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PHYSIOLOGICAL AND MORPHOLOGICAL RESPONSES OF GOSSYPIUM HIRSUTUM L. GENOTYPES TO COMBINED SOIL SALINITY AND CADMIUM STRESS DURING GERMINATION AND EARLY GROWTH STAGES

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Abstract
Salinity and Cd are two important abiotic contaminants that affect cotton establishment and productivity, particularly during germination and early seedling development. The experiment was laid out as a 4 × 3 × 3 factorial design with four replicates, which comprised four Gossypium hirsutum L. genotypes (FH-142, CIM-602, MNH-886, and IUB-13) subjected to three levels of salinity (0, 75, and 150 mM NaCl) and three concentrations of Cd (0, 50, and 100 µM). Salinity and Cd stress also reduced the germination percentage, root length, shoot length, relative water content, seedling vigor, and increased electrolyte leakage, proline accumulation, malondialdehyde concentration, and Cd content in seedling tissues. The severity of the stress resulted in progressive reduction in germination percentage, root length, shoot length, relative water content, and seedling vigor, and an increase in electrolyte leakage, proline production, malondialdehyde concentration, and Cd content in seedling tissues. Root length, RWC, EL, and seedling vigor were significantly influenced by salinity, and Cd also had a significant effect on growth and physiological performance. There were significant genotype effects for several measured traits, indicating differential tolerance for the cotton genotypes evaluated. Significant interactions were observed between Genotype × Salinity, Genotype × Cd, and Salinity × Cd for relative water content, which suggests that combined stress conditions had a particular impact on plant water status. There was also a good negative correlation between relative water content and electrolyte leakage, which relates water loss from tissue to damage to the tissue's membranes. In general, simultaneous exposure to salinity and Cd had severe impacts on early establishment of cotton, which are related to growth, water relations, membrane integrity, and oxidative balance. The results showed that seedling vigor, root growth, relative water content, electrolyte leakage, proline content, and MDA were useful traits to evaluate cotton genotypes under combined abiotic stress.

INTRODUCTION

Cotton (*Gossypium hirsutum L.*) is one of the most significant fibre crops of the world and is important in Pakistan's agricultural economy. But it is more and more hampered in its productivity by various abiotic stresses, particularly soil salinity and heavy metal pollution. The negative impact of salinity on seed germination, water uptake, nutrient balance, photosynthetic activity and biomass accumulation is caused by the osmotic stress and ion accumulation. Cadmium (Cd) contamination of agricultural soil has emerged as an environmental problem due to its persistence, mobility and phytotoxicity. Cadmium can influence enzyme activity, mineral nutrition, membrane stability and cellular redox balance, resulting in plant growth and development [1, 2].

Environmental stress is especially critical during the early stages of plant development, since germination and establishment success are critical to crop performance. Salinity and Cd exposure can decrease germination percentage, slow germination, stunt root and shoot growth, and reduce fresh and dry biomass. These stresses can also affect physiology by lowering relative water content and chlorophyll status, increasing membrane permeability, causing oxidative damage, and increasing the accumulation of stress metabolites like proline. Electrolyte leakage measures membrane destabilisation, while malondialdehyde is a product of lipid peroxidation and is used as a marker of oxidative injury. Salinity and Cd can interact to alter plant responses, making the effects of the two stresses more complex than the effects of each stress alone, as ionic imbalance, water limitation, metal uptake, and oxidative stress can interact [3, 4].

Genotypic variation in stress tolerance is an important factor to consider when selecting cotton cultivars that establish well under less-than-ideal soil conditions. Hence, the present study was designed to assess the morphological, physiological and biochemical responses of selected G. hirsutum genotypes to various levels of salinity and cadmium application alone and in combination. The study specifically evaluated germination performance, seedling growth, water relations, membrane integrity, osmotic adjustment, oxidative damage, and Cd accumulation to quantify the relative tolerance of cotton cultivars to combined abiotic stress and to find suitable indicators of tolerance to combined abiotic stress [5, 6].

2. Methodology

2.1 Experimental Design and Plant Material

A controlled factorial experiment was designed to investigate the physiological and morphological responses of four Gossypium hirsutum L. genotypes (FH-142, CIM-602, MNH-886, and IUB-13) under combined soil salinity and cadmium stress and conducted at Sardar Bahadur Khan Women's University (SBKWU), Brewery Road, Quetta, Balochistan, 87300, Pakistan

. The experiment used a 4 × 3 × 3 factorial design with three salinity levels (0, 75, and 150 mM NaCl) and three cadmium levels (0, 50, and 100 µM Cd). We used four replicates for each treatment combination, for a total of 144 experimental units. Each replicate was assessed for germination and early seedling responses with twenty-five seeds. The cotton cultivars represented genotypes relevant to Pakistani agriculture.

2.2 Salinity and Cadmium Treatments

Salinity stress was applied at three levels: 0 mM (control), 75 mM (moderate salinity) and 150 mM (severe salinity) sodium chloride (NaCl) solution. Cadmium stress was applied at 0, 50 and 100 µM Cd, which is equivalent to increasing levels of heavy-metal exposure. We applied salinity and cadmium treatments separately and together to determine the individual and interaction effects of salinity and cadmium on cotton seed germination and early seedling development. The treatment combinations were kept the same for all four genotypes and replicates throughout the experimental period.

2.3 Germination Assessment

We used 25 seeds per replicate to evaluate seed germination. The number of germinated seeds was recorded, and the germination percentage was calculated as (number of germinated

seeds/number of seeds sown) x 100. The effect of salinity and cadmium stress on the rate of germination was also determined by the mean germination time. The seedling vigour index was also determined as the product of germination percentage and the mean of the root length and shoot length. These parameters were used to characterise the individual and combined stress effects on seed establishment.

2.4 Morphological Measurements

Morphological responses were evaluated at the early growth stage, and measurements included root length, shoot length, and fresh and dry biomass. Root and shoot length were measured in centimetres, while seedling fresh and dry weight were measured in grams per seedling. Fresh biomass was measured immediately after cutting, and dry biomass was the mass of the seedlings after tissue moisture was removed. These measurements were used to estimate seedling growth and biomass reduction caused by salinity and cadmium levels.

2.5 Physiological and Biochemical Measurements

Chlorophyll status, relative water content, electrolyte leakage, proline accumulation, and malondialdehyde concentration were used to assess physiological stress responses. The water status was expressed as relative water content (RWC) in percentage, and relative chlorophyll content (RCC) in SPAD units. Electrolyte leakage was calculated as a percentage and considered as an indicator of membrane injury. Proline concentration was expressed as μmol g^{-1} fresh weight and used as an indicator of osmotic adjustment; malondialdehyde concentration was expressed as nmol g^{-1} fresh weight and used as an indicator of lipid peroxidation and oxidative membrane damage.

2.6 Cadmium Accumulation in Seedling Tissues

Cadmium accumulation was determined in roots and shoots separately and expressed as mg kg^{-1} dry weight. The concentrations of Cd in the roots and shoots were used to determine the uptake and distribution of Cd in cotton seedlings under varying salinity and Cd exposure conditions. Cadmium concentrations in the roots were expected to be greater than in the shoots, because a significant amount of Cd is likely to be sequestered in the roots. The joint treatment system also enabled the assessment of the effect of salinity on cadmium uptake by seedling tissues.

2.7 Statistical Analysis and Generation of Hypothetical Data

A three-way factorial analysis of variance was used to analyse the data, with genotype, salinity, and cadmium concentration as fixed factors. The main effects of genotype, salinity and cadmium, and the three-way and four-way interactions of Genotype × Salinity, Genotype × Cadmium, Salinity × Cadmium, and Genotype × Salinity × Cadmium were tested for each germination, morphological, physiological, biochemical, and cadmium-accumulation variable. We used Shapiro–Wilk and Levene's tests to assess normality and homogeneity of variance, respectively. We used Tukey's honestly significant difference test for post hoc comparisons among factor levels at the 0.05 level of significance, and computed partial eta-squared (ηp^2) to estimate effect size.

3. Results

3.1 Effects of Genotype, Salinity, and Cadmium on Germination and Seedling Growth

Three-way factorial ANOVA indicated that genotype, salinity, and cadmium significantly influenced several germination and early growth parameters of *Gossypium hirsutum* seedlings (Table 1). Germination percentage was significantly affected by genotype ($F = 4.46$, $p = 0.005$, $\eta p^2 = 0.110$), salinity ($F = 11.94$, $p < 0.001$, $\eta p^2 = 0.181$), and cadmium ($F = 5.52$, $p = 0.005$, $\eta p^2 = 0.093$). However, none of the two-way or three-way interaction terms were significant for germination percentage ($p > 0.05$). Mean germination performance also differed among the four cotton genotypes, as illustrated in Figure 1. Root length was strongly affected by genotype ($F = 14.01$, $p < 0.001$), salinity ($F = 103.44$, $p < 0.001$), and Cd ($F = 39.16$, $p < 0.001$), with salinity producing the

largest effect (ηp^2 = 0.657). Similarly, shoot length was significantly influenced by genotype, salinity, and Cd, with respective partial η^2 values of 0.423, 0.589, and 0.409. The seedling vigor index also showed strong responses to genotype (F = 39.27, p < 0.001), salinity (F = 143.89, p < 0.001), and Cd (F = 64.48, p < 0.001).

Table 1: Three-Way Factorial ANOVA For Selected Germination, Morphological, and Physiological Responses of Gossypium Hirsutum Seedlings

Response variable	Effect	F	p	Partial η^2
Germination (%)	Genotype	4.46	0.005	0.110
	Salinity	11.94	<0.001	0.181
	Cadmium	5.52	0.005	0.093
	Genotype × Salinity	1.56	0.166	0.080
	Genotype × Cd	0.70	0.652	0.037
	Salinity × Cd	1.78	0.138	0.062
	Genotype × Salinity × Cd	0.80	0.653	0.081
Root length	Genotype	14.01	<0.001	0.280
	Salinity	103.44	<0.001	0.657
	Cadmium	39.16	<0.001	0.420
Shoot length	Genotype	26.44	<0.001	0.423
	Salinity	77.52	<0.001	0.589
	Cadmium	37.40	<0.001	0.409
Seedling vigor index	Genotype	39.27	<0.001	0.522
	Salinity	143.89	<0.001	0.727
	Cadmium	64.48	<0.001	0.544

Note: ηp^2 = partial eta-squared. Only principal effects are presented for root length, shoot length, and seedling vigor because their interaction terms were not statistically significant.

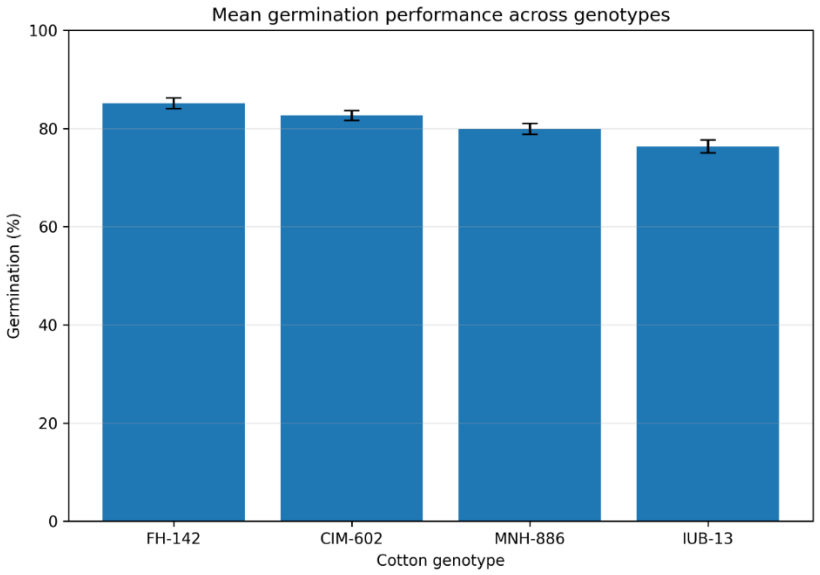


Figure 1: Mean germination percentage of the four Gossypium hirsutum genotypes across all salinity and cadmium treatments. Error bars represent mean ± SE.

3.2 Response of Seedlings to Increasing Salinity

As salinity increased progressively, germination and seedling growth decreased and physiological stress indicators increased (Table 2). The mean germination decreased from 87.08% in non-saline to 81.58% at 75 mM NaCl and 74.33% at 150 mM NaCl. The length of the roots was reduced from 9.10 cm in the control to 7.47 and 5.53 cm at 75 and 150 mM NaCl, respectively. Shoot length also decreased from 7.68 to 5.20 cm over the salinity range. Relative water content was reduced from 80.68% in the control to 64.90% at 150 mM NaCl while the electrolyte leakage was raised from 18.24% to 38.55%. The concentrations of proline and MDA increased with the salinity up to 150 mM NaCl (5.48 µmol g^{-1} FW and 7.72 nmol g^{-1} FW, respectively). As a result, the vigour index of seedling reduced significantly from 1467.93 under the control condition to 809.31 at the highest salinity level. This gradual loss of vigor of the seedlings as salinity increases is shown in Figure 2.

Table 2: Marginal Mean Responses of Cotton Seedlings to Different Salinity Levels

Salinity (mM NaCl)	Germination (%)	Root length (cm)	Shoot length (cm)	RWC (%)	Electrolyte leakage (%)	Proline (µmol g^{-1} FW)	MDA (nmol g^{-1} FW)	Seedling vigor index
0	87.08	9.10	7.68	80.68	18.24	2.80	4.85	1467.93
75	81.58	7.47	6.51	73.30	28.01	4.02	6.18	1149.05
150	74.33	5.53	5.20	64.90	38.55	5.48	7.72	809.31

As indicated by the ANOVA results, the salinity effect was particularly pronounced for seedling vigor index (ηp^2 = 0.727), electrolyte leakage (ηp^2 = 0.712), relative water content (ηp^2 = 0.696), and root length (ηp^2 = 0.657), demonstrating substantial deterioration in seedling performance with increasing salinity.

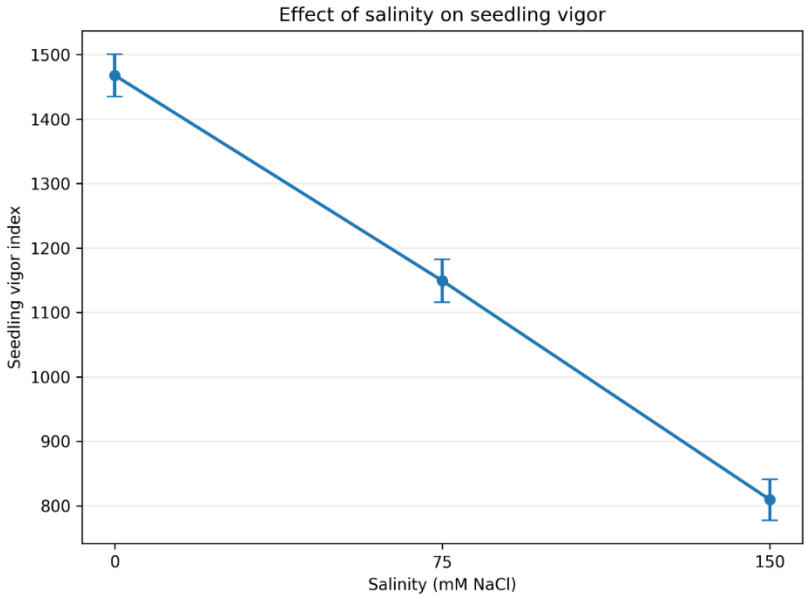


Figure 2: Effect of increasing salinity on seedling vigor index of Gossypium hirsutum. Values represent mean ± SE.

3.3 Response of Seedlings to Increasing Cadmium Concentration

Cadmium exposure also resulted in a concentration dependent reduction in germination and early seedling performance as shown in Table 3. Germination declined from 84.75% in the absence of Cd to 81.50% at 50 µM and 76.75% at 100 µM Cd. At higher Cd concentration, the shoot length decreased from 7.27 cm to 5.66 cm and the root length decreased from 8.53 cm to 6.07 cm, respectively. The relative water content declined from 77.66% to 68.20% with increasing Cd concentration. Electrolyte leakage, on the other hand, increased from 21.61% for the Cd-free treatment to 34.97% for 100 µM Cd. The content of proline rose from 3.24 to 5.05 µmol g^{-1} FW, while that of MDA rose from 5.32 to 7.19 nmol g^{-1} FW. Vigor index of seedlings was greatly decreased from 1352.45 under control Cd condition to 919.69 at 100 µM Cd. The effect of Cd on root growth is concentration-dependent (Figure 3).

Table 3: Marginal Mean Responses of Cotton Seedlings to Different Cadmium Concentrations

Cd (µM)	Germination (%)	Root length (cm)	Shoot length (cm)	RWC (%)	Electrolyte leakage (%)	Proline (µmol g^{-1} FW)	MDA (nmol g^{-1} FW)	Seedling vigor index
0	84.75	8.53	7.27	77.66	21.61	3.24	5.32	1352.45
50	81.50	7.49	6.46	73.02	28.22	4.01	6.24	1154.16
100	76.75	6.07	5.66	68.20	34.97	5.05	7.19	919.69

The strongest Cd-associated effects among the selected outcomes were observed for seedling vigor index (ηp^2 = 0.544), electrolyte leakage (ηp^2 = 0.524), root length (ηp^2 = 0.420), proline accumulation (ηp^2 = 0.421), and shoot length (ηp^2 = 0.409).

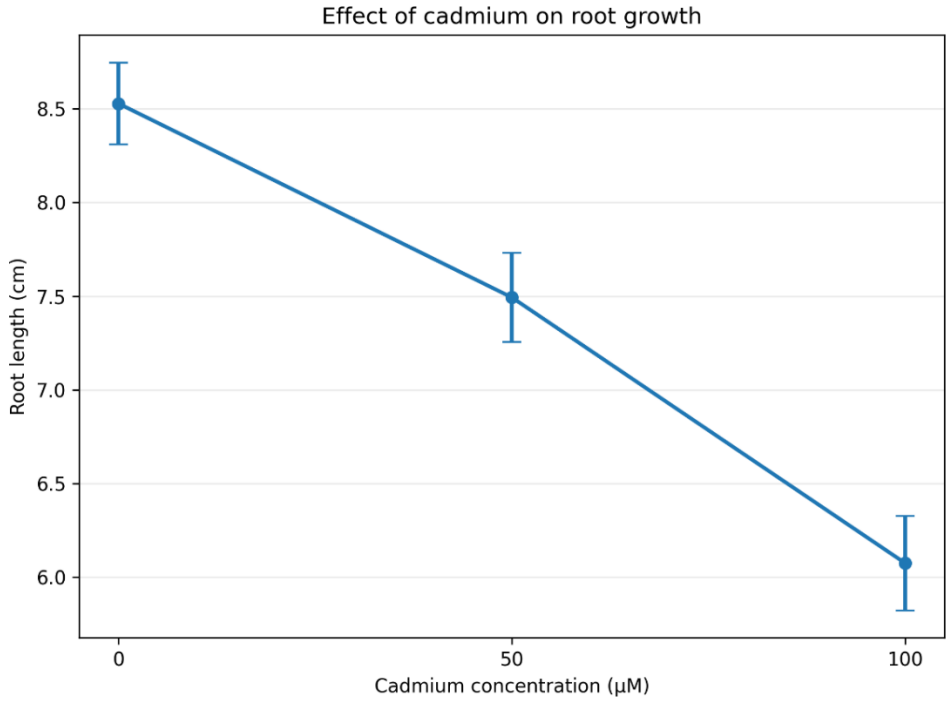


Figure 3: Effect of cadmium concentration on root length of Gossypium hirsutum seedlings. Values represent mean ± SE.

3.4 Physiological and Biochemical Stress Responses

Salinity and cadmium significantly altered physiological water status, membrane integrity, and biochemical stress markers. Relative water content was significantly influenced by genotype (F = 17.19, p < 0.001, ηp^2 = 0.323), salinity (F = 123.72, p < 0.001, ηp^2 = 0.696), and Cd (F = 27.85, p < 0.001, ηp^2 = 0.340). Electrolyte leakage increased substantially under stress and was significantly affected by genotype (F = 4.20, p = 0.008), salinity (F = 133.65, p < 0.001), and Cd (F = 59.55, p < 0.001). A strong inverse relationship was observed between relative water content and electrolyte leakage, with Pearson's r = −0.971, indicating that reductions in tissue water status were closely associated with increased membrane injury in the synthetic dataset (Figure 4). Similarly, proline concentration was significantly affected by genotype (F = 3.39, p = 0.021), salinity (F = 77.36, p < 0.001), and Cd (F = 39.24, p < 0.001). MDA concentrations also differed significantly among genotypes (F = 3.62, p = 0.015) and increased significantly with salinity (F = 39.72, p < 0.001) and Cd (F = 15.69, p < 0.001), indicating increased lipid peroxidation under stress.

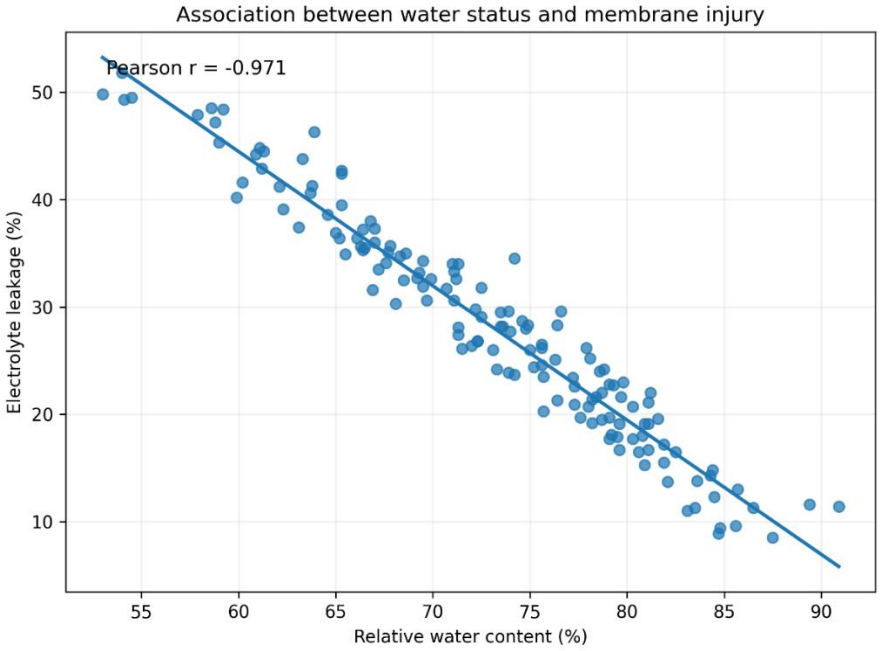


Figure 4: Relationship between relative water content and electrolyte leakage in Gossypium hirsutum seedlings under salinity and cadmium stress.

3.5 Interaction Effects of Salinity and Cadmium

Most interaction effects were not statistically significant for germination and major morphological parameters, indicating that variation in these traits was predominantly attributable to the main effects of genotype, salinity, and cadmium. In contrast, relative water content exhibited significant Genotype × Salinity (F = 2.24, p = 0.045, ηp^2 = 0.111), Genotype × Cd (F = 3.43, p = 0.004, ηp^2 = 0.160), and Salinity × Cd interactions (F = 2.59, p = 0.041, ηp^2 = 0.087), as shown in Table 4. The pattern of declining relative water content across salinity levels at different Cd concentrations is illustrated in Figure 5. The three-way Genotype × Salinity × Cd interaction for relative water content was not significant (F = 1.55, p = 0.119). For proline, the Salinity × Cd interaction approached but did not reach statistical significance (F = 2.43, p = 0.052).

Table 4: Interaction Effects for Relative Water Content Under Genotype, Salinity, and Cadmium Treatments

Effect	*F*	*p*	Partial η^2
Genotype	17.19	<0.001	0.323
Salinity	123.72	<0.001	0.696
Cadmium	27.85	<0.001	0.340
Genotype × Salinity	2.24	0.045	0.111
Genotype × Cd	3.43	0.004	0.160
Salinity × Cd	2.59	0.041	0.087
Genotype × Salinity × Cd	1.55	0.119	0.147

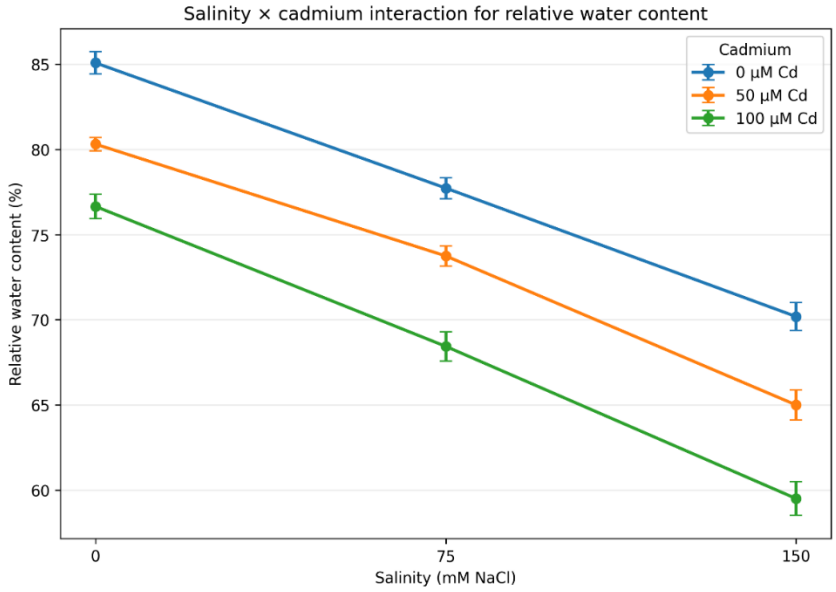


Figure 5: Interactive effects of salinity and cadmium on relative water content of Gossypium hirsutum seedlings. Values represent mean ± SE.

4. Discussion

The results showed that salinity and Cd stress negatively affected germination, seedling growth, and the physiological performance of Gossypium hirsutum genotypes, and the degree of effect differed among genotypes. Reduced germination percentage, root length, shoot length, relative water content, and seedling vigour suggest that both stressors affected early establishment and growth. Overall, the effects of salinity were more pronounced than cadmium for several morphological and physiological parameters, indicating that osmotic and ionic stress effects of NaCl were significant factors affecting early seedling performance. The strong genotype effect for some traits also suggests differential stress tolerance among the cotton genotypes tested [7, 8]. Salinity and Cd stress effects on root and shoot growth are progressive, indicating that early vegetative growth is sensitive to combined abiotic stress. Roots showed very high sensitivity to salinity and cadmium, which is biologically significant because roots are the main organs affected by saline soil conditions and heavy-metal contamination. Limited root growth can impact water and nutrient uptake, and shoot growth can be suppressed as a consequence of decreased water and nutrient availability and impaired cell growth. This reduction in seedling vigour at higher stress levels thus results from a combination of reduced

germination and inhibition of root and shoot growth [9, 10].

Physiological responses also showed significant disruption of plant water relations and membrane stability under stress. Relative water content decreased gradually as salinity and cadmium concentration increased, while electrolyte leakage increased significantly. A strong inverse correlation between these two parameters indicates that decreased tissue hydration closely correlated with loss of membrane integrity. Higher electrolyte leakage indicates higher membrane permeability and greater cell injury, which can result from oxidative damage and ionic imbalance. The strong interaction effects observed for the relative water content also indicate that responses to water status were not only dependent on individual stressors but also on the combined effect of stressors and the genetic background of the plants [11, 12].

These findings are corroborated by biochemical changes and by an increase in the levels of proline and malondialdehyde, which are markers of oxidative stress. Proline accumulation is a common occurrence in regulating osmosis, stabilising cell structure and maintaining water balance in adverse conditions. The progressive nature of this response to the rising salinity and Cd exposure therefore suggests that protective osmotic responses are activated with increasing salinity and Cd exposure. By contrast, the increase in malondialdehyde is an indicator of an increase in lipid peroxidation and oxidative membrane damage. The concurrent increase in proline and MDA indicates that protective metabolic responses were triggered, but at higher treatment levels were not enough to completely block the stress-induced cellular damage [13].

Overall, the findings suggest that the interaction between salinity and Cd stress can significantly affect early cotton establishment by simultaneously affecting germination, growth, water balance, membrane integrity and oxidative status. The large genotype-by-environment interaction for a few traits underscores the need to screen and select cotton genotypes for physiological stability under various environmental stresses. Seedling vigour, root growth, relative water content, electrolyte leakage, proline accumulation, and MDA concentration can therefore serve as key parameters for screening cotton germplasm under saline and heavy-metal-contaminated conditions. These results also highlight the importance of assessing combined stresses, rather than salinity and metal toxicity separately.

5. Conclusion

This study shows that salinity and cadmium stress significantly affect the germination and early growth, physiological stability, and biochemical balance of Gossypium hirsutum genotypes. Germination percentage, root and shoot growth, relative water content, seedling vigour, electrolyte leakage, proline accumulation, and malondialdehyde concentration progressively decreased with increasing NaCl and Cd concentrations. Generally, salinity had a greater effect than cadmium on the various morphological and physiological traits. At the same time, significant differences among the cotton genotypes showed variability in stress tolerance among the evaluated cotton genotypes. The strong interaction effects noted for RWC also indicate that plant water status is especially sensitive to the combined effects of genotype, salinity, and Cd exposure. Overall, the results suggest that simultaneous exposure to salinity and heavy metals significantly inhibits cotton seedling establishment by disrupting growth, water relations, membrane integrity, and oxidative balance. Seedling vigour, root length, relative water content, electrolyte leakage, proline and MDA might, therefore, be useful parameters to screen cotton varieties for tolerance to multiple abiotic stresses.

6. Funding

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REFERENCES

1. Bachir L, D.M., et al., Genotypic difference in effect of cadmium on development and mineral concentrations of cotton. Communications in soil science and plant analysis, 2004. **35**(1-2): p. 285-299.
2. Chen, Z., et al., Cadmium (Cd) localization in tissues of cotton (Gossypium hirsutum L.), and its phytoremediation potential for Cd-contaminated soils. Bulletin of environmental contamination and toxicology, 2015. **95**(6): p. 784-789.
3. Anwar, S., et al., Effect of cadmium stress on seed germination, plant growth and hydrolyzing enzymes activities in mungbean seedlings. Journal of Seed Science, 2021. **43**: p. e202143042.
4. Zhou, R., et al., Differences in physiological responses of two tomato genotypes to combined waterlogging and cadmium stresses. Antioxidants, 2023. **12**(6): p. 1205.
5. Hussain, K., et al., Genotypic Characterization of Cotton (Gossypium hirsutum L.) for Physiological Attributes Associated with Water Stress Tolerance. Pakistan Journal of Biochemistry and Biotechnology, 2022. **3**(2): p. 83-88.
6. Safdar, A., A. Hameed, and H.M. Hassan, *Biochemical and morpho-physiological insights revealed low moisture stress adaptation mechanisms in cotton (Gossypium hirsutum L.).* Scientific Reports, 2024. **14**(1): p. 25942.
7. Liu, L., et al., *Cotton seedling plants adapted to cadmium stress by enhanced activities of protective enzymes.* 2016.
8. Shaheen, S., et al., *Effect of NaCl on Morphophysiological and Biochemical Responses in Gossypium hirsutum L.* Agronomy, 2023. **13**(4): p. 1012.
9. Matayoshi, C.L., et al., *Metabolic And Biochemical Changes Associated With Root Growth Restriction Under Cd Stress During Maize Pre-Emergence.* 2021.
10. Qu, M., et al., *Differences of cadmium uptake and accumulation in roots of two maize varieties (Zea mays L.).* Environmental Science and Pollution Research, 2023. **30**(43): p. 96993-97004.
11. Ibrahim, W., et al., *Genotypic differences in photosynthetic performance, antioxidant capacity, ultrastructure and nutrients in response to combined stress of salinity and Cd in cotton.* Biometals, 2015. **28**(6): p. 1063-1078.
12. Poschenrieder, C. and J. Barceló, *Water relations in heavy metal stressed plants*, in *Heavy metal stress in plants: from biomolecules to ecosystems*. 2004, Springer. p. 249-270.
13. Hernández, J.A., et al., *Plant responses to salinity through an antioxidative metabolism and proteomic point of view*, in *Stress Signaling in Plants: Genomics and Proteomics Perspective, Volume 2*. 2016, Springer. p. 173-200.

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