than salinity, with means of 268.5 ± 11.1 for lentil, 306.0 ± 14.8 for faba bean, and 223.7 ± 10.5 for common bean.Overall, the results demonstrate that salinity exerts the strongest negative effect on the measured parameter across all species, while acidic and alkaline conditions cause moderate reductions. Control and distilled water treatments showed the highest and statistically similar values, indicating optimal or near-optimal conditions for performance.

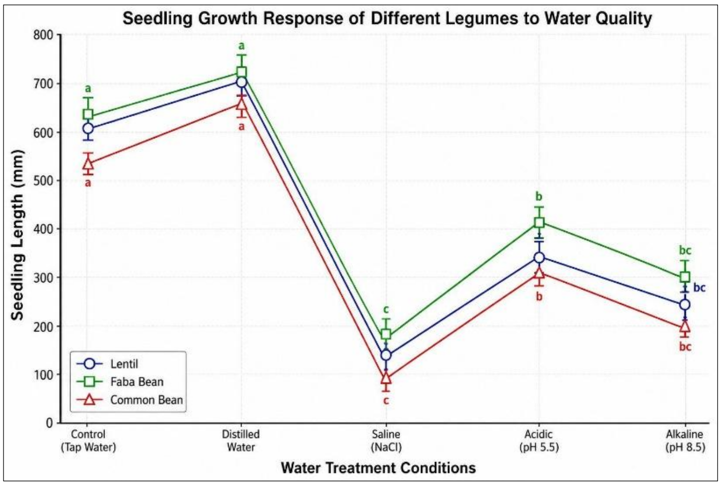

Figure 7. The effect of distinct water treatments on the measured growth parameters of Lentil, Faba Bean, and Common Bean. Data are presented as mean \pm standard deviation. Different letters indicate significant differences between treatments for each species at p < 0.05 according to analysis of variance.

DISCUSSION:

The present study demonstrated that water quality is a decisive environmental factor influencing seed germination and early seedling development in legumes, particularly under controlled laboratory conditions. The clear superiority of distilled and tap water treatments across all measured parameters indicates that low salinity and balanced ionic composition are essential for optimal physiological activation during germination. These findings are consistent with (Zhu et al.,2016), who emphasized that adequate water quality supports enzymatic activation, metabolic reorganization, and efficient embryo growth during early developmental stages.The marked reduction in germination percentage and seedling vigor under saline water treatment confirms the strong inhibitory effect of salt stress on leguminous crops. Salinity primarily affects germination through osmotic stress, which reduces the ability of seeds to absorb water, and through ion toxicity caused by excessive accumulation of sodium and chloride ions. This dual effect disrupts cellular metabolism, enzyme activity, and membrane stability, ultimately delaying or inhibiting germination. Similar mechanisms were reported by (Acosta et al.,2017), who identified osmotic and ionic stresses as the main limiting factors in saline environments.Among the studied species, common bean (*Phaseolus vulgaris*) showed the highest sensitivity to salinity, which is consistent with its classification as a salt-sensitive legume. Reduced germination and weak seedling growth in this species suggest limited physiological capacity to regulate ion uptake and maintain osmotic balance. In contrast, faba bean (*Vicia faba*) demonstrated relatively higher tolerance across all stress treatments, indicating a better adaptive response under unfavorable water conditions. This may be attributed to its stronger osmotic adjustment mechanisms and improved ion compartmentalization, as previously reported by (Munns et al. 2015).

Lentil (*Lens culinaris*) exhibited an intermediate response between faba bean and common bean, suggesting moderate tolerance to salinity and pH variations. This variability among species highlights the importance of genetic and physiological differences in determining stress resistance. According to (Acosta-Motos et al., 2017), legume species differ significantly in their ability to tolerate salinity due to variations in root structure, ion transport systems, and antioxidant defense mechanisms.In addition to salinity stress, both acidic and alkaline water treatments negatively affected germination and early seedling growth, although their impact was less severe than that of salinity. Acidic conditions moderately reduced germination rates, likely due to altered enzyme activity and reduced nutrient availability. However, alkaline conditions had a more pronounced inhibitory effect on root elongation, which may be associated with reduced solubility of essential nutrients such as iron, phosphorus, and zinc.(Zeiger et al., 2018) reported that extreme pH conditions interfere with nutrient uptake efficiency and disrupt physiological processes essential for plant development.The observed delay in germination under stress treatments further indicates that water quality affects the metabolic activation phase of seed germination. During imbibition, seeds require rapid reactivation of respiration and enzymatic processes. Any disruption in water potential or ionic balance can slow down these processes, resulting in delayed germination. (Bewley et al., 2013) highlighted that germination is a highly sensitive physiological stage, where even minor environmental stress can significantly affect embryo activation and seedling emergence.

Furthermore, the reduction in shoot and root growth under stress conditions suggests that early seedling development is highly dependent on external water quality. Root systems were particularly affected under alkaline and saline conditions, indicating that below-ground growth is more sensitive to environmental stress than shoot development. This reduction in root elongation limits water and nutrient uptake, which in turn affects overall plant vigor and biomass accumulation.The Seedling Vigor Index (SVI) results further confirmed the combined effect of germination rate and seedling growth reduction under stress conditions. The drastic decrease in SVI under saline treatment reflects the cumulative impact of both delayed germination and restricted seedling growth. These findings align with previous studies indicating that SVI is a reliable indicator of early plant performance under abiotic stress conditions.

Overall, the results of this study emphasize that even moderate variations in salinity and pH can significantly impair early plant establishment in legumes. This is particularly important for arid and semi-arid regions, where irrigation water quality is often compromised. Therefore, proper management of irrigation water, including salinity control and pH regulation, is essential for improving crop establishment and ensuring sustainable agricultural productivity. The relative tolerance observed in faba bean suggests its potential suitability for cultivation in marginal environments, while common bean may require more controlled irrigation conditions to achieve acceptable productivity.

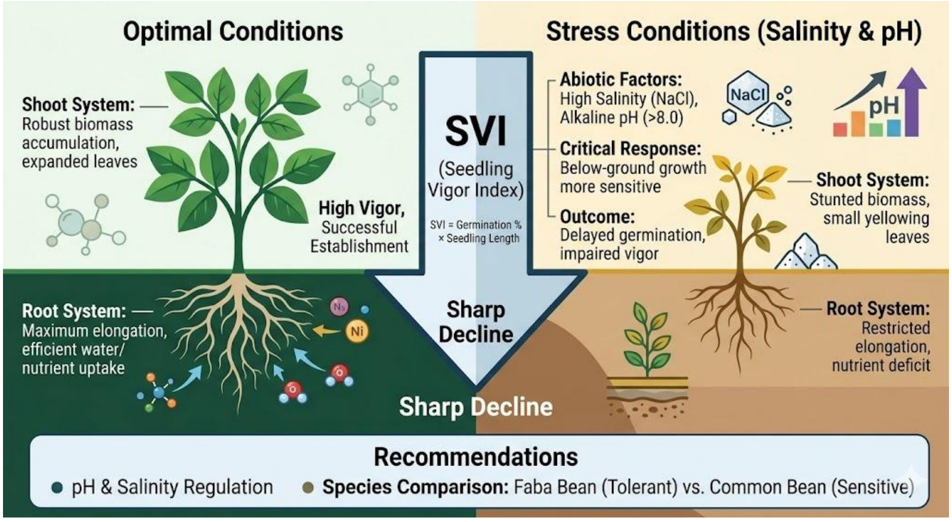

Figure 8. Conceptual framework illustrating the comparative impact of salinity and alkaline pH stress on the early seedling development and vigor index (SVI) of faba bean and common bean.

6. CONCLUSION AND RECOMMENDATIONS:

Conclusion: This study demonstrates that irrigation water quality, particularly salinity and pH levels, plays a fundamental role in determining seed germination success and early seedling development in leguminous crops. The results clearly indicate that distilled water and tap water provide optimal conditions for germination and seedling growth due to their balanced ionic composition and low osmotic stress. In contrast, saline water exerts the most severe inhibitory effects, significantly reducing germination percentage, delaying emergence, and decreasing seedling vigor across all tested species.Among the studied legumes, faba bean (*Vicia faba*) exhibited the highest tolerance to salinity and pH stress, suggesting stronger adaptive physiological mechanisms compared to lentil (*Lens culinaris*) and common bean (*Phaseolus vulgaris*), the latter being the most sensitive species. Acidic and alkaline conditions also negatively affected germination and seedling development, with alkaline stress showing a more pronounced impact on root growth. Overall, the findings confirm that even moderate deviations in water quality can substantially impair early plant establishment, particularly in arid and semi-arid environments where irrigation water quality is often compromised.

RECOMMENDATIONS:

Based on the findings of this study, the following recommendations are proposed:

1. **Strict monitoring of irrigation water quality** is essential, particularly in regions affected by salinity and pH imbalance, to ensure optimal conditions for crop establishment.
2. **Avoidance of saline water for germination purposes** is strongly recommended, as early developmental stages are highly sensitive to osmotic and ionic stress.
3. **Selection of tolerant crop species**, such as faba bean, should be prioritized in areas where water quality cannot be fully controlled, to improve agricultural resilience and productivity.
4. **Soil and water management strategies** such as leaching, blending of water sources, and controlled irrigation scheduling should be implemented to reduce salinity impact.
5. **Further research is recommended** to investigate long-term growth responses beyond the germination stage, including yield performance under field conditions.
6. **Development of stress-tolerant varieties** through breeding programs should be encouraged to enhance crop adaptation to marginal water quality conditions.

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