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RESEARCH COMMUNICATION

Influence of NaCl stress on germination, growth and vigour of onion (*Allium cepa* L.) seedlings

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Abstract

Onion (*Allium cepa* L.), a globally important vegetable crop, is highly sensitive to salinity stress, particularly during its early developmental phases, especially the germination stage. This study evaluated the effect of varying sodium chloride (NaCl) concentrations (0, 50, 100, 150, 200 and 250 mM) on seed germination and early seedling growth of four improved onion cultivars-Bhima Shweta, Bhima Red, Bhima Shakti and Bhima Kiran-under controlled laboratory conditions using a factorial completely randomised design (FCRD) with three replications. Germination percentage, shoot and root length, fresh and dry weights, survival and mortality rates and seed vigour indices were measured. Results demonstrated that NaCl concentrations exceeding 50 mM significantly reduced germination, growth and vigour parameters in all cultivars, with the most severe inhibition observed at 250 mM (37-49 % germination, 70-80 % reduction in seedling elongation and > 50 % mortality). Among the cultivars tested, Bhima Shakti exhibited the highest salt tolerance, maintaining greater germination percentages, biomass accumulation, survival rates and vigour indices compared to other cultivars. The findings indicate that increasing salinity delayed emergence, impaired water uptake, disrupted ion homeostasis and reduced seedling survival, underscoring the importance of selecting salt-tolerant cultivars for sustainable onion production in saline-affected regions.

Keywords: germination; mortality percentage; onion; salinity stress; seed vigour

Introduction

Onion (*Allium cepa* L.), a member of the family Alliaceae, is one of the most important vegetable and spice crops grown worldwide, valued for its pungent flavour, nutritional significance and therapeutic properties (1). The edible bulb consists of fleshy scale leaves and a basal stem plate (2). Globally, onion is cultivated across more than 9 million hectares, with major producers including China, India, the United States, Turkey and Russia (3). India ranks second after China, contributing nearly one-fifth of global onion output.

The crop is extensively grown during both the *kharif* and *rabi* seasons across major onion-growing states such as Maharashtra, Karnataka and Madhya Pradesh. In 2023-24, India cultivated onions over 1.47 million hectares with a production of 25.47 million metric tons (4). Despite its vast production base, onion productivity and market stability are frequently constrained by seasonal variability and abiotic stresses.

Among these stresses, soil salinity poses a particularly severe challenge, especially in arid and semi-arid regions of India. Nearly 6.73 million hectares of cultivable land in the country are already affected by salinity and sodicity (5). Coastal onion-growing regions such as Gujarat, Maharashtra, Andhra Pradesh, Odisha, Tamil Nadu and West Bengal are highly vulnerable due to seawater intrusion, rising groundwater salinity and secondary salinisation caused by poor irrigation practices (6). Globally, it is estimated that 20 % of the world's cultivated land and almost half of irrigated land suffer from salinity-related problems, making it one of the most critical threats to sustainable onion cultivation (3).

Onion is classified as a salt-sensitive crop with a threshold of only 1-2 dS m^{-1} electrical conductivity (7). Seed germination, the first and most vulnerable stage of crop establishment, is particularly impaired under saline conditions. High concentrations of soluble salts impose osmotic stress, restrict water uptake and induce ionic toxicity, leading to delayed or reduced germination, poor seedling vigour and diminished establishment (8). Elevated Na^+ and Cl^- concentrations also disrupt cellular metabolism and impair root-shoot elongation, further suppressing early growth (9). Although the effects of salinity on onion growth and bulb yield have been studied extensively, relatively fewer investigations have focused on its impact during the germination stage, despite its critical role in determining crop performance under stress (10, 11). The sensitivity of onion seeds to salinity is attributed to their thin seed coats, shallow rooting and limited osmotic adjustment capacity during early developmental stages, which collectively impair imbibition and radicle emergence.

Therefore, this study was designed to investigate the effects of varying NaCl concentrations on onion seed germination and seedling growth, to identify salt-tolerant cultivars suitable for cultivation in saline-affected regions.

Materials and Methods

The present study was conducted at the Soil Science Laboratory, ICAR–Directorate of Onion and Garlic Research (ICAR–DOGR), Pune, Maharashtra, India. The site is located at 18.32° N latitude, 73.51° E longitude and 645 m above mean sea level (MSL). The trial was conducted during September 2023.

Experimental details

The experiment included four onion cultivars and six NaCl concentrations. Factor A: (i) Bhima Shweta, (ii) Bhima Red, (iii) Bhima Shakti and (iv) Bhima Kiran - all improved cultivars from ICAR-DOGR.

Factor B: concentrations of NaCl (i) control, distilled water, (ii) 50 mM, (iii) 100 mM, (iv) 150 mM, (v) 200 mM and (vi) 250 mM. The present experiment was conducted following FCBD with three replications. NaCl solutions of control (0), 50, 100, 150, 200 and 250mM were prepared. Distilled water was used as the control.

Twenty-five seeds of each of the onion cultivars were placed for germination on two folds of Whatman No. 1 filter paper in Petri dishes (9 cm diameter). Each dish was moistened with 5 mL of distilled water or one of the NaCl solutions (50, 100, 150, 200 and 250 mM). The level of water or salt solution was assessed daily and applied as required to maintain adequate moisture. Observations were recorded daily from day 2 onwards until day 14.

Observations recorded

Germination percentage was calculated as:

Germination percentage = (number of seeds germinated / total seeds sown) × 100 ... (1)

Shoot length and root length (cm) were measured on day 12 using a ruler. Fresh weight was recorded immediately after sampling (10 seedlings), while dry weight was determined by oven-drying samples at 70 °C for 48 hr (mg). The time taken to germination was noted every 2 days.

Survival percentage = (number of surviving seedlings / total seeds sown) × 100 ... (2)

Mortality rate = 100 - survival percentage ... (3)

Seed vigour index-I = germination percentage × (mean shoot length + mean root length) ... (4)

Seed vigour index-II = germination percentage × mean seedling dry weight ... (5)

Statistical analysis

Data were analysed using KAU GRAPES (General R-shiny-based analysis platform empowered by statistics) under an FCRD with three replications. Analyses were performed for all growth and physiological parameters. For all parameters, two-way analysis of variance (ANOVA) was carried out using treatment (T) and cultivars (C) as factors. Throughout the analysis, the standard error of the mean (SEM) was computed. All F-values generated by KAU GRAPES were compared with tabulated F-values at the 5 % significance level. Wherever significant differences were found, the critical difference (CD) test was applied for further pairwise comparisons of means. This analytical framework enabled robust phenotypic comparison among cultivars under varying salinity stress, although genetic parameter estimation was not included in the present study.

Results and Discussion

A general trend was observed across all measured parameters, where increasing salinity above 50 mM NaCl (i.e., 100, 150, 200 and 250 mM NaCl) led to a significant and gradual decline in growth and vigour, accompanied by an increase in the time required for germination and seedling mortality. Among all salinity levels, the 50 mM treatment recorded comparatively higher growth and vigour values across most parameters.

Germination percentage and time taken to germination

Salinity significantly affected the germination behaviour of onion cultivars (Table 1). Germination percentage and the speed of germination declined significantly ($p < 0.05$) with increasing electrical conductivity of the medium. The highest germination (90-94 %) and shortest germination period (3-4 days) were recorded in the control and 50 mM treatments, whereas the 250 mM treatment resulted in delayed germination (9-10 days) and reduced the germination percentage (37-49 %). Among cultivars, Bhima Shakti and Bhima Shweta maintained higher germination and rapid emergence compared with Bhima Red and Bhima Kiran, indicating inherent variation in salt tolerance.

These observations are consistent with the findings of earlier studies, which reported that onion seed germination remained above 80 % up to 20 dS m^{-1} but seedling emergence declined sharply beyond 4.9 dS m^{-1} because of salt accumulation and hypocotyl injury (12). Similarly, other researchers observed a 3-57 % decline in germination and a 0.46-4.68-day delay at 50-250 mM NaCl (13). The present findings therefore confirm that osmotic potential and ionic toxicity are the primary constraints on germination under saline

Table 1. Effect of different salinity levels on germination percentage (%) and time taken for germination (days) of onion cultivars

	Cultivars							
	Germination percentage (%)				Time taken for germination (days)			
Salinity treatments	**Bhima Shweta**	**Bhima Red**	**Bhima Shakti**	**Bhima Kiran**	**Bhima Shweta**	**Bhima Red**	**Bhima Shakti**	**Bhima Kiran**
Control	90	87	91	86	4	4	4	4
50 mM	94	93	94	93	3	3	2	3
100 mM	82	79	85	79	6	6	4	6
150 mM	72	61	75	62	7	9	8	7
200 mM	58	46	60	45	8	9	8	8
250 mM	47	38	49	37	10	10	9	10
Factors	SEm (±)		C.D. (5 %)		SEm (±)		C.D. (5 %)	
Treatments	0.38		1.08		0.10		0.28	
Cultivars	0.31		0.88		0.08		0.23	
Treatments × cultivars	0.76		2.16		0.19		0.55	

conditions (14). A slight improvement in germination under moderate salinity (50 mM) was evident across all cultivars, suggesting mild osmotic stimulation of enzymatic activity and reserve mobilisation as described by previous reports (15).

Shoot and root growth

Shoot and root elongation decreased significantly ($p < 0.05$) with increasing salinity (Table 2). At control and 50 mM, mean shoot length ranged from 7.0-10.4 cm and root length from 4.2-5.4 cm, whereas at 250 mM they declined to 0.8-3.9 cm and 0.3-1.7 cm, respectively, representing a 70-80 % reduction relative to control. Bhima Shakti exhibited the least reduction in both, suggesting a superior capacity to maintain turgor and cell expansion.

The inhibition of elongation under saline conditions is attributed to reduced water uptake, impaired cell division and accumulation of toxic ions such as Na^+ and Cl^- in meristematic tissues (12, 13). Earlier studies reported that plumule length in onion seedlings decreased when NaCl increased from 0 to 200 mM, whereas radicle length decreased (16). The stronger suppression of shoot growth than root growth observed here agrees with their report and indicates that aerial tissues are more sensitive to osmotic imbalance and oxidative stress generated by excess Na^+ and Cl^- (12).

Fresh weight and dry weight

Seedling biomass was markedly affected by salinity (Table 3). In control plants, fresh weight varied from 208-315 mg seedling^{-1} and dry weight from 17.8-31.5 mg seedling^{-1}, while at 250 mM NaCl reduced to 30-35 mg and 2.6-3.4 mg per seedling, respectively. Bhima Shakti and Bhima Shweta consistently retained greater biomass than Bhima Red and Bhima Kiran. The reduction in biomass corresponds to the inhibition of photosynthetic efficiency and metabolic activity caused by ionic imbalance and decreased turgor (17).Salinity induces oxidative damage and limits the synthesis of growth regulators and proteins essential for cell expansion (18). Comparable reductions in seedling weight were also observed in seedling, fresh and dry weights decreased by 60-80 % at 150 mM NaCl (13).

Survival percentage and mortality rate

Salinity also had a significant impact on seedling survival and mortality rate ($p < 0.05$) (Table 4). Survival percentage decreased from 86-91 % in control to 37-49 % at 250 mM, while mortality rose from 9-14 % to 51-63 %. Genotypic differences were clear, with Bhima Shakti showing 49 % survival compared to only 37 % in Bhima Kiran at the highest salinity. Similar seedling mortality patterns were reported by earlier researchers, who attributed the death of young onion seedlings to salt injury at the cotyledon–soil contact region and leaching of accumulated salts into the root zone after irrigation or rainfall (12).

Mortality at high salinity is primarily due to membrane destabilisation and excessive influx of Na^+ and Cl^- that disturb cytoplasmic enzyme systems (12, 18). As Na^+ replaces essential cations such as K^+ and Ca^{2+} on membrane binding sites, the permeability and integrity of the plasma membrane are impaired, leading to ion leakage and metabolic failure (14). The tolerant cultivars evidently possess stronger membrane stability and selective ion transport mechanisms that mitigate cytotoxic effects (13).

Seed vigour indices

Table 2. Effect of different salinity levels on shoot and root length of onion cultivars at the germination stage

	Cultivars							
	Shoot length (cm)				Root length (cm)			
Salinity treatments	Bhima Shweta	Bhima Red	Bhima Shakti	Bhima Kiran	Bhima Shweta	Bhima Red	Bhima Shakti	Bhima Kiran
Control	9.57	8.30	8.90	7.00	4.80	4.20	5.00	4.33
50 mM	10.37	9.50	9.80	7.90	5.27	4.80	5.37	4.50
100 mM	8.33	6.80	7.80	4.97	4.07	3.40	3.53	2.03
150 mM	6.90	4.03	5.73	3.50	3.20	1.93	2.73	3.20
200 mM	5.10	2.47	4.07	2.33	2.20	1.27	1.83	2.27
250 mM	3.87	0.93	2.43	0.80	1.67	0.33	0.47	0.53
Factors	SEM (±)		C.D. (5 %)		SEM (±)		C.D. (5 %)	
Treatments	0.06		0.18		0.06		0.17	
Cultivars	0.05		0.15		0.05		0.14	
Treatments × cultivars	0.12		0.35		0.18		0.33	

Table 3. Effect of different salinity levels on fresh and dry weight (mg) of onion cultivars at the germination stage

	Cultivars							
	Fresh weight (mg)				Dry weight (mg)			
Salinity treatments	Bhima Shweta	Bhima Red	Bhima Shakti	Bhima Kiran	Bhima Shweta	Bhima Red	Bhima Shakti	Bhima Kiran
Control	280.0	208.3	243.0	222.7	23.3	20.8	24.3	17.8
50 mM	298.7	264.7	315.3	285.7	24.9	26.5	31.5	22.9
100 mM	144.0	158.7	197.7	150.7	12.0	15.9	19.8	12.1
150 mM	95.3	100.3	130.7	113.0	7.9	10.0	13.1	9.0
200 mM	66.0	66.7	67.0	72.0	5.5	6.7	6.7	5.8
250 mM	35.3	30.3	33.7	32.7	2.9	3.0	3.4	2.6
Factors	SEM (±)		C.D. (5 %)		SEM (±)		C.D. (5 %)	
Treatments	1.20		3.42		0.11		0.32	
Cultivars	0.98		2.80		0.09		0.26	
Treatments × cultivars	2.41		6.85		0.22		0.63	

Table 4. Effect of different salinity levels on survival percentage and mortality rate (%) of onion cultivars at the germination stage

	Cultivars							
	Survival percentage (%)				Mortality rate (%)			
Salinity treatments	Bhima Shweta	Bhima Red	Bhima Shakti	Bhima Kiran	Bhima Shweta	Bhima Red	Bhima Shakti	Bhima Kiran
Control	90	87	91	86	10	13	9	14
50 mM	94	93	94	93	6	7	6	7
100 mM	82	79	85	79	18	21	15	21
150 mM	72	61	75	62	28	39	25	38
200 mM	58	46	60	45	42	54	40	55
250 mM	47	38	49	37	53	62	51	63
Factors	SEM(±)		C.D. (5 %)		SEM (±)		C.D. (5 %)	
Treatments	0.38		1.08		0.38		1.08	
Cultivars	0.31		0.88		0.31		0.88	
Treatments × cultivars	0.76		2.16		0.76		2.16	

Both seed vigour index-I (based on seedling length) and index-II (based on seedling dry weight) followed the decreasing trend of other growth parameters (Table 5). At 50 mM, slight increases in SVI-I and SVI-II (1470-2451) over the control (1289-2212) were recorded, suggesting a mild stimulatory effect of moderate osmotic stress. However, beyond 100 mM, both indices declined sharply, reaching minimum values (48-262 for SVI-I and 98-166 for SVI-II) at 250 mM. Bhima Shakti again exhibited higher vigour than the other cultivars, implying superior ability to maintain metabolic activity under saline conditions, which could be attributed to better osmoregulation through higher osmolyte accumulation or enhanced antioxidant enzyme activity to scavenge reactive oxygen species.

A strong correlation between seed vigour and ion homeostasis has been reported in onion and other vegetable crops (19). Vigorous seeds can better regulate Na^+ exclusion and K^+/Ca^{2+} uptake, ensuring efficient osmotic adjustment (20). The decline in vigour at high salinity is attributed to reduced mobilisation of reserve carbohydrates and proteins due to ionic toxicity (21).

Conclusion

Salinity stress significantly affects onion seed germination and early growth. When salt levels exceed 50 mM, there is a clear decline in germination, seedling length, weight and vigour, accompanied by higher seedling death. This reduction in growth occurs because high salinity causes osmotic stress, leading to reduced water uptake, cellular damage and interference with the mobilisation of stored food reserves. Among the four types tested, Bhima Shakti was the most tolerant, Bhima Shweta had medium tolerance and Bhima Red and Bhima Kiran were more sensitive. A slight improvement in growth at 50 mM indicates that low salinity may help exert a mild osmotic priming effect. Therefore, selecting and promoting salt-tolerant onion varieties can help farmers sustain onion cultivation in regions where soil and water salinity are increasing.

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Authors' contributions

MBP led the conceptualisation of the study and contributed extensively to data curation, formal analysis, investigation and methodology development. He conducted the statistical analysis and prepared the original manuscript draft, followed by substantial involvement in the review and editing process. ARP supported data curation, formal analysis and investigation, contributed to the methodological framework and participated in drafting the original manuscript. SSP and AT were responsible for data curation, formal analysis and investigation, contributed to methodology and statistical analysis and assisted in manuscript review and editing. TRP, PAM and KAG participated in formal analysis and investigation and contributed to the review and editing of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Table 5. Effect of different salinity levels on seed vigour index-I and seed vigour index-II of onion cultivars at germination stage

	Cultivars							
	Seed vigour index-I				Seed vigour index-II			
Salinity treatments	Bhima Shweta	Bhima Red	Bhima Shakti	Bhima Kiran	Bhima Shweta	Bhima Red	Bhima Shakti	Bhima Kiran
Control	1289	1088	1265	975	2092	1812	2212	1532
50 mM	1470	1324	1426	1149	2340	2451	2964	2118
100 mM	1017	810	964	553	984	1259	1680	952
150 mM	727	364	635	416	572	612	980	561
200 mM	426	172	354	207	321	307	402	259
250 mM	262	48	143	50	140	115	166	98
Factors	SEM (±)		C.D. (5 %)		SEM (±)		C.D. (5 %)	
Treatments	10.21		29.03		10.38		29.51	
Cultivars	8.33		23.70		8.47		24.09	
Treatments × cultivars	28.88		20.42		20.75		59.02	

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During the preparation of this work, the authors used CHATGPT to improve the readability and language of the work. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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