



Research article

Mitigating Salinity Stress in Groundnut (*Arachis hypogaea* L.) Through Salicylic Acid Application

*Olayinka, B. U.,¹ Abdulbaki A. S^{2,3}, Mahmud, H.U⁴,
Muhammed, G.Y.³, Akinyemi, O.C³ and Ayuba, A.K⁵

¹Department of Plant Biology, Faculty of Life Sciences, University of Ilorin, Ilorin, Nigeria

²Department of Plant Science and Biotechnology, Faculty of Life Sciences, Federal University Dutsinma, Katsina State, Nigeria.

³Department of Biological Sciences, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia.

⁴Department of Agricultural Economics and Extension Services, Kwara State University, Malete

⁵Department of Biochemistry, Faculty of Life Sciences, University of Ilorin, Ilorin, Nigeria

*Correspondence author: abdulbakias@gmail.com

Submission: 03/04/2025

Accepted: 18/08/2025

Abstract

Soil salinity is a major abiotic stress factor that adversely affects the growth, yield, and quality of many crops, including *Arachis hypogaea* (groundnut). This study investigated the potential of salicylic acid (SA) in mitigating the negative effects of salinity stress in groundnut. A germination experiment was conducted on two groundnut varieties, SAMNUT-11 and SAMNUT-14, which were exposed to varying concentrations of sodium chloride (NaCl) solutions (0, 50, 100, 150, and 200 mM), with or without SA treatment. The experiment followed a completely randomized design with ten treatment combinations and three replications. The effects of SA were evaluated on morphological parameters such as germination percentage, fresh weight, and plumule length, alongside key biochemical indicators of oxidative stress, including reactive oxygen species (ROS), malondialdehyde (MDA), and reduced glutathione (GSH). Results showed that SA significantly enhanced seed germination and seedling growth under saline conditions, particularly at moderate salt concentrations (≤ 100 mM). In addition, SA application effectively reduced ROS and MDA levels while increasing GSH content, indicating its protective role against oxidative damage. Among the two varieties tested, SAMNUT-14 exhibited greater salt tolerance, demonstrated by superior morphological performance and more favourable biochemical responses compared to SAMNUT-11. These findings suggest that exogenous SA application can improve salt tolerance in groundnut by modulating oxidative stress responses, offering a promising approach for enhancing crop productivity in saline soils. Further research is warranted to elucidate the underlying physiological and molecular mechanisms of SA-mediated stress mitigation and to optimize its field application.

Keywords: Salicylic acid; salinity stress; *Arachis hypogaea*; salt tolerance; SAMNUT.

INTRODUCTION

Groundnut/Peanut (*Arachis hypogaea*) is an important legume that is valued worldwide for its edible seed which serve as a source of protein and healthy fat (Bertioli et al., 2011). Globally, the production of groundnut is up to 54 million tonnes in 2020 (FAOSTAT, 2020). Seed germination is often used as an indicator of environmental suitability. However, the environmental stresses a plant faces may not always support the expected growth. A notable abiotic stress that affects the stable growth and production of groundnut is salinity. The adverse

effect of salinity on groundnut is felt throughout its life cycle right from germination till yielding (Mensah et al., 2006; Nithila et al., 2013). The development of methods and strategies to ameliorate deleterious effects of salt stress on plants has received considerable attention. Salinity stress is a leading environmental challenge that affects the growth and yield of many major crops. The reduction in yield caused by the menace of salinity stress ranges from 50-80 % (Panta et al., 2014). The stress tends to reduce the capacity of agriculture to sustain the burgeoning human population (Flowers, 2004).

Through osmotic stress (leading to reduced water uptake) and ionic imbalance, salinity decreases seed germination rate and percentage (Munns, 2002; Uçarlı, 2021). Other major developmental processes such as photosynthesis, protein synthesis and energy and lipid metabolism are also affected during the onset of salt stress within a plant (Parida & Das, 2005). Like other abiotic stresses, the salinity usually leads to excessive production of reactive oxygen species (ROS). The oxidative damage is controlled by the plant through enzymatic and non-enzymatic oxidants (Hasanuzzaman et al., 2021).

Salicylic acid (SA) has been shown as an important signalling molecule for modulating plant responses to environmental stress (Kaur et al., 2022). SA occurs in plants naturally and plays a significant role in regulating plant growth and development (Khodary, 2009). Seed pretreatment or imbibition with SA leads to an activation of germination and seedling growth (Shakirova et al., 2003; Singh & Chaturvedi, 2012). The present study therefore aims to determine the level of salt tolerance of local varieties of groundnut and further explore the role of SA in ameliorating the salinity stress. Despite the extensive studies on salinity stress in crops, there remains a significant research gap in understanding the varietal differences in salt tolerance among improved groundnut cultivars, especially under the influence of exogenous salicylic acid (SA) application. SAMNUT 11 and SAMNUT 14 were selected for this study due to their widespread cultivation in Nigeria and their contrasting responses to abiotic stress, making them ideal for evaluating salinity tolerance.

While SA has been implicated in enhancing plant resilience under abiotic stress, its specific effects on the germination and early seedling development of groundnut under saline conditions are not well elucidated. This study hypothesizes that pretreatment with salicylic acid can enhance the germination rate and seedling vigour of improved groundnut varieties under salt stress. This research aims to assess the salt tolerance of local groundnut varieties SAMNUT 11 and SAMNUT 14 during germination and early growth, and to evaluate salicylic acid's effectiveness in mitigating salinity stress on these varieties.

MATERIALS AND METHODS

The experiment was carried out in the plant physiology and biochemistry laboratory in the University of Ilorin, Ilorin, Nigeria in geographical coordinate of latitude 10°53'0"N and longitude 4°35'E of the equator from March 2019 to July 2019.

Plant materials

The seeds (SAMNUT 11 and SAMNUT 14) used for this experiment were obtained from Ahmadu Bello University, Zaria, Nigeria.

Experiment design

The germination study was conducted at room temperature in 9 cm Petri dishes under a randomized factorial design comprising two groundnut varieties (SAMNUT 11 and SAMNUT 14) $\times$ five salinity levels (0, 50, 100, 150, 200 mM NaCl) $\times$ two SA treatments (with or without 1 mM SA), yielding a total of $2 \times 5 \times 2 = 20$ treatment combinations. With three replicates per treatment, this resulted in a total of 60 Petri dishes. Each dish received 10 surface-sterilized seeds evenly placed on moistened filter paper. Treatments included distilled water only (control), NaCl alone, SA alone, or NaCl + SA in the defined combinations. On day 1, SA solution was applied; thereafter NaCl or water (10 mL initially, later reduced to 5 mL by day 6) was added as needed to maintain moisture without waterlogging.

Germination was monitored daily for 10 days, and the number of germinated seeds was recorded every 24 hours. On day 10, seedlings were harvested. Radicle and plumule lengths were measured using a ruler by gently straightening each root and shoot and measuring from seed to tip.

Seedling fresh weight was recorded immediately, then samples were oven-dried to constant weight to obtain dry weight. For biochemical analyses, stems and shoots were cut, ground at low temperature using mortar and pestle, homogenized in 0.1 M potassium phosphate buffer (pH 7.4), aliquoted into 5 mL tubes, and stored at -80°C until assayed

Data Collection

The vegetative data taken include:

- i. number of germinating seeds
- ii. seedling length (radicle and plumule length)

$$\text{iii. Germination Percentage (GP)} = \frac{\text{Number of germinated seeds}}{\text{Number of plated seeds}} \times 100\%$$

$$\text{iv. Seed vigor index (SVI)} = \text{Germination Percentage} \times \text{seedling length}$$

$$\text{v. Germination index (GI)} = \frac{n}{d}$$

Where n = number of germinated seeds and d = number of days.

Biochemical analysis

Determination of reduced glutathione (GSH) concentration

GSH was calculated following the steps used by Ellman (1959)

Determination of superoxide anion (O_2^-) and Hydrogen peroxide (H_2O_2) concentrations

The concentration of O_2^- and H_2O_2 was estimated as described by Ajiboye *et al.*, (2016) and Velikova *et al.* (2000) respectively.

Malonaldehyde (MDA) concentration

The concentration of MDA was determined by the procedures of Reilly and Aust (1999).

Statistical analysis

Collected data were analysed statistically by using IBM SPSS Statistics 20 for the one-way analysis of variance (ANOVA) and the means compared by Duncan's multiple range test ($p < 0.05$).

RESULTS

Germination Percentage (GP), Germination Index (GI), Seed Vigour Index (SVI)

The values of GP vary across treatments, ranging from 53.33% to 100% (Table 1). Between the varieties, SAMNUT 14 had a better germination percentage since each of its treatments had a higher or at least similar percentage of germination when compared with its counterpart in SAMNUT 11. In SAMNUT 11, the application

of SA improved the germination percentage considerably as the treatments with SA have relatively high germination percentages, indicating successful seed germination.

Aside from the treatment of 100 mM NaCl (where equal germination percentage was recorded for both the SA treated i.e. T₈ and untreated seeds i.e. T₃) the SA-treated plants had higher germination percentage in all the treatments and in the control. In SAMNUT 14, the values of germination percentage range from 80.00% to 100%, showing the variability in germination rates across different treatments. Regardless of the presence or absence of SA, treatments with salinity concentrations not exceeding 100 mM achieved 100% germination.

SVI was generally higher in SAMNUT 14 than in SAMNUT 11 except for 50 and 200 mM NaCl without SA (Table 1). Overall, the negative control in SAMNUT 14 has the highest SVI, indicating that seeds under that treatment have strong vigour. For SAMNUT 11, while the positive control i.e. distilled water without the addition of NaCl has the highest SVI, suggesting strong and healthy germination, the lowest seedling vigour index, indicating weak germination, was recorded for 150mM NaCl with SA treatment. As for SAMNUT 14, the values of SVI vary from 88.00 to 1145.33 with the negative control i.e. SA without NaCl having the highest. Comparing the varieties, SAMNUT 11 was only better off in the germination indices at the highest level of salinity concentration with SA i.e. 150 and 200 mM NaCl + SA and in the negative controls (Table 1). The treatment receiving 50 mM + SA has the overall highest GI values, suggesting that seeds under these treatments not only germinated well but also exhibited good germination quality.

Table 1: Impact of Salinity Stress and Salicylic Acid on Germination Percentage, Vigour Index, and Germination Index of Two Groundnut Varieties

Variety	Treatment	Germination (%)	Seed Vigour Index	Germination Index
SAMNUT 14	T ₁	80.00± 11.54 ^b	863.33± 267.22 ^{ab}	3.833± 0.44 ^a
	T ₂	86.67± 6.67 ^{ab}	726.67± 213.65 ^{bc}	4.167± 0.44 ^a
	T ₃	80.00± 20.00 ^b	396.67± 178.91 ^{cd}	3.111± 0.59 ^{ab}
	T ₄	53.33± 17.60 ^d	56.67± 23.73 ^d	1.694± 0.72 ^b
	T ₅	66.67± 24.03 ^c	142.67± 73.26 ^d	1.694± 0.76 ^b
	T ₆	93.33± 6.67 ^a	175.53± 101.64 ^a	4.500± 0.50 ^a
	T ₇	86.67± 6.67 ^{ab}	503.33± 128.17 ^{bcd}	4.000± 0.58 ^a

	T ₈	80.00± 11.54 ^b	356.67±43.33 ^{cd}	3.583± 0.74 ^a
	T ₉	93.33± 6.67 ^a	470.00±56.86 ^{bcd}	4.667± 0.33 ^a
	T ₁₀	93.33± 6.67 ^a	406.67±96.84 ^{cd}	4.167± 0.44 ^a
	Mean	81.33± 4.18	509.80±69.37	3.542± 0.24
	P-value	0.510	0.001	0.01
SAMNUT 14	T ₁	93.33 ± 6.67 ^{ab}	1082.67 ± 163.75 ^a	3.92 ± 0.53 ^{ab}
	T ₂	100 ± 0.00 ^a	486.67 ± 82.93 ^{bc}	4.33 ± 0.44 ^{ab}
	T ₃	100 ± 0.00 ^a	420.00 ± 115.47 ^{bc}	3.5 ± 0.48 ^{ab}
	T ₄	86. 67 ± 6.67 ^{ab}	188.67 ± 71.93 ^{bc}	2.78 ± 0.68 ^b
	T ₅	80. 00 ± 0.00 ^b	88.00 ± 40.27 ^c	2.65 ± 0.84 ^b
	T ₆	93.33 ± 6.67 ^{ab}	1145.33 ± 226.51 ^a	4.08 ± 0.68 ^{ab}
	T ₇	100 ± 0.00 ^a	1023.33 ± 172.95 ^a	4.72 ± 0.28 ^a
	T ₈	100 ± 0.00 ^a	556.67 ± 127.19 ^b	4.25 ± 0.14 ^{ab}
	T ₉	93.33 ± 6.67 ^{ab}	571.33 ± 19.88 ^b	3.89 ± 0.34 ^{ab}
	T ₁₀	80.00 ± 11.55 ^b	504.00 ± 105.00 ^b	3.39 ± 0.24 ^{ab}
	Mean	92.64 ± 1.50	606.66 ± 64.26	3.66 ± 0.15
	P-value	0.001	0.001	0.001

Table legend:

T1 — 0 mM NaCl, no SA (distilled water control).
T2 — 50 mM NaCl, no SA.
T3 — 100 mM NaCl, no SA.
T4 — 150 mM NaCl, no SA.
T5 — 200 mM NaCl, no SA.
T6 — 0 mM NaCl + 1 mM SA (SA only / negative control).
T7 — 50 mM NaCl + 1 mM SA.
T8 — 100 mM NaCl + 1 mM SA.
T9 — 150 mM NaCl + 1 mM SA.
T10 — 200 mM NaCl + 1 mM SA.

Relative to the control, it was observed that the GI of SAMNUT 11 greatly increased on application of SA (Table 2). The highest GI was achieved at 150mM NaCl with SA and the lowest was recorded when only 150mM NaCl was applied. The GI was at average on the application of

100mM NaCl. The GI in SAMNUT 14 was highest in the 50mM NaCl concentration and is followed in a decreasing order up until the 200mM NaCl concentration. Significant increase is shown with SA in the rate of the GI at all salt concentrations.

Fresh Weight (FW), Plumule Length (PL), Radicle Length (RL)

Between the two varieties, each of the SAMNUT 14 treatments was weightier than its corresponding counterpart in SAMNUT 11 in all of the treatments devoid of SA application (Table 2). In the SA treatments, SAMNUT 14 was better in the 50 and 200 mM + SA treatments. As for PL, SAMNUT 14 was better in all of the treatments except in the 100 mM NaCl without SA. As for RL, SAMNUT 11 was better in the SA-untreated plants except for when salt concentration was 100 and 150 mM. In the SA-treated plants, SAMNUT 14 had higher RL values except for when salt concentration was 0 and 100 mM (Table 2).

The values of FW and PL in SAMNUT 11 vary across treatments, ranging from 0.526 to 1.043

and 0.000 to 2.060 respectively. Aside the control, the treatment receiving 50 mM + SA has relatively highest FW and PL among the treatments. SAMNUT 11 RL values span a range from 0.967 to 10.66 with the control receiving just SA without salt having the longest **RL**, indicating stronger root development. SAMNUT 14 followed a similar trend with SAMNUT 11 for FW and PL with the 50 mM + SA recording the highest values for both parameters among the treatments. The FW and PL values of SAMNUT 14 range from and respectively 0.57 to 1.31 and 0.00 to 4.00 respectively. The RL value of SAMNUT 14 ranging from 1.10 to 9.60 was highest in the control receiving just SA without salt and followed by the 50 mM + SA treatment.

Table 2: Growth Response of Groudnut Seedlings to Salinity Stress and Salicylic Acid: Biomass and Organ Length

Variety	Treatment	FW	PL	RL
SAMNUT 11	T1	1.02± 0.42ab	2.000±0.28a	8.333±2.52ab
	T2	0.933±0.11ab	1.000±0.57ab	7.166±1.36abc
	T3	0.853±0.13ab	1.167±0.60ab	3.040±1.00de
	T4	0.710±0.06ab	0.000±0.00b	0.967±0.15e
	T5	0.526±0.13b	0.000±0.00b	1.667±0.66de
	T6	1.013±0.09a	2.060±0.52a	10.66±1.59a
	T7	1.043±0.14ab	1.500±0.76a	4.160±0.44cde
	T8	0.927±0.11ab	0.000±0.00b	4.500±0.29cde
	T9	0.923±0.12ab	0.000±0.00b	5.000±0.29bcd
	T10	0.917±0.06ab	0.000±0.00b	4.330±0.88cde
	Mean	0.827±0.52	0.773±0.18	4.980±0.61
	P-value	0.003	0.002	<0.001
SAMNUT 14	T1	1.31 ± 0.15a	4.00 ± 0.96a	7.60 ± 0.51ab
	T2	1.17 ± 0.14ab	1.90 ± 0.55bcd	2.97 ± 0.29cd
	T3	1.04 ± 0.24ab	0.57 ± 0.57cde	3.63 ± 0.72cd
	T4	0.82 ± 0.29ab	0.40 ± 0.40de	1.83 ± 0.55d
	T5	0.66 ± 0.06b	0.00 ± 0.00e	1.10 ± 0.50d
	T6	0.95 ± 0.26ab	2.43 ± 0.12b	9.60 ± 1.76a
	T7	1.04 ± 0.21ab	2.23 ± 0.15bc	8.00 ± 1.68ab
	T8	0.57 ± 0.05b	1.53 ± 0.38bcde	4.03 ± 0.90cd
	T9	0.89 ± 0.19ab	1.10 ± 0.36bcde	5.07 ± 0.67bc
	T10	1.18 ± 0.13ab	2.07 ± 0.77bcd	4.13 ± 0.88cd
	Mean	0.96 ± 0.05	1.62 ± 0.21	4.79 ± 0.05
	P-value	0.004	0.0001	0.0001

O₂⁻, H₂O₂, MDA, GSH

Taking the two varieties together, SAMNUT 11 in the absence of SA had more O₂ concentration than SAMNUT 14 when each corresponding treatment were compared except when the salt concentration was 0 and 100 mM (Table 3). Upon the application of SA, SAMNUT 14 had more concentration of O₂⁻ except when the salt concentration was 100 and 200 mM. Using the same comparison, SAMNUT 11 in each of its treatments produced more H₂O₂ than its corresponding treatment in SAMNUT 14. A similar trend was recorded in both MDA and GSH concentrations. However, for the MDA concentration, SAMNUT 14 had a higher concentration at 150 mM NaCl without SA, 0 mM NaCl + SA and 150 mM NaCl + SA treatments. In the GSH concentration, it had higher

concentrations at 100 and 150 mM without SA and 150 mM NaCl + SA (Table 3).

In SAMNUT 11, treatment receiving 150 mM NaCl without SA and treatment receiving 200 mM + SA have the highest values of O₂⁻. This implies that under high salt concentration, the O₂⁻ increases. As for H₂O₂ and MDA, the highest values were achieved in the absence of SA application when salt concentration did not exceed 50 and 100 mM respectively. 100 mM NaCl without SA also has the highest GSH concentration. In SAMNUT 14, the treatment of 150 mM + SA was highest in O₂⁻ and H₂O₂. For the concentrations of MDA and GSH, treatments 50 mM NaCl + SA and 100 mM without SA recorded the highest values respectively.

Table 3: Biochemical Response of Groundnut to Salinity and Salicylic Acid: Reactive Oxygen Species and Antioxidants

Variety	Treatment	O ₂	H ₂ O ₂	MDA	GSH
SAMNUT 11	T ₁	1.55 ^c	16.88 ^a	2.56 ^b	4.49 ^{abcd}
	T ₂	2.25 ^c	16.88 ^a	6.20 ^b	2.38 ^e
	T ₃	2.90 ^c	13.93 ^{cd}	4.49 ^b	6.07 ^a
	T ₄	8.97 ^a	13.29 ^d	1.22 ^b	2.82 ^{de}
	T ₅	7.31 ^{ab}	15.29 ^d	1.78 ^{ab}	4.36 ^{abcd}
	T ₆	3.94 ^{bc}	16.37 ^{ab}	1.14 ^a	4.74 ^{abc}
	T ₇	2.32 ^c	15.47 ^{ab}	4.59 ^{ab}	3.22 ^{cde}
	T ₈	4.59 ^{bc}	15.85 ^{ab}	3.85 ^b	3.74 ^{bcde}
	T ₉	1.71 ^c	15.21 ^{bc}	3.85 ^b	5.18 ^{ab}
	T ₁₀	8.97 ^a	13.68 ^{bc}	4.27 ^b	5.10 ^{ab}
	Mean	4.45	15.28	7.13	4.21
	P-value	< 0.001	<0.001	0.05	< 0.01
SAMNUT 14	T ₁	1.61 ^d	1.32 ^a	1.16 ^{cd}	1.29 ^d
	T ₂	1.53 ^a	1.18 ^a	1.01 ^{ab}	2.24 ^{ab}
	T ₃	4.02 ^d	1.08 ^a	1.29 ^{cd}	9.19 ^d
	T ₄	7.61 ^b	1.18 ^a	5.77 ^b	5.62 ^{cd}
	T ₅	1.53 ^d	9.80 ^a	1.42 ^{cd}	1.19 ^{bcd}
	T ₆	5.55 ^c	1.11 ^a	5.88 ^c	3.87 ^{bc}
	T ₇	6.59 ^{bc}	1.11 ^a	8.12 ^{cd}	2.12 ^{cd}
	T ₈	1.08 ^d	1.15 ^a	1.25 ^{cd}	2.12 ^d
	T ₉	9.80 ^d	1.42 ^a	1.52 ^d	5.62 ^d
	T ₁₀	5.99 ^{bc}	1.25 ^a	1.75 ^a	2.46 ^a
	Mean	4.53 ± 0.53	2.06 ± 0.48	2.91 ± 0.46	3.57 ± 0.44
	P-value	0.0001	0.0001	0.0001	0.0001

DISCUSSION

Effect of salinity and SA on the germination and morphological attributes of groundnut.

Salinity generally suppressed GP and GI in SAMNUT 11 from when the concentration was 100 mM NaCl. This reduction was much earlier with regards to SVI as it was noticed at lower salt concentration of 50 mM NaCl. SA was effective in combatting these reductions in germination percentage, GI and SVI when the salt concentration was at or higher than 100 mM NaCl. The germination percentage, GI and SVI started to drop and continued further in SAMNUT 14 at NaCl concentration of 150 mM, 100 mM and 50 mM respectively. SA was not only able to combat this drop in values, but it also improved it in all the treatments for GI and SVI and when the concentration of salt was 150 mM for the germination percentage.

Right from 50 mM NaCl, both varieties of groundnut had considerable reductions in fresh weight and lengths of radicle and plumule. For SAMNUT 11, when each plant treated with SA is

compared with its untreated counterpart, an increase can be noticed in the radicle length in all the treatments except at 50 mM NaCl. An increase in plumule length due to SA despite salt stress was however noticed at only 50 mM NaCl. The SA-treated plants equally had slightly higher fresh weights. This positive effect of SA was more felt in SAMNUT 14 as the SA treated plants were weightier at 150 and 200 mM NaCl and also had longer radicles and plumules in all the treatments. In mechanistic terms, SA activates defensive pathways (boosting antioxidants, osmolyte synthesis and photosynthesis) that can counteract osmotic and ionic stress during salinity.

In agreement with the present research, salinity, especially when high, has been shown to reduce germination percentage (Redondo-Gómez et al., 2008), germination index (Cokkizgin, 2012), SVI (Ferraz et al., 2016), FW, radicle and plumule lengths (Bybordi & Tabatabaei, 2009). It has been established by research that the role of SA in germination during salinity stress is dose-

dependent (Lee et al., 2010). Thus, the ability of SA to improve the germination parameters may be attributed to the usage of adequate dosage of SA. The effectiveness of SA in overturning salinity-induced drop in FW in tomato (Souri & Tohidloo, 2019), SVI in maize (Kumari et al., 2017) GI, PL and RL in *Vicia faba* (Anaya et al., 2018) has also been recorded.

Effect of salinity and SA on the biochemical attributes of groundnut.

From 50 mM NaCl, concentrations of O_2^- , H_2O_2 , and MDA increased progressively in SAMNUT 11. SA did not significantly overturn this increase. GSH concentration dropped significantly at 50 mM NaCl and remained rather constant at higher salt concentration. The GSH concentration was, nevertheless, increased by SA at 150 mM and 200 mM NaCl. As for SAMNUT 14, while the H_2O_2 remained quite constant throughout the treatments and controls, the GSH (especially at 100 mM NaCl) increased all through the treatments and the O_2^- and MDA increased onwards from 100 mM NaCl and in the SA treatments. SA, however, reduced the O_2^- concentration significantly at 100 mM NaCl.

The current investigation aligns with the fact that ROS (O_2^- and H_2O_2) production is usually on the increase in response to salinity stress (Hasanuzzaman et al., 2021; Tomar et al., 2021). Also, MDA, which is a manifestation of lipid peroxidation, increased due to salinity as observed in rice (Mostofa et al., 2015). Specifically, as seen in SAMNUT 14, the result of this study agreed with the finding of Mostofa et al. (2015) where despite the significant increase in GSH as a result of salinity, it could not curtail

the excessive production of ROS. This could mean that the enzymatic antioxidants are much needed in scavenging the ROS in the groundnut varieties. The ability of SA to raise the concentration of the GSH as found in SAMNUT 11 at high salt concentration is corroborated by a previous study (Li et al., 2013). Especially SA was able Unlike SA in this study, SA in maize other priming agents like KNO_3 in rice proved effective in attenuating excessive ROS production (Olayinka et al., 2022; Tahjib-Ul-Arif et al., 2019).

Conclusion

The current investigation demonstrated that the germination of groundnut seedlings was significantly affected under high saline conditions. Groundnut seeds were able to tolerate salinity stress at low concentrations (<100 mM). The addition of salicylic acid was found to be effective in promoting better seed establishment, especially in saline conditions below 100 mM. Furthermore, the study revealed that the accumulation of hydrogen peroxide indicated the presence of oxidative stress under high salinity. The application of salicylic acid (SA) resulted in significant improvements in key germination traits and biochemical responses under salinity stress. These findings support the potential of SA as a seed priming agent to enhance groundnut performance in saline conditions. This research suggests the need for further studies on groundnut plants under a wider range of field and laboratory conditions to assess the potential of salicylic acid in improving the growth of groundnuts under saline and other restrictive conditions.

REFERENCES

- Ajiboye, T. O., Naibi, A. M., Abdulazeez, I. O., Alege, I. O., Mohammed, A. O., Bello, S. A., Yusuf, I. I., Ibitoye, O. B., and Muritala, H. F. (2016). Involvement of oxidative stress in bactericidal activity of 2-(2-nitrovinyl) furan against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. *Microbial Pathogenesis*, 91, 107–114. <https://doi.org/10.1016/j.micpath.2015.11.020>
- Anaya, F., Fghire, R., Wahbi, S., and Loutfi, K. (2018). Influence of salicylic acid on seed germination of *Vicia faba* L. under salt stress. *Journal of the Saudi Society of Agricultural Sciences*, 17(1), 1–8. <https://doi.org/10.1016/j.jssas.2015.10.002>
- Bertioli, D. J., Seijo, G., Freitas, F. O., Valls, J. F. M., Leal-Bertioli, S. C. M., and Moretzsohn, M. C. (2011). An overview of peanut and its wild relatives. *Plant Genetic Resources: Characterisation and Utilisation*, 9(1), 134–149. <https://doi.org/10.1017/S1479262110000444>

- Bybordi, A., and Tabatabaei, J. (2009). Effect of salinity stress on germination and seedling properties in canola cultivars (*Brassica napus* L.). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 37(2), 71–76. <https://www.notulaebotanicae.ro/corten-garden.com/index.php/nbha/article/view/3299>
- Cokkizgin, A. (2012). Salinity stress in common bean (*Phaseolus vulgaris* L.) seed germination. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 40(1), 177–182. <https://doi.org/10.15835/nbha4017493>
- Ellman, G. L. (1959). Tissue sulfhydryl groups. *Archives of Biochemistry and Biophysics*, 82(1), 70–77. [https://doi.org/10.1016/0003-9861\(59\)90090-6](https://doi.org/10.1016/0003-9861(59)90090-6)
- FAOSTAT. (2020). <https://www.fao.org/faostat/en/#data/QCL>
- Ferraz, M. V., Franco, C. F., Batista, G. S., and Pivetta, K. F. L. (2016). Salinity on the germination of seed and index of germination speed of three ornamental species. *Ornamental Horticulture*, 22(2), 196–201. <https://doi.org/10.14295/oh.v22i2.919>
- Flowers, T. J. (2004). Improving crop salt tolerance. *Journal of Experimental Botany*, 55(396), 307–319. <https://doi.org/10.1093/jxb/erh003>
- Hasanuzzaman, M., Raihan, M. R. H., Masud, A. A. C., Rahman, K., Nowroz, F., Rahman, M., Nahar, K., and Fujita, M. (2021). Regulation of reactive oxygen species and antioxidant defense in plants under salinity. *International Journal of Molecular Sciences*, 22(17). <https://doi.org/10.3390/ijms22179326>
- Kaur, G., Tak, Y., and Asthir, B. (2022). Salicylic acid: a key signal molecule ameliorating plant stresses. *Cereal Research Communications*, 50(4), 617–626. <https://doi.org/10.1007/s42976-021-00236-z>
- Khodary, S. E. . (2009). Effect of Salicylic Acid on the Growth and Mineral nutrition in Salt Stressed Wheat Plants. *International Journal of Agriculture and Biology*, 19(1), 177–180. <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=7841ae6488ae777eb390b04bae635cb3ccc8029b>
- Kumari, N., Rai, P. K., Bara, B. M., Singh, I., and Rai, K. (2017). Effect of halo priming and hormonal priming on seed germination and seedling vigour in maize (*Zea mays* L.) seeds. *Journal of Pharmacognosy and Phytochemistry*, 6(4), 27–30. <https://www.phytojournal.com/archives/2017.v6.i4.1322/effect-of-halo-priming-and-hormonal-priming-on-seed-germination-and-seedling-vigour-in-maize-zea-mays-l-seeds>
- Lee, S., Kim, S. G., and Park, C. M. (2010). Salicylic acid promotes seed germination under high salinity by modulating antioxidant activity in *Arabidopsis*. *New Phytologist*, 188(2), 626–637. <https://doi.org/10.1111/j.1469-8137.2010.03378.x>
- Li, G., Peng, X., Wei, L., and Kang, G. (2013). Salicylic acid increases the contents of glutathione and ascorbate and temporally regulates the related gene expression in salt-stressed wheat seedlings. *Gene*, 529(2), 321–325. <https://doi.org/10.1016/j.gene.2013.07.093>
- Mensah, J. K., Akomeah, P. A., Ikhajiagbe, B., and Ekpekurede, E. O. (2006). Effects of salinity on germination, growth and yield of five groundnut genotypes. *African Journal of Biotechnology*, 5(20), 1973–1979. <https://www.ajol.info/index.php/ajb/article/view/55923>
- Mostofa, M. G., Hossain, M. A., and Fujita, M. (2015). Trehalose pretreatment induces salt tolerance in rice (*Oryza sativa* L.) seedlings: oxidative damage and co-induction of antioxidant defense and glyoxalase systems. *Protoplasma*, 252(2), 461–475. <https://doi.org/10.1007/s00709-014-0691-3>
- Munns, R. (2002). Comparative physiology of salt and water stress. *Plant, Cell and Environment*, 25(2), 239–250. <https://doi.org/10.1046/j.0016-8025.2001.00808.x>
- Nithila, S., D, D. D., Velu, G., Amutha, R., and Rangaraju, G. (2013). Physiological Evaluation of Groundnut (*Arachis hypogaea* L.) Varieties for Salt Tolerance and Amelioration for Salt Stress. *Research*

- Journal of Agriculture and Forestry Sciences*, 1(11), 1–8. http://www.isca.me/AGRI_FORESTRY/Archive/v1/i11/1.ISCA-RJAFS-2013-035.pdf
- Olayinka, B. U., Abdulkareem, K. A., Abdalbaki, A. S., Alsamadany, H., Alzahrani, Y., Isiaka, K., Ayinla, A., Kolawole, O. S., Idowu, A. O., Odudu, F. U., Ibuowo, M. B., Mustapha, O. T., and Sulyman, A. (2022). EFFECTS OF PRIMING ON GERMINATION AND BIOCHEMICAL ATTRIBUTES OF THREE MAIZE LINES UNDER NaCl STRESS CONDITION. *Bioagro*, 34(3), 233–244. <https://doi.org/10.51372/bioagro343.3>
- Panta, S., Flowers, T., Lane, P., Doyle, R., Haros, G., and Shabala, S. (2014). Halophyte agriculture: Success stories. *Environmental and Experimental Botany*, 107, 71–83. <https://doi.org/10.1016/j.envexpbot.2014.05.006>
- Parida, A. K., and Das, A. B. (2005). Salt tolerance and salinity effects on plants: A review. *Ecotoxicology and Environmental Safety*, 60(3), 324–349. <https://doi.org/10.1016/j.ecoenv.2004.06.010>
- Redondo-Gómez, S., Naranjo, E. M., Garzón, O., Castillo, J. M., Luque, T., and Figueroa, M. E. (2008). Effects of salinity on germination and seedling establishment of endangered *Limonium emarginatum* (Willd.) O. Kuntze. *Journal of Coastal Research*, 24(1 SUPPL. A), 201–205. <https://doi.org/10.2112/05-0617.1>
- Reilly, C. A., and Aust, S. D. (1999). Measurement of Lipid Peroxidation. *Current Protocols in Toxicology*, 00(1). <https://doi.org/10.1002/0471140856.tx0204s00>
- Shakirova, F. M., Sakhabutdinova, A. R., Bezrukova, M. V., Fatkhutdinova, R. A., and Fatkhutdinova, D. R. (2003). Changes in the hormonal status of wheat seedlings induced by salicylic acid and salinity. *Plant Science*, 164(3), 317–322. [https://doi.org/10.1016/S0168-9452\(02\)00415-6](https://doi.org/10.1016/S0168-9452(02)00415-6)
- Singh, P. K., and Chaturvedi, V. K. (2012). Effects of salicylic acid on seedling growth and nitrogen use efficiency in cucumber (*Cucumis sativus* L.). *Plant Biosystems*, 146(2), 302–308. <https://doi.org/10.1080/11263504.2011.602991>
- Souri, M. K., and Tohidloo, G. (2019). Effectiveness of different methods of salicylic acid application on growth characteristics of tomato seedlings under salinity. *Chemical and Biological Technologies in Agriculture*, 6(1). <https://doi.org/10.1186/s40538-019-0169-9>
- Tahjib-Ul-Arif, M., Afrin, S., Polash, M. A. S., Akter, T., Ray, S. R., Hossain, M. T., and Hossain, M. A. (2019). Role of exogenous signaling molecules in alleviating salt-induced oxidative stress in rice (*Oryza sativa* L.): a comparative study. *Acta Physiologiae Plantarum*, 41(5). <https://doi.org/10.1007/S11738-019-2861-6>
- Tomar, R. S., Kataria, S., and Jajoo, A. (2021). Behind the scene: Critical role of reactive oxygen species and reactive nitrogen species in salt stress tolerance. *Journal of Agronomy and Crop Science*, 207(4), 577–588. <https://doi.org/10.1111/jac.12490>
- Uçarlı, C. (2021). Effects of Salinity on Seed Germination and Early Seedling Stage. *Abiotic Stress in Plants*. <https://doi.org/10.5772/intechopen.93647>
- Velikova, V., Yordanov, I., and Edreva, A. (2000). Oxidative stress and some antioxidant systems in acid rain-treated bean plants protective role of exogenous polyamines. *Plant Science*, 151(1), 59–66. [https://doi.org/10.1016/S0168-9452\(99\)00197-1](https://doi.org/10.1016/S0168-9452(99)00197-1)