COTTON'S RESPONSE TO SALINITY STRESS: EXPLORING SODIUM AND POTASSIUM SALT EFFECTS ON GERMINATION AND VIGOR

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Abstract. This study was conducted in 2022 under laboratory conditions (25°C) with the registered cotton variety MAY-455, with the collaboration of Gaziantep University, Nurdagi Vocational School, and Kahramanmaras Sutcu Imam University, Goksun Vocational School. The study involved two different types of salts (NaCl and KCl) and seven different salt concentrations (control, 20, 40, 60, 80, 100 and 120 mM). The evaluated parameters included radicle length, germination rate, germination index, mean germination time, germination speed coefficient, and seed vigor index. The statistical analysis revealed significant differences in these parameters with respect to salt concentrations (0, 20, 40, 60, 80, 100, and 120 mM). However, differences between the types of salts (NaCl and KCl) were statistically significant for germination index and hypocotyl length. Results from this laboratory study indicate that increasing salt concentrations (0, 20, 40, 60, 80, 100, and 120 mM) led to a decrease in radicle length, hypocotyl length, germination rate, germination index, germination speed coefficient, and seed vigor index, while mean germination time increased. Although cotton is relatively salt-tolerant, high salt concentrations negatively affected the germination of cotton seeds. Taking both NaCl and KCl salts into consideration, the dose-effect analysis with natural logarithmic transformation revealed that using higher salt concentrations would further increase the rate of seeds failing to germinate.
Keywords: *Gossypium hirsutum, osmotic stress, halotolerance, seedling growth, germination index*

Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most important fiber-producing plants worldwide and belongs to the Malvaceae family. Four species of the *Gossypium* genus are commercially cultivated (Ahmed et al., 2018). As a vital source of natural fiber, cotton holds significant importance for the textile, oil, and feed industries (Rezaee et al., 2015). Many factors affect the germination of cotton seeds and the growth of the cotton plant. Key environmental factors influencing cotton seed germination and plant growth include soil salinity, temperature, and drought conditions (Chakma et al., 2021).

In seeds that do not germinate under suitable conditions, growth problems arise, leading to yield losses. Seed germination and plant development are crucial for optimal fiber yield. The seed germination process is divided into three phases: rapid water uptake, preparation for cell elongation, and radicle protrusion. These stages are influenced by different environmental stress conditions (Ahmadvand et al., 2012). Interruptions during the germination phases significantly impact plant growth and yield.

Cotton seed germination is highly affected by different environmental conditions (Barpete et al., 2015). For example, soil salinity affects cotton production negatively. (Chachar et al., 2008; Nazir et al., 2014). Salts present in the root environment cause damage to crops. These damages include osmotic stress, ion-specific toxicity, ion imbalance stress, nutrient deficiency, and secondary stress caused by sodium (Chachar et al., 2008).

While cotton is considered a salt-tolerant plant, different cotton species exhibit varying levels of salt tolerance (Ergin et al., 2021). Generally, cotton is considered moderately salt-tolerant, but the germination phase is particularly sensitive to soil salinity. Thus, the yield of cotton growing in saline soils decreases due to poor germination and plant development (Rezaee et al., 2015). Furthermore, soil salinity leads to significant reductions in yield and fiber quality in cotton plants (Manikandan et al., 2019).

Soil salinity has become a serious issue threatening agricultural production in many countries (Sattar et al., 2010). Various studies have shown that NaCl salinity significantly reduces cotton seed germination (Rezaee et al., 2015). The Na and Cl ions in the soil prevent water from entering the seed through osmosis (Ergin et al., 2021). Therefore, the effects of NaCl salinity and other salinity levels present in the soil on cotton seed germination are important.

This study investigates the effects of different concentrations of KCl and NaCl (0, 20, 40, 60, 80, 100, and 120 mM) on cotton seed germination.

Material and methods

Experimental design

This research utilized the MAY-455 cotton variety due to its commercial significance, widespread cultivation in major cotton-producing regions of Turkey, and the practical importance of understanding its response to salinity stress for local agricultural practices. The experiment was conducted in a completely randomized design (CRD) with three replications, with 20 seeds per petri dish under climate-controlled conditions (25°C). Two types of salt (NaCl and KCl) and seven different salt concentrations (0, 20, 40, 60, 80, 100, and 120 mM) were used. The selected salt concentrations (0, 20, 40, 60, 80, 100, and 120 mM) were chosen to represent a range of salinity levels from non-saline to highly saline conditions, which are relevant to cotton-growing regions worldwide. According to the classification by Ayers and Westcot (1985), these concentrations correspond to soil electrical conductivity (EC) values ranging from approximately 2 dS/m (slightly saline) to 12 dS/m (highly saline), allowing for a comprehensive assessment of the variety's response threshold.

Seed sterilization and germination

The equipment and seeds used in the study were thoroughly sterilized prior to germination. The sterilization process involved soaking the seeds in a 5% sodium hypochlorite (NaOCl) solution for 10 min, followed by rinsing the seeds with sterile water (Cokkizgin, 2012; Sutradhar et al., 2021; Bošnjak Mihovilović et al., 2024; Cokkizgin et al., 2025a, b). A 10 ml salt solution was added, and the seeds were germinated for 12 days at an optimal temperature of 25°C for cotton (ISTA, 2011; Ergin et al., 2021). Abnormal germinations or non-germinated seeds were identified according to the rules of the International Seed Testing Association (2011).

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Parameters studied

The following parameters were examined in the study:

Coefficient of Velocity of Germination (CVG): Calculated based on the formula by Maguire (1962) (*Eq. 1*).

$$CVG = \frac{(G_1 + ... + G_n)}{(1xG_1 + ... + nxG_n)} \quad \text{(Eq.1)}$$

In this formula, G denotes the number of seeds that have germinated, while n signifies the last day of the germination process.

Germination Index (GI): Calculated using the formula adopted from AOSA (1990) (*Eq. 2*):

$$GI = \sum \left(\frac{GT}{Tt}\right) \quad \text{(Eq.2)}$$

In the formula, G represents the number of germinated seeds, while T represents time.

Germination percentage (GP): Germinated seeds were counted daily according to the rules of the Association of Official Seed Analysts (AOSA, 1990). The percentage of germinated seeds in each petri dish was calculated, and the germination percentage (GP) was obtained at the end of day 12 (Tanveer et al., 2010).

Radicle length (RL): The radicle lengths of germinated cotton seeds were measured.

Hypocotyl length (HL): The hypocotyl lengths of germinated cotton seeds were measured.

Seed vigor index (SVI): Determined according to Baki and Anderson (1973) (*Eq. 3*):

$$SVI = GP * (RL + HL) \quad \text{(Eq.3)}$$

Mean germination time (MGT): Calculated based on the formula by Ellis and Roberts (1981) (*Eq. 4*):

$$MGT = \frac{\sum(Dn)}{\sum n} \quad \text{(Eq.4)}$$

In the formula, where n is the number of seeds germinated on each day and D is the day of counting.

Statistical analysis

The data obtained from the germination study were analyzed using the SAS software (SAS, 2004). Variance analysis was performed, and differences between means were determined at the P = 0.01 level using the Least Significant Difference (LSD) test (Duzgunes et al., 1987). The dose-effect analysis was conducted using the XLSTAT software (XLSTAT, 2022). Prior to this analysis, the normality of the data was checked using the Shapiro-Wilk test, and log transformation was applied to the data to achieve better normalization and analysis accuracy.

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Results and discussion

Coefficient of velocity of germination (CVG)

Based on the results obtained, the difference between salt treatments (NaCl, KCl) for the Coefficient of Velocity of Germination (CVG) was statistically insignificant (*Table 1,* $P > 0.05$). However, the differences between salt doses were significant (*Table 1,* $P < 0.0001$). The highest CVG was observed in the control (0.1059), which was statistically similar only to the 40 mM treatment. A significant decrease in germination speed began at the 20 mM dose. The lowest CVG values were recorded for the 80, 100, and 120 mM treatments, which were statistically grouped together (*Table 2*). This reduction in CVG with higher salt concentrations is consistent with the findings of previous research. For instance, Dong et al. (2023) found that high salt concentrations negatively affect the germination rate and speed of cotton seeds. Similarly, Katembe et al. (1998) and Muhammad et al. (2023) reported that increased salt concentrations reduce both the germination rate and seedling survival rates. Moreover, Ahmad Saad et al. (2014) found that salt concentrations significantly impact root growth and weight.

Table 1. *ANOVA analysis summary for measurement parameters*

Sour. of var.	df	MS						
		CVG	GI	GP	RL	HL	SVI	MGT
Salt app.	1	0.00000092	278.4863**	1.5621	2.6752	5.5010**	6327.15	0.0077
Salt doses	6	0.00000768**	10.6379**	377.9994**	13.2678**	0.6066	410089.81**	0.0644**
Salt app. X salt dose int.	6	0.00000175	1.3508	18.9994	0.7464	0.0793	7117.57	0.0142
Error	28	0.00000098	1.7631	28.2667	1.2521	0.3060	11823.67	0.0083
CV (%)		0.9536	18.1636	5.9577	13.3213	9.8022	8.6031	0.9496

The general trend of a decreasing CVG with increasing salt concentrations can be attributed to the deleterious effects of salinity on plant physiology (Okon, 2019). High salinity levels can cause osmotic stress and ion toxicity, which adversely affect seed germination and seedling vigor (Shahid et al., 2020; Alharbi et al., 2022). The negative impacts on the germination mechanism were also evident in this study, as higher salt concentrations resulted in lower germination velocity coefficients. This implies that salinity interferes with the water uptake and metabolic activities required for successful germination (Sosa et al., 2005; Ludwiczak et al., 2021).

The detrimental impacts of salinity on seed germination observed in this study align with those reported by Cokkizgin (2012), Cokkizgin et al. (2025b) who identified significant inhibitory effects of saline conditions on seed germination in common bean (*Phaseolus vulgaris* L.). Similarly, Shahid et al. (2020) emphasized the physiological and biochemical stress that salinity imposes on plant growth and development, further corroborating the findings of this study. The need for selecting and cultivating salt-tolerant cotton genotypes is underscored by the differential responses observed among various genotypes. Ashraf and Harris (2004) pointed out the importance of genetic diversity in enhancing crop resilience under saline conditions. Therefore, it is imperative to prioritize such varieties to ensure successful agricultural practices in saline-prone regions (Rengasamy, 2006; Flowers and Colmer, 2008).

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Germination index (GI)

The results of our study provide a comprehensive analysis of the effects of different salt applications and doses on the germination index of cotton. The analysis revealed a significant difference between the two salt types for the germination index (*Table 1,* $P < 0.01$). KCl application resulted in a substantially higher germination index (9.89) compared to NaCl application (4.74) (*Table 2*). This substantial difference underscores the distinct physiological roles that potassium (K) and sodium (Na) play in plant germination. Potassium, being essential for various cellular processes, enhances germination, while sodium, often associated with osmotic stress, adversely impacts germination rates (Zhu, 2001; Assaha et al., 2017).

Table 2. *Effect of KCl and NaCl applications on germination and seedling vigor metrics of cotton seeds*

Salt application							
	CVG	**GI**	**GP**	**RL**	**HL**	**SVI**	**MGT**
KCl	0.1040 ± 0.002	9.89 ± 2.59a	89.05 ± 8.41	8.65 ± 2.04	5.28 ± 0.59b	1251.71 ± 298.11	9.60 ± 0.20
NaCl	0.1037 ± 0.001	4.74 ± 0.93b	89.43 ± 9.03	8.15 ± 1.75	6.00 ± 0.61a	1276.19 ± 251.95	9.63 ± 0.11
LSD value	0.0006	0.8394	3.3609	0.7074	0.3497	68.738	0.0577
Salt doses							
	CVG	**GI**	**GP**	**RL**	**HL**	**SVI**	**MGT**
0 mM	0.1059 ± 0.001a	9.12 ± 3.51a	98.33 ± 1.57a	9.92 ± 1.07a	6.05 ± 0.50a	1570.17 ± 77.01a	9.45 ± 0.13c
20 mM	0.1047 ± 0.002b	8.50 ± 3.31ab	96.10 ± 2.12ab	9.83 ± 0.81ab	5.65 ± 0.51abc	1487.97 ± 98.13ab	9.56 ± 0.15b
40 mM	0.1048 ± 0.001ab	7.84 ± 2.78abc	92.22 ± 7.64abc	9.35 ± 0.55abc	5.67 ± 0.67abc	1388.00 ± 186.01bc	9.55 ± 0.07bc
60 mM	0.1040 ± 0.000bc	7.52 ± 2.71bcd	90.55 ± 6.24bc	8.23 ± 1.46cd	5.95 ± 0.50ab	1285.50 ± 160.90c	9.62 ± 0.05ab
80 mM	0.1033 ± 0.001c	6.76 ± 2.69cde	89.17 ± 5.05dc	8.55 ± 0.95bc	5.68 ± 0.75abc	1268.08 ± 133.00c	9.69 ± 0.06a
100 mM	0.1029 ± 0.001c	6.10 ± 3.11cde	83.33 ± 6.24d	6.92 ± 1.50de	5.38 ± 0.51bc	1021.48 ± 54.16d	9.73 ± 0.15a
120 mM	0.1029 ± 0.001c	5.34 ± 3.21e	75.00 ± 5.77e	6.00 ± 2.10e	5.12 ± 0.75c	826.33 ± 54.40e	9.72 ± 0.06a
LSD	0.0012	1.5703	6.2877	1.3234	0.6542	128.60	0.108
Mean	0.1040	7.3102	89.2410	8.4000	5.6429	1263.9260	9.6131

Furthermore, the effects of increasing salt doses on the germination index are elucidated. A clear negative correlation is observed between salt concentration and germination index. The control group (0 mM) showed the highest germination index (9.1150), which was statistically similar to the 20 mM and 40 mM treatments. A gradual decline was observed as the salt concentration increased, with the lowest value recorded at the highest concentration (120 mM, 5.3417). These findings highlight the detrimental effects of salt stress on seed germination (Cokkizgin, 2012, 2025b; Ertekin et al., 2017, 2018).

High salt concentrations impose osmotic stress, limiting water uptake necessary for germination. Additionally, ionic stress caused by high levels of sodium ions can interfere with metabolic processes, further inhibiting germination (Ashraf et al., 1987; Almansouri et al., 2001). The statistical grouping of the data, showing distinct categories (A-E), indicates significant differences among the treatment groups, reinforcing the robustness of the observed effects.

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Our findings are consistent with existing literature, which also reports the negative impacts of high salinity on plant germination and development (Cokkizgin, 2012, 2025b; Cokkizgin and Colkesen, 2012; Ertekin et al., 2017; Ertekin et al., 2018; Rajabi Dehnavi et al., 2020).

Germination percentage (GP)

Regarding germination percentage (GP), there was no significant difference between the two salt types (*Table 1,* $P > 0.05$). Both KCl (89.05%) and NaCl (89.43%) treatments resulted in similar germination rates (*Table 2*). However, the negative correlation between increasing salt doses and germination rates is evident. Both KCl and NaCl treatments resulted in approximately equal germination rates, indicating that the ionic composition of the salts did not markedly influence seed germination within the observed range.

However, the negative correlation between increasing salt doses and germination rates is evident. As the concentration of salt increased, the germination rate progressively decreased (Cokkizgin, 2012, 2025b; Cokkizgin and Colkesen, 2012; Basahi, 2023; Algopishi, 2025). This trend is indicative of the osmotic and ionic stress imposed by higher salt concentrations, which adversely affects seed germination. High salt concentrations can lead to reduced water uptake and ion toxicity, disrupting metabolic processes essential for germination.

The control (98.333%), 20 mM (96.100%), and 40 mM (92.217%) treatments were statistically similar and showed the highest germination percentages. The germination rate progressively decreased with increasing salt concentration, with the lowest rate observed at 120 mM (75.000%) (*Table 2*). Our findings are consistent with recent research, which also reports the negative impacts of high salinity on plant germination and development (Atta et al., 2023; Tarchoun et al., 2022; Kumar et al., 2021).

Radicle length (RL)

For radicle length (RL), the difference between the two salt types was not statistically significant (*Table 1,* $P > 0.05$). The average RL was 8.65 cm for plants treated with KCl and 8.15 cm for plants treated with NaCl (*Table 2*). Although the difference between the two salt types was not statistically significant, KCl resulted in slightly longer radicle growth compared to NaCl. This may suggest that KCl is less toxic or that NaCl induces higher ionic stress on the plant development. These findings are consistent with previous research indicating that NaCl generally has a more detrimental effect on plant growth compared to other salts (Greenway and Munns, 1980).

The effects of salt doses on RL showed a noticeable decrease in RL with increasing salt concentrations. The control group (0 mM) had a RL of 9.917 cm, while 20 mM and 40 mM salt doses resulted in RLs of 9.833 cm and 9.350 cm, respectively. At higher salt doses (60 mM, 80 mM, 100 mM, and 120 mM), significant reductions in RL were observed, with the lowest RL (6.000 cm) recorded at 120 mM salt dose groups (*Table 2*). These results align with studies demonstrating that high salt concentrations significantly inhibit radicle growth in various plant species (Parida and Das, 2005; Munns and Tester, 2008; Cokkizgin, 2012; Cokkizgin and Colkesen, 2012).

These results indicate that high salt concentrations significantly inhibit radicle growth in cotton plants. It was observed that low and moderate salt concentrations have relatively less detrimental effects on the development of the cotton plant’s radicle, whereas high

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concentrations severely hinder growth. Further research is recommended to explore the physiological mechanisms underlying the observed responses to different salt types and doses (Ashraf and Harris, 2004).

Hypocotyl length (HL)

The type of salt had a statistically significant effect on hypocotyl length (*Table 1,* $P < 0.01$). Specifically, plants treated with NaCl had longer hypocotyls (6.00 cm) compared to those treated with KCl (5.28 cm) (*Table 2*). Such a finding suggests that NaCl may exert a less inhibitory effect on hypocotyl elongation than KCl. These observations align with prior studies that emphasize the differential impacts of various salts on plant growth (Greenway and Munns, 1980).

The analysis of salt dose effects on hypocotyl length did not present a clear dose-response relationship. The control group (0 mM) exhibited a hypocotyl length of 6.0500 cm, while the other doses (20 mM, 40 mM, 60 mM, 80 mM, 100 mM, and 120 mM) resulted in lengths varying from 5.1167 cm to 5.9500 cm. Despite the absence of significant differences among the doses, minor variations suggest that increasing salt concentrations may not have a straightforward impact on hypocotyl length. This phenomenon can be attributed to the complex interactions between salt ions and plant physiological processes. It has been well-documented that increasing salt concentrations lead to a progressive decrease in hypocotyl length, to the extent that at higher salt doses, elongation may entirely cease (Ghanad et al., 2016). Understanding the physiological responses of plants to varying salt types and concentrations will enhance our ability to cultivate cotton in saline environments, thereby improving crop productivity and sustainability (Munns and Tester, 2008; Parida and Das, 2005; Ashraf and Harris, 2004).

Seed vigor index (SVI)

For the Seed Vigor Index (SVI), no statistically significant difference was observed between KCl and NaCl applications (*Table 1,* $P > 0.05$). The results show that as the salt dose increases, the SVI value decreases. The results show that as the salt dose increases, the SVI value decreases. The highest SVI value was observed at 0 mM salt dose, with an average of 1570.12, while the lowest SVI value was recorded at the highest salt dose of 120 mM, with an average of 826.33. Intermediate salt doses (20 mM, 40 mM, 60 mM, 80 mM, and 100 mM) showed a gradual decline in SVI values, confirming the dose-dependent negative effect of salt on seed vigor (*Table 2*).

The observed decrease in SVI with increasing salt doses suggests that higher concentrations of NaCl and KCl significantly impair the seed vigor of cotton. This aligns with previous studies indicating that salt stress adversely affects seed germination and seedling growth by causing osmotic stress and ion toxicity (Parida and Das, 2005). The reduction in SVI values at higher salt concentrations can be attributed to the disruption of cellular functions and metabolic processes due to osmotic imbalance and nutrient toxicity. The statistical grouping of SVI values reveals that the differences between each concentration are statistically significant, highlighting the critical threshold levels of salt that can be tolerated by the seeds. The highest SVI at 0 mM indicates optimal conditions for seed germination without the presence of salt stress. Conversely, the lowest SVI at 120 mM demonstrates the severe impact of high salt concentration on seed vigor, likely due to increased osmotic stress and nutrient imbalance within the seed tissues (Shahbaz

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and Ashraf, 2013). It is reported that the SVI value decreases depending on the concentration of NaCl or KCl (Al-Mutawa, 2003; Cokkizgin, 2012; Ghanad et al., 2016; Cokkizgin, 2025b; Gao et al., 2025b).

According to Hossain and Fujita (2010), the application of osmoprotectants such as glycinebetaine and proline has been shown to enhance antioxidant defenses under salt stress. This suggests that these substances could potentially mitigate the negative effects of salt on seed vigor.

Additionally, the suppression of nitrate reduction at high salt concentrations, as indicated by Blumwald, Aharon, and Apse (2000), may also contribute to reduced seed vigor and growth. These findings emphasize the importance of managing salt levels in agricultural soils to maintain optimal seed vigor and ensure successful germination and seedling establishment.

Mean germination time (MGT)

When comparing the two salt types, there was no significant difference in Mean Germination Time (MGT) (*Table 1,* P > 0.05). According to the data, when a 0 mM salt dose was applied, the MGT was determined to be 9.44500, representing the shortest germination time. When a 20 mM salt dose was applied, this time was recorded as 9.55500 and statistically included in group B. When a 40 mM salt dose was applied, the average germination time was 9.54667, placing it in group BC. The 60 mM salt dose increased the germination time to 9.61833, and this result was evaluated in group AB. The 80 mM, 100 mM, and 120 mM salt doses had germination times of 9.68500, 9.72500, and 9.71667, respectively, and were included in group A (*Tables 1* and 2).

The findings of the study reveal that the increase in salt doses significantly extends the mean germination times of plants. This indicates that plants experience stress when exposed to high salt concentrations, which prolongs germination times. The increase in germination times between 0 mM and 20 mM salt doses suggests that even low salt concentrations negatively affect plant growth.

Overall, the results obtained indicate that salt has a significant effect on the germination time of plants, and high salt doses extend the MGT (Cokkizgin, 2012). The current findings are consistent with those of Pujol et al. (2000), who found that higher salinity levels lead to a decrease in the percentage of seeds that germinate and cause a delay in the start of the germination process. In some cases, increased salinity can even completely prevent germination from occurring. The NaCl concentrations exceeded the species' tolerance thresholds. Previous studies (Ayers and Westcot, 1985; Welbaum et al., 1990; Rahman et al., 2000; Murillo-Amador et al., 2002; Mensah and Ihenyen, 2009; Gao et al., 2025a) have shown that salinity can delay the germination process.

These findings provide important insights into the management of salt stress in plant production. The stress caused by salt on plants can reduce agricultural productivity, and therefore, the establishment of salt management strategies in agricultural activities is of great importance. Selecting and cultivating plant species that are more resistant to salt stress can contribute to increased productivity in agricultural production.

Dose effect analysis

The effects of KCl and NaCl doses were analyzed using dose-effect analysis with natural logarithmic transformation; it was determined that the rate of seeds losing germination ability/dying increased at higher doses (*Fig. 1a, b*).

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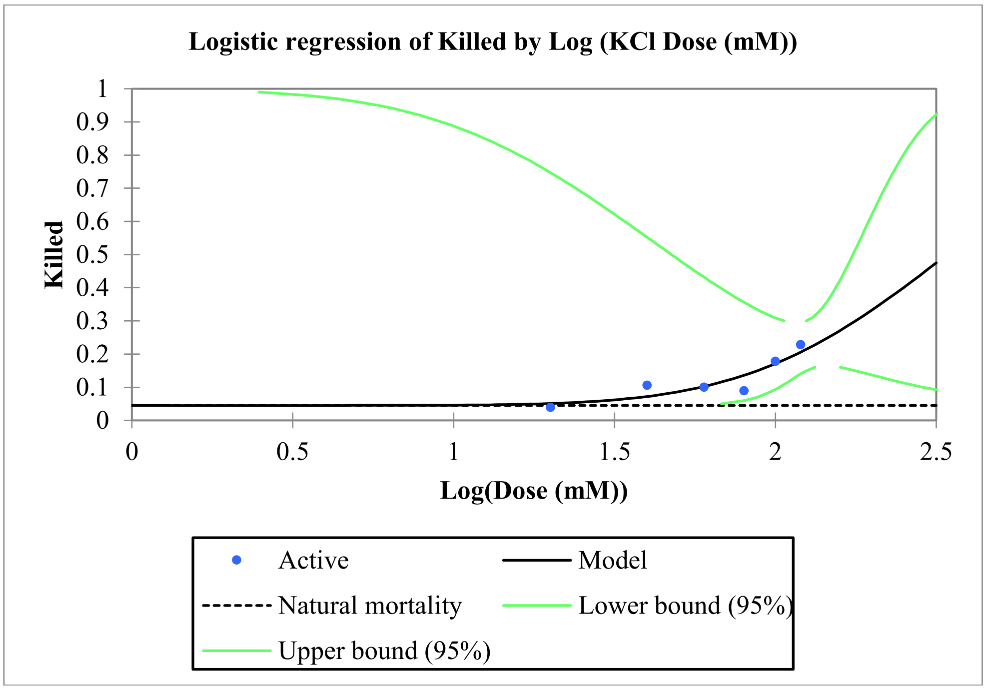

Figure 1a. *Dose-effect analysis results of KCl salts after log transformation*

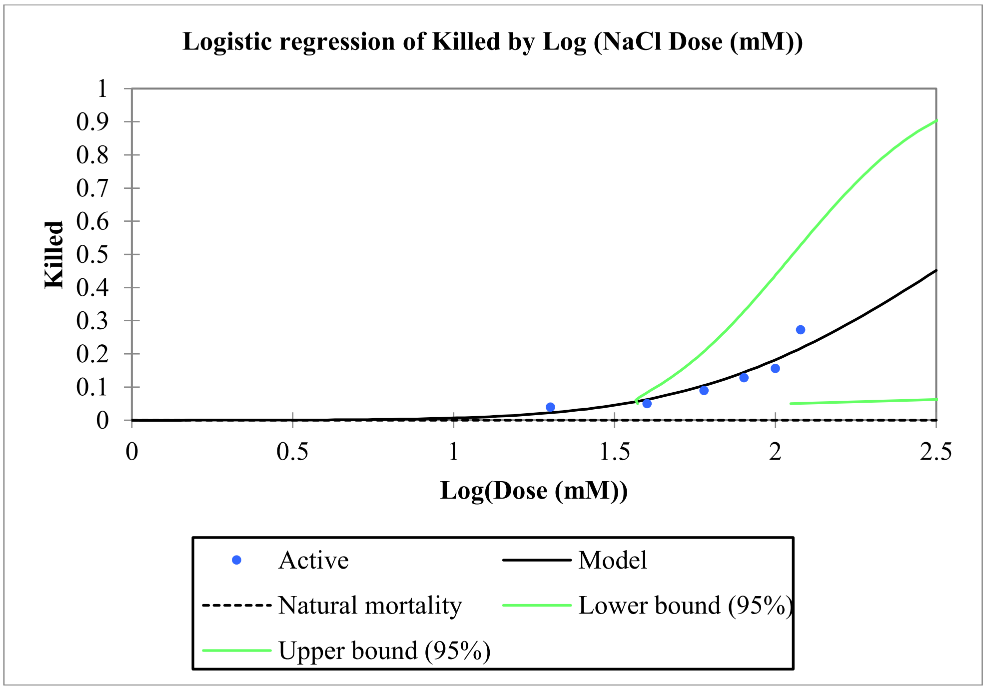

Figure 1b. *Dose-effect analysis results of NaCl salts after log transformation*

Conclusion

This study comprehensively examined the impact of different salt applications on plant germination and growth parameters. The results indicate that both KCl and NaCl have significant effects on various germination indices, including CVG, GI, GP, RL, HL, SVI,

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and MGT. Specifically, the application of NaCl resulted in a lower germination index (GI) compared to KCl, indicating a more pronounced inhibitory effect on germination.

When examining the effects of different salt doses, it was observed that increasing salt concentrations generally led to a decline in the germination percentage (GP), root length (RL), and seedling vigor index (SVI). High salt doses, particularly at 100 mM and 120 mM, significantly reduced these parameters, demonstrating the adverse effects of salinity on plant development. Notably, the mean germination time (MGT) also increased with higher salt doses, highlighting the delay in the germination process under saline conditions.

These findings underscore the importance of managing salt stress in agricultural production. High salinity levels can significantly hinder germination and seedling growth, ultimately reducing crop productivity. Therefore, developing and implementing effective salt management strategies is crucial for sustaining agricultural yields. Selecting and cultivating plant species that exhibit higher tolerance to salt stress can further enhance productivity and contribute to more resilient agricultural practices.

Overall, the findings from this study shed light on the significant impact of salinity on plant germination and growth. These results underscore the importance of developing effective strategies for managing salt stress in agricultural practices. By understanding the adverse effects of high salinity, we can better implement measures to enhance crop resilience and productivity under saline conditions. Given these insights, it is crucial to continue and expand salinity research to further improve our understanding and management of salt stress in crops.

Considering both NaCl and KCl salts, dose-effect analysis determined that if higher salt concentrations were used, the rate of seeds failing to germinate would further increase.

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