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Growth, yield, and salt tolerance of tomato genotypes as influenced by plant growth regulators under saline-sodic soil conditions

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Salinity and sodicity are major constraints limiting tomato production in irrigated semi-arid regions of Nigeria. A field experiment was conducted during the 2020 and 2021 dry seasons at the Kano River Irrigation Scheme to evaluate the response of tomato genotypes to selected plant growth regulators under saline-sodic soil conditions. The treatments consisted of four tomato genotypes (F1 Anaya, F1 Mona, F1 Thorgal, and Roma VF) and four plant growth regulator treatments (control, potassium silicate at 16 g L^{-1}, salicylic acid at 130 mg L^{-1}, and tamarind extract at 8%) arranged in a split plot design with eight replications. Plant growth regulators were assigned to the main plots, while genotypes were allocated to the subplots. Data were collected on growth and yield parameters and subjected to analysis of variance using GenStat and SAS statistical packages. The results revealed significant varietal differences in plant height, leaf area, marketable fruits, and fruit yield during both seasons. Salicylic acid significantly improved fruit yield, producing the highest yields of 5 057 and 14 607 kg ha^{-1} during the 2020 and 2021 seasons, respectively. Among the genotypes, F1 Mona and F1 Thorgal exhibited superior growth and yield performance under saline-sodic conditions. Significant interaction effects were observed between plant growth regulators and genotypes for marketable fruits, non-marketable fruits, and fruit yield. F1 Thorgal combined with salicylic acid produced the highest fruit yield (17 542 kg ha^{-1}) during the 2021 season. The study concluded that salicylic acid in combination with F1 Mona and F1 Thorgal can effectively enhance tomato productivity under saline-sodic conditions in the Sudan Savanna of Nigeria.

Keywords: abiotic stress tolerance; phytohormones; foliar application; saline-sodic soils; osmotic adjustment; irrigated agriculture

INTRODUCTION

Tomato (Solanum lycopersicum L.) is one of the most economically important vegetable crops globally due to its nutritional, industrial, and medicinal value. It constitutes a major source of vitamins, minerals, antioxidants, and bioactive compounds essential for human health and food security (Kussmann, 2022; Kussmann et al., 2023). In Nigeria and many semi-arid regions of sub-Saharan Africa, tomato production contributes significantly to household income, employment generation, and rural livelihoods. However, sustainable tomato production is increasingly threatened by soil salinity and sodicity, particularly in irrigated agroecosystems where poor-quality irrigation water, inadequate drainage, and continuous cultivation accelerate salt accumulation in the root zone. (Abbas and Al-Naemi, 2026).

Salinity stress adversely affects tomato growth and productivity by inducing osmotic imbalance, ion toxicity, nutrient disorders, oxidative stress, and metabolic dysfunction. Excessive accumulation of sodium (Na+) and chloride (Cl-) ions reduces water uptake, suppresses photosynthesis, impairs enzymatic activities, and disrupts membrane integrity, ultimately leading to reduced vegetative growth, poor flowering, fruit abortion, and significant yield losses (Roșca et al., 2023; Ntanasi et al., 2023). Tomato is generally considered moderately sensitive to salinity, although considerable variation exists among genotypes regarding tolerance mechanisms and adaptive responses. (Anand et al., 2026)

The problem of salinity is particularly pronounced in irrigated areas of northern Nigeria such as the Kano River Irrigation Scheme, where long-term irrigation practices and fluctuating water quality have contributed to the development of saline and sodic soils. Under such conditions, tomato farmers experience declining productivity, poor fruit quality, and reduced profitability. Despite the increasing severity of salinity stress under climate change and irrigation intensification, effective and economically viable management strategies suitable for local production systems remain inadequate. (Muhammad et al., 2024).

Recent advances in plant stress physiology have shown that exogenous application of plant growth regulators and biostimulants can alleviate the detrimental effects of salinity stress in tomato. Compounds such as salicylic acid, silicon-based products, melatonin, tannin biostimulants, and other growth-promoting substances have been reported to enhance osmotic adjustment, antioxidant defense, ion homeostasis, chlorophyll stability, and overall plant resilience under saline environments. For instance, salicylic acid has been associated with improved physiological performance and stress signaling under saline conditions, while silicon compounds enhance membrane stability and reduce sodium toxicity. (Nikolaou et al., 2020; Masoumi et al., 2024) Likewise, exogenous growth regulators have been shown to improve plant height, leaf area development, chlorophyll retention, and fruit yield under salinity stress conditions. (Yildirim et al., 2024; Mir et al., 2025).

Although several studies have investigated salinity management in tomato production, most existing research has focused on controlled greenhouse conditions, physiological responses at seedling stages, or the use of single biostimulants under laboratory environments (Argentel-Martínez et al., 2024; Abbas Al-Naemi, 2026). Information on the combined performance of diverse tomato genotypes and locally adaptable plant growth regulators under field conditions in saline-sodic soils of the Sudan Savanna region remains limited. Furthermore, there is inadequate comparative information regarding the effectiveness of natural extracts and synthetic growth regulators in improving yield performance and identifying salt-tolerant tomato genotypes suitable for irrigated production systems in northern Nigeria.

Bridging this knowledge gap is essential for developing practical and climate-resilient tomato production strategies capable of sustaining productivity under salt-affected soils. Identification of tolerant genotypes combined with efficient plant growth regulators could provide farmers with affordable and environmentally sustainable options for mitigating salinity stress, improving resource-use efficiency, and enhancing tomato yield under irrigated conditions.

Therefore, this study was conducted to evaluate the growth and yield performance of tomato genotypes as influenced by plant growth regulators under saline-sodic soil conditions at the Kano River Irrigation Scheme. Specifically, the study aimed to:

• Evaluate the growth and yield of tomato genotypes as affected by plant growth regulators under saline and sodic soil conditions; and

• Identify salt-tolerant tomato genotype(s) suitable for cultivation in the study area.

MATERIALS AND METHODS

Experimental sites

Field experiments were conducted during the 2020 and 2021 dry seasons in the eastern and western sectors of the Kano River Irrigation Scheme (KRIS), Kano State, Nigeria. The study area is located between latitudes 11°45" N and 12°05" N and longitudes 08°45" E and 09°05" E, at an average elevation of 442 m above sea level and approximately 30 km southwest of Kano metropolis. The area lies within the Sudan Savanna agro-ecological zone of Nigeria and is characterized by a semi-arid climate with low annual rainfall, high evapotranspiration, and irrigated dry-season farming. The experiments were conducted on farmers' fields, with each farmer representing a replication.

Treatments and experimental design

The experiment was laid out in a split-plot design consisting of sixteen (16) treatment combinations replicated eighteen times. The treatments comprised four tomato genotypes, namely F1 Anaya, F1 Mona, F1 Thorgal, and Roma VF (local check), combined with four plant growth regulator treatments: control (0), salicylic acid at 130 mg L^{-1}, potassium silicate at 16 g L^{-1}, and tamarind extract at 8%. Plant growth regulators were assigned to the main plots, while tomato genotypes were allocated to the subplots.

Soil sampling and analysis

Composite soil samples were collected randomly from the experimental fields at a depth of 0–30 cm before transplanting for routine physical and chemical analyses using standard laboratory procedures. Soil parameters determined included particle size distribution, soil pH, electrical conductivity, organic carbon, total nitrogen, available phosphorus, exchangeable bases, exchangeable sodium percentage, sodium adsorption ratio, and extractable micronutrients

Meteorological data

Meteorological data, including rainfall, minimum and maximum temperature, relative humidity, wind speed, and wind direction during the experimental period, were obtained from the GIS Laboratory of the Centre for Dryland Agriculture.

Plot size and layout

Each gross plot measured 3.0 m × 3.0 m (9.0 m^2), while the net plot size was 1.8 m × 1.8 m (3.24 m^2). Alleys of 0.5 m and 1.0 m were maintained between plots and replications, respectively, to minimize treatment interference and facilitate field operations.

Agronomic practices

Nursery practices

Tomato seedlings were first raised in a nursery before transplanting to the field. The nursery bed was prepared to a fine tilth to enhance seed germination and seedling establishment. Seeds were sown using the drilling method, and the nursery was kept free from weeds and crop residues throughout the nursery period. Regular irrigation and manual weeding were carried out to ensure healthy seedling growth.

Land preparation

The experimental fields were cleared, ploughed, and harrowed before layout. Experimental plots were demarcated according to the design using measuring tape, pegs, ropes, and ranging poles.

Seed source, nursery raising, transplanting, and spacing

Seeds of the tomato genotypes used for the experiment were obtained from TechniSeed, a commercial seed company known for tropical vegetable seed production. The seeds were sown in the nursery and raised for six weeks, after which healthy and vigorous seedlings were transplanted into the experimental plots at a spacing of 60 cm × 60 cm between and within rows, respectively.

Fertilizer application

Fertilizer was applied at the rate of 100 kg N, 30 kg P_2O_5, and 30 kg K_2O ha^{-1}. Half of the nitrogen and the full doses of phosphorus and potassium were applied during land preparation using NPK (15:15:15) fertilizer. The remaining nitrogen was supplied as top dressing at 3 weeks after transplanting (WAT) using urea (46% N).

Irrigation

All experimental plots were irrigated at four-day intervals throughout the experimental period to maintain adequate soil moisture for optimum crop growth and development.

Weed control

The experimental fields were maintained weed-free through manual weeding at 2 and 5 WAT.

Pest and disease control

Grasshopper infestation caused by Zonocerus variegatus was observed shortly after transplanting. The infestation was controlled using Liptol insecticide applied at the manufacturer’s recommended rate on four occasions during the cropping period.

Preparation and application of plant growth regulators

Salicylic acid solution was prepared by dissolving 130 mg L^{-1} in 100 ml of distilled water. Potassium silicate solution was prepared at 16 g L^{-1} concentration. Tamarind extract at 8% concentration was prepared by crushing 5 kg of tamarind leaves and shoots in 2 litres of water using mortar and pestle, followed by filtration to obtain the stock solution. Thereafter, 320 ml of the extract was diluted in 1 litre of water to obtain the required treatment concentration. The plant growth regulator treatments were applied foliarly using a knapsack sprayer at 3 WAT before the commencement of flowering.

Harvesting

Harvesting was carried out manually by hand picking mature fruits at three-day intervals during the early harvest period and subsequently at two-day intervals during peak harvest. Harvested fruits from the net plot area were sorted into marketable and non-marketable categories before weighing.

Data collection

Data were collected on growth, flowering, and yield parameters throughout the cropping period. The parameters assessed included plant height (cm), leaf area (cm^2), days to 50% flowering, number of marketable fruits $plant^{-1}$, number of non-marketable fruits $plant^{-1}$, and fresh fruit yield (t ha^{-1}). All measurements and observations were carried out using standard agronomic procedures.

Data analysis

All data collected were subjected to analysis of variance (ANOVA) using GenStat 17th Edition and SAS statistical software packages. Treatment means were separated using Student–Newman–Keuls (SNK) test at 5% level of probability. Correlation analysis was also conducted to determine the relationships among growth, yield, and yield-related characters following the procedure described by Steel and Torrie (1981).

RESULTS AND DISCUSSION

Meteorological conditions of the experimental site

The meteorological data obtained during the 2020 and 2021 dry seasons at the Kano River Irrigation Scheme (Figure 1) revealed considerable variations in temperature, relative humidity, solar radiation, and wind characteristics across the cropping periods, which could have influenced the growth and yield performance of tomato genotypes under saline-sodic soil conditions.

During the 2020 dry season, solar radiation increased progressively from 210 Wm^{-2} in February to 340 Wm^{-2} in June, indicating increasing solar intensity toward the late dry season. Maximum temperature also increased from 30.3°C in February to a peak of 41.0°C in April before declining slightly to 36.2°C in June. Similarly, minimum temperature rose from 13.8°C in February to 24.5°C in May, suggesting a gradual transition from cool dry-season conditions to warmer and more humid conditions. Relative humidity values were generally low during the early months of the season, particularly in March where minimum relative humidity was as low as 9.51%, but increased substantially from May to June, reaching 83.6% in June. Wind speed also increased from 0.33 to 3.48 m s^{-1} during the same period.

The high temperatures, intense solar radiation, and low relative humidity observed during the early part of the 2020 season could have increased evapotranspiration and intensified salinity stress through enhanced salt accumulation around the root zone. Similar findings were reported by Abbas and Al-Naemi (2026), who observed that high evaporative demand under semi-arid conditions accelerated salt concentration in irrigated tomato fields. Likewise, Kumari et al. (2023) reported that elevated temperatures and moisture stress disrupt physiological processes and aggravate osmotic stress in tomato under saline environments. The gradual increase in relative humidity and slight reduction in temperature toward June may have created relatively favorable conditions for vegetative growth and fruit development. This observation aligns with the findings of Gedeon et al. (2022), who reported improved tomato growth and stress adaptation under moderate humidity conditions due to enhanced physiological efficiency.

In the 2021 dry season, maximum temperature ranged from 31.5°C in January to 36.5°C in March, while minimum temperature increased from 12.4°C to 19.6°C over the same period. Relative humidity remained relatively low, ranging from 27.9 to 34.7%, which is typical of the Sudan Savanna dry season. Wind speed remained fairly stable, varying from 2.2 to 2.4 m s^{-1}. The relatively high temperatures and low humidity during the season may have promoted rapid evapotranspiration and moisture depletion, thereby aggravating salinity effects on tomato plants. Similar observations were made by Masoumi et al. (2024), who reported that high temperature and low atmospheric humidity increased oxidative stress and reduced water-use efficiency in tomato grown under saline conditions.

Overall, the meteorological conditions during both seasons reflected the typical semi-arid environment of the Sudan Savanna region, characterized by high temperature, intense solar radiation, low humidity, and moderate wind movement during the dry season. These environmental conditions likely increased salinity stress intensity at the experimental sites and provided suitable conditions for evaluating the effectiveness of plant growth regulators and tomato genotypes under

saline-sodic soils. Similar environmental conditions were reported by Elhag et al. (2023) in irrigated semi-arid regions, where high temperature and evaporative demand were identified as major contributors to salt accumulation and reduced crop productivity.

Soil physical and chemical properties

The physical and chemical properties of the soils at the experimental sites during the 2020 and 2021 dry seasons at the Kano River Irrigation Scheme (Table 1 and 2) indicated considerable variability among sampling points, reflecting the heterogeneous nature of irrigated soils in the Sudan Savanna agro-ecological zone.

The particle size distribution showed that sand was the dominant soil fraction in both seasons, ranging from 625 -772 g kg^{-1} in 2020 and 528 –750 g kg^{-1} in 2021, indicating that the soils were predominantly sandy loam to sandy clay loam in texture. The dominance of sand suggests low water- and nutrient-holding capacity, which is characteristic of most Sudan Savanna soils. Similar findings were reported by Sanda and Ismail. (2022) and Temgu and Solomon (2025), who observed that irrigated soils in northern Nigeria are predominantly sandy with poor nutrient retention capacity due to low clay content.

Soil pH ranged from 5.79-6.16 in 2020 and 5.63-6.89 in 2021, indicating slightly acidic to near-neutral soil conditions suitable for tomato production. These pH values favor nutrient availability and root development in tomato. This aligns with the findings of Abdulmuddallib et al. (2026), who reported slightly acidic soils as common under irrigated vegetable production systems in northern Nigeria.

Electrical conductivity (EC) values varied from 55.1–116 µS cm^{-1} in 2020 and 70.3–119 µS cm^{-1} in 2021, suggesting the presence of soluble salts within the soils. Although the EC values were not excessively high, they indicate moderate salinity influence associated with continuous irrigation practices. Similar findings were reported by Mohanavelu et al. (2021) and Jumaah (2025), who noted gradual salt accumulation in irrigated semi-arid soils due to high evapotranspiration and insufficient leaching.

Exchangeable sodium percentage (ESP) ranged from 1.92–3.57% in 2020 and 1.46–3.92% in 2021, while sodium adsorption ratio (SAR) values remained relatively low across the sampling points. The low SAR values suggest that severe sodicity had not yet developed; however, the presence of exchangeable sodium indicates the potential risk of sodicity under prolonged irrigation. This observation agrees with El-Akhdar et al. (2025), who reported that continuous irrigation in semi-arid environments often leads to gradual sodium accumulation and deterioration of soil structure over time.

Organic carbon values were generally low, ranging from 4.3–7.6 g kg^{-1} in 2020 and 2.79–8.29 g kg^{-1} in 2021, while total nitrogen contents were also low across the sampling points. The low organic matter status could be attributed to rapid mineralization under high temperatures and continuous cultivation. Similar findings were reported by Yusuf et al. (2024), who observed low organic carbon and nitrogen contents in irrigated soils of the savanna region of northern Nigeria due to intensive land use and limited organic residue incorporation.

Available phosphorus values were low in both seasons, ranging from 2.37–6.49 mg kg^{-1} in 2020 and 1.68–8.47 mg kg^{-1} in 2021, indicating inadequate phosphorus supply for optimum tomato production. This agrees with the findings of Bebeley et al. (2024), who reported low available phosphorus levels in most irrigated soils of northern Nigeria due to phosphorus fixation and low native fertility.

Exchangeable calcium was the dominant basic cation across the sites, followed by magnesium and potassium. However, potassium levels were relatively low in some sampling points, which may

negatively affect fruit formation and yield because potassium plays a major role in photosynthesis, osmotic regulation, and fruit quality development in tomato plants.

The micronutrient analysis revealed relatively high iron contents, while zinc, manganese, and copper varied considerably across sampling points. The high iron concentration is typical of ferruginous tropical soils. However, the low zinc levels observed in some locations may predispose tomato plants to micronutrient deficiency. Similar observations were reported by Singh and Prasad. (2022), who found variable micronutrient distribution in irrigated Sudan Savanna soils due to differences in soil texture and management history.

Overall, the soils of the experimental sites were characterized by sandy texture, low organic matter, low nutrient status, and moderate salinity influence. These conditions provided a suitable environment for evaluating the response of tomato genotypes and plant growth regulators under saline-sodic soil conditions.

Plant height of tomato genotypes as influenced by plant growth regulators

Plant height of tomato was significantly influenced by plant growth regulators at 6 WAT during the 2020 dry season and at 9 WAT during the 2021 dry season, while varietal differences significantly affected plant height at all sampling periods in both seasons (Table 3).

During the 2020 season, potassium silicate produced the tallest plants at 6 WAT (34.7 cm), although no significant differences were observed among the plant growth regulator treatments at 9 WAT despite its numerical superiority. Similarly, during the 2021 season, plant growth regulators had no significant effect on plant height at 3 and 6 WAT, but at 9 WAT the control treatment produced taller plants (48.24 cm) than potassium silicate, while salicylic acid and tamarind extract were statistically comparable. The improved vegetative growth associated with potassium silicate may be attributed to enhanced nutrient uptake, cell elongation, and reduced salinity stress. Similar findings were reported by Masoumi et al. (2024) and Gedeon et al. (2022), who observed improved tomato growth and stress tolerance following the application of silicon-based and growth-promoting substances under saline conditions. The variation in response across seasons may be due to differences in environmental conditions such as temperature and relative humidity, as similarly reported by Abbas and Al-Naemi (2026).

Varietal differences significantly influenced plant height during both seasons, with F1 Mona producing the tallest plants throughout the 2020 season, while F1 Thorgal consistently recorded superior plant height during the 2021 season across all sampling periods. The superior growth performance of these genotypes suggests better adaptability and tolerance to saline-sodic conditions through improved physiological efficiency and stress resilience. Similar findings were reported by Da Silva Oliveira et al. (2022) and Takács et al. (2022), who observed that salt-tolerant tomato genotypes maintained superior vegetative growth under saline conditions due to better osmotic adjustment and ion regulation.

The interaction between plant growth regulators and tomato genotypes was not significant in both seasons, indicating that the genotypes responded similarly to the applied plant growth regulator treatments across the sampling periods.

Leaf area of tomato genotypes as influenced by plant growth regulators

Leaf area was not significantly influenced by plant growth regulators at 3, 6, and 9 WAT during the 2020 dry season (Table 4). However, tamarind extract consistently produced numerically higher leaf area values across the sampling periods compared to the other treatments. The improved leaf expansion observed with tamarind extract may be associated with enhanced physiological activity and better stress tolerance under saline conditions. Similar findings were reported by Ntanasi et al. (2024), who observed improved vegetative growth and leaf development in tomato following

application of plant-based biostimulants under abiotic stress conditions.

Tomato genotypes significantly influenced leaf area at all sampling periods. F1 Thorgal, F1 Mona, and F1 Anaya produced significantly larger leaf areas compared to Roma VF throughout the growth stages. At 9 WAT, F1 Thorgal recorded the highest leaf area (19.3 cm^2), while Roma VF had the lowest value (14.7 cm^2). The superior leaf area development observed in the improved genotypes suggests greater adaptability and better photosynthetic potential under saline-sodic conditions. This aligns with the findings of Roșca et al. (2023) and Ntanasi et al. (2023), who reported that salt-tolerant tomato genotypes maintained larger leaf area and better vegetative growth under salinity stress due to improved osmotic adjustment and nutrient utilization.

The interaction between plant growth regulators and tomato genotypes was not significant at all sampling periods, indicating similar responses of the genotypes to the applied treatments.

Days to 50% flowering, marketable fruits, non-marketable fruits, and fruit yield of tomato genotypes as influenced by plant growth regulators

Table 5 presents the number of days to 50% flowering, marketable fruits, non-marketable fruits, and fruit yield of tomato genotypes as influenced by plant growth regulators. Result show that plant growth regulators did not significantly influence days to 50% flowering during both seasons, although tamarind extract and potassium silicate slightly hastened flowering during the 2021 season. Similar observations were reported by Di Mola et al. (2022), who found that biostimulants had limited influence on flowering time of tomato under salinity stress conditions.

Varietal effects on days to 50% flowering were not significant during the 2020 season; however, significant differences were observed in 2021, where F1 Thorgal flowered earlier (32 days) than the other genotypes, while Roma VF recorded the longest period to 50% flowering (36 days). The early flowering observed in F1 Thorgal may indicate better adaptation and stress tolerance under saline-sodic conditions, enabling the genotype to complete its reproductive phase more rapidly under environmental stress. Similar findings were reported by Sun et al. (2024), who observed that salt-tolerant tomato genotypes attained earlier flowering under salinity stress due to improved physiological adjustment and stress adaptation mechanisms.

The number of marketable fruits plant-1 was significantly influenced by tomato genotypes in both seasons and by plant growth regulators during the 2021 season. Among the plant growth regulators, the control treatment produced the highest number of marketable fruits (96 fruits plant-1), followed closely by salicylic acid, while potassium silicate recorded the lowest value. The superior performance of the control treatment may be attributed to the absence of possible physiological disturbances associated with foliar applications under the prevailing environmental conditions, which may have favored better fruit retention and development. However, the comparatively higher values observed under salicylic acid suggest its potential in improving stress tolerance and assimilate partitioning under saline conditions.

Among the genotypes, F1 Anaya produced the highest number of marketable fruits (27 fruits plant-^{1}) during the 2020 season, while F1 Anaya and Roma VF maintained comparatively higher values during the 2021 season. The superior marketable fruit production observed in these genotypes may indicate better reproductive adaptation and fruit retention ability under saline-sodic conditions. Similar findings were reported by Yang et al. (2023) and Wang et al. (2026), who observed significant improvements in fruit set, marketable yield, and genotypic adaptability of tomato under salinity stress conditions.

The number of non-marketable fruits plant-^{1} was not significantly influenced by plant growth regulators and tomato genotypes during the 2020 season. However, significant differences were observed in the 2021 season for both factors. Among the plant growth regulators, the control treatment produced the highest number of non-marketable fruits (18 fruits plant-^{1}), while

potassium silicate recorded the lowest value (12 fruits plant-¹) although at par with other treatments. The reduced number of non-marketable fruits under potassium silicate application may be attributed to improved membrane stability and reduced physiological disorders under salinity stress conditions. Among the genotypes, F1 Anaya produced the highest number of non-marketable fruits (21 fruits plant-¹), whereas Roma VF and F1 Thorgal recorded lower values. The lower incidence of non-marketable fruits in these genotypes may indicate better fruit quality maintenance and stress tolerance under saline-sodic conditions. Similar findings were reported by He et al. (2025), who observed that silicon application and varietal tolerance significantly reduced fruit defects and improved fruit quality in tomato grown under saline environments.

Fruit yield was significantly influenced by both plant growth regulators and tomato genotypes in both seasons. Salicylic acid produced the highest fruit yield in 2020 (5.1 t ha-¹) and 2021 (14.6 t ha-¹), while among the genotypes, F1 Mona recorded the highest yields of 4.9 and 14.2 t ha-¹ during the 2020 and 2021 seasons, respectively. The superior yield obtained under salicylic acid treatment may be due to enhanced physiological activities, improved nutrient uptake, and better osmotic adjustment under saline conditions. Similar findings were reported by Fozia et al. (2024), who observed increased tomato yield following salicylic acid application under salt stress. Likewise, the superior performance of F1 Mona suggests better genetic adaptability and tolerance to saline-sodic conditions. This aligns with the findings of Zhang et al. (2024), who reported significant genotypic differences in tomato yield performance under salinity stress.

The interaction of plant growth regulators and tomato genotypes was significant for marketable fruits, non-marketable fruits, and fruit yield during the 2021 season, indicating differential responses of the genotypes to the applied treatments under varying environmental conditions and are shown in Figures 2-4.

Interaction between plant growth regulators and tomato genotypes yield and yield related traits

The interaction of plant growth regulators and tomato genotypes significantly influenced the number of marketable fruits per plant during the 2021 dry season as presented in Figure 2. Roma VF treated with the control produced the highest number of marketable fruits (107 fruits plant-¹), which was statistically comparable with F1 Thorgal treated with salicylic acid (102 fruits plant-¹) and F1 Anaya treated with tamarind extract (100 fruits plant-¹) compared to F1 Thorgal combined with potassium silicate that resulted in the lowest number of marketable fruits (50 fruits plant-¹).

The superior performance observed in some genotype–treatment combinations may be attributed to improved physiological adaptation and enhanced assimilate partitioning under saline conditions. Similar findings were reported by Boussora et al. (2026), who observed significant interaction effects between tomato genotypes and biostimulants on fruit retention and marketable yield under salinity stress conditions.

Figure 3 on the other hand shows that the interaction between plant growth regulators and tomato genotypes significantly influenced the number of non-marketable fruits during the 2021 dry season. F1 Anaya treated with tamarind extract produced the highest number of non-marketable fruits (24 fruits plant-¹), whereas F1 Thorgal combined with potassium silicate recorded the lowest value (8 fruits plant-¹). Roma VF treated with potassium silicate and tamarind extract also produced relatively fewer non-marketable fruits. The lower number of non-marketable fruits observed under potassium silicate application may be attributed to improved membrane stability and enhanced stress tolerance, which minimized fruit deformities and physiological disorders under saline conditions. Similar findings were reported by Ferrández-Gómez et al. (2024), who observed that silicon application reduced fruit damage and improved fruit quality in tomato grown under saline environments.

The plant growth regulators x tomato genotypes interaction significantly influenced fruit yield

during both the 2020 and 2021 dry seasons as shown in Figure 4. During the 2020 season, F1 Mona treated with salicylic acid produced the highest fruit yield (6.74 t ha^{-1}), while Roma VF combined with tamarind extract recorded the lowest yield (2.36 t ha^{-1}). In the 2021 season, F1 Thorgal treated with salicylic acid produced the highest fruit yield (17.5 t ha^{-1}), followed closely by F1 Anaya treated with salicylic acid (15.9 t ha^{-1}) compared to Roma VF treated with tamarind extract that had the lowest fruit yield (8.50 t ha^{-1}).

The superior performance of salicylic acid in combination with improved genotypes suggests enhanced salinity tolerance through improved osmotic regulation, photosynthetic efficiency, and nutrient uptake. Similar findings were reported by Nóbrega et al. (2021) and Xu et al. (2022), who observed significant increases in tomato fruit yield when salicylic acid was combined with salt-tolerant genotypes under saline conditions. Likewise, Zuzunaga-Rosas et al. (2023) reported that genotype × biostimulant interactions significantly influenced tomato productivity under abiotic stress environments.

CONCLUSION

The study revealed that tomato growth, yield, and yield components under saline-sodic conditions at the Kano River Irrigation Scheme were significantly influenced by tomato genotypes and plant growth regulators. Salicylic acid proved most effective in enhancing marketable fruit production and fruit yield, while potassium silicate improved vegetative growth and reduced non-marketable fruits. Among the genotypes evaluated, F1 Mona and F1 Thorgal exhibited superior adaptability and yield performance under saline conditions. The interaction results further showed that combining salicylic acid with improved tomato genotypes, particularly F1 Mona and F1 Thorgal, produced the best yield performance.

Therefore, salicylic acid in combination with F1 Mona and F1 Thorgal should be recommended for tomato production in saline-affected irrigated areas due to their superior adaptability, enhanced growth performance, higher marketable fruit production, and improved fruit yield under saline-sodic conditions.

REFERENCES

Abbas F., Al-Naemi S. (2026). Managing salinity stress through microclimate control to enhance tomato productivity in arid regions. Scientific Reports, 16: 13042.

Abdulmuddallib M.A., Musa S.A., Tahir M.A., Umar U.K., Abdulqadir A.S., Saddiq A.M. (2026). Assessment of soil fertility status and nutrient distribution in agricultural soils of Gusau Local Government Area, Zamfara State, Nigeria. Sahel Journal of Life Sciences Fudma, 4: 262-270.

Anand R., Vardhan S., Parihar A., Bhatt D., Arora S. (2026). Salinity stress mitigation in tomato (Solanum lycopersicum L.): Mechanisms, impacts and copper nanoparticle-based solution. Frontiers in Plant Science, 17: 1777876.

Argentel-Martínez L., Peñuelas-Rubio O., Amador C.Á., Armenta-Calderón A.D., Pérez-Espinoza C.Y., Aguilera-Rodríguez M., Garatuza-Payan J. (2024). Mitigating salinity stress on tomato growth, water regime, gas exchange, and yield with the application of QuitoMax. Scientific Reports, 14: 31755.

Bebeley J.F., Kamara A.Y., Jibrin J.M., Tofa A.I., Solomon R., Kamai N. (2024). Effect of combined use of supplementary irrigation, manure and P fertilization on grain yield and profitability of soybean in northern Nigeria. Heliyon, 10: e28749.

Boussora F., Ali S.B., Triki T., Ghanmi A., Bagues M., Ferchichi A., Guasmi F. (2026). Coordinated

antioxidant and physiological responses at flowering promote yield stability in salinity-stressed barley genotypes. International journal of molecular sciences, 27: 2454.

Da Silva Oliveira C.E., Zoz T., Jalal A., Vendruscolo E.P., Nogueira T.A.R., Jani A.D., Teixeira Filho M.C.M. (2022). Tolerance and adaptability of tomato genotypes to saline irrigation. Crops, 2: 306-322.

Di Mola I., Ottaiano L., Cozzolino E., El-Nakhel C., Fiorentino N., Pelosi M.E., Rouphael Y., Mori M. (2024). Impact of salinity and biostimulants on cherry tomato yield and quality. Horticulturae, 10: 1239.

El-Akhdar I., Elhawat N., Shabana M.M.A., Aboelsoud H.M., Alshaal T. (2025). Physiological and agronomic responses of maize (zea mays l.) To compost and pgpr under different salinity levels. Plants, 14: 1539.

Ferrández-Gómez B., Jordá J.D., Cerdán M., Sánchez-Sánchez A. (2024). Enhancing salt stress tolerance in tomato (Solanum lycopersicum L.) Through silicon application in roots. Plants, 13: 1415.

Fozia Yike G., Zahid A., Naveed S.A., Attia K.A., Mohammed A. A., Chishti S.A., Uzair M. (2024). Exogenous application of salicylic acid and NPK promotes tomato growth parameters, yield, and nutraceutical quality under cold stress. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 52: 13667.

Gedeon S., Ioannou A., Balestrini R., Fotopoulos V., Antoniou C. (2022). Application of biostimulants in tomato plants (Solanum lycopersicum) to enhance plant growth and salt stress tolerance. Plants, 11: 3082.

He B., Wei Y., Wang Y., Zhong Y., Fan M., Gong Q., Lu S., Hassan M.U., Li X. (2025). Silicon application improves tomato yield and nutritional quality. BMC plant biology, 25: 252.

Jumaah M.S. (2025). The effect of electrical conductivity on physical and chemical properties of different types of soil. 17: 386-401.

Kussmann M. (2022). Prediction, discovery, and characterization of plant- and food-derived health-beneficial bioactive peptides. Nutrients, 14: 4810.

Kussmann M., Abe Cunha D.H., Berciano S. (2023). Bioactive compounds for human and planetary health. Frontiers in nutrition, 10: 1193848.

Masoumi Z., Haghighi M., Mozafarian M. (2024). Effects of foliar spraying with melatonin and chitosan Nano-encapsulated melatonin on tomato (Lycopersicon esculentum L. cv. Falcato) plants under salinity stress. BMC Plant Biology, 24: 961.

Mir B.A., Parrey Z.A., Kapoor P., Parihar P., Rakhra G. (2025). Mitigation of salt stress in tomato (solanum lycopersicum L.) Through sulphur, calcium, and nitric oxide: impacts on ionic balance, nitrogen-sulphur metabolism, and oxidative stress. Nitrogen, 6: 93.

Mohanavelu A., Naganna S.R., Al-Ansari N. (2021). Irrigation induced salinity and sodicity hazards on soil and groundwater: an overview of its causes, impacts and mitigation strategies. Agriculture, 11: 983.

Muhammad M., Waheed A., Wahab A., Majeed M., Nazim M., Liu Y.-H., Li L., Li W.-J. (2024). Soil salinity and drought tolerance: An evaluation of plant growth, productivity, microbial diversity, and amelioration strategies. Plant Stress, 11: 100319.

Nikolaou G., Neocleous D., Christou A., Kitta E.,Katsoulas N. (2020). Implementing sustainable irrigation in water-scarce regions under the impact of climate change. Agronomy, 10: 1120.

Nóbrega J.S., Figueiredo F.R.A., Silva T.I., Ribeiro J.E.S., Fátima R.T., Ferreira J.T.A., Albuquerque M.B., Dias T.J., Bruno R.L.A. (2021). Water salinity and salicylic acid on tomato plants growth. Research, Society and Development, 10: e41210716630.

Ntanasi T., Karavidas I., Spyrou G.P., Giannothanasis E., Aliferis K.A., Saitanis C., Fotopoulos V., Sabatino L., Savvas D., Ntatsi G. (2024). Plant biostimulants enhance tomato resilience to salinity stress: insights from two greek landraces. Plants (Basel, Switzerland), 13: 1404.

Ntanasi T., Karavidas I., Zioviris G., Ziogas I., Karaolani M., Fortis D., Conesa M.À., Schubert A., Savvas D., Ntatsi G. (2023). Assessment of growth, yield, and nutrient uptake of mediterranean tomato landraces in response to salinity stress. Plants (Basel, Switzerland), 12: 3551.

Roșca M., Mihalache G., Stoleru V. (2023). Tomato responses to salinity stress: From morphological traits to genetic changes. Frontiers in plant science, 14/ 1118383.

Sanda A.R., Ismail Y.M. (2012). Soil fertility assessment of research and teaching farm of Audu Bako College of Agriculture Danbatta, Kano State, Nigeria. Nature Environment and Pollution Technology, 11: 639–642.

Singh I.R., Prasad A. (2022). Assessment of available micronutrients status in the soils of Macuata Province of Fiji. International Journal of Plant Soil Science, 34: 1792–1797.

Sun, F., Wang, Y., Liu, G., Fang, D., Sun, M., Bao, Z., Ma F. (2024). Salt stress induces SFT expression to promote early flowering and inhibits floral organ development by disturbing cell cycle in tomato. Vegetable Research, 4: e019.

Takács Z., Czékus Z., Tari I., Poór P. (2022). The role of ethylene signalling in the regulation of salt stress response in mature tomato fruits: Metabolism of antioxidants and polyamines. Journal of Plant Physiology, 277: 153793.

Temgu A.M., Solomon A.U. (2025). Evaluation of the micronutrients and macronutrients levels in soils among selected local government in Benue North-West Benue State, Nigeria. UKR Journal of Agriculture and Veterinary Sciences, 1: 9–17.

Wang C., Wang S., Shi A., Zhang J., Qie L., Miao F., Yin Q. (2026). Field-Based Screening and Evaluation of Salt-Tolerant Tomato Germplasm. HortScience, 61: 201–208.

Xu L., Chen H., Zhang T., Deng Y., Yan J., Wang L. (2022). Salicylic acid improves the salt tolerance capacity of Saponaria officinalis by modulating its photosynthetic rate, osmoprotectants, antioxidant levels, and ion homeostasis. Agronomy, 12: 1443.

Yang, W., Zhou, Z., Chu, Z. (2023). Emerging Roles of Salicylic Acid in Plant Saline Stress Tolerance. International Journal of Molecular Sciences, 24(4), 3388.

Yildirim E., Ekinci M., Turan M., Yuce M., Ors S., Araz O., Torun U., Argin S. (2024). Exogenous dopamine mitigates the effects of salinity stress in tomato seedlings by alleviating oxidative stress and regulating phytohormones. Acta Physiologiae Plantarum, 46: 59.

Yusuf Z., Garba Y. I., Richard M.A., Haruna U.J. (2024). Assessment of the physicochemical properties of soil in farmlands of Birnin Yero, Igabi local government area, Kaduna State, Nigeria. Fudma Journal of Science, 8: 388-400.

Zhang Y., Hussain A., Arif M., Alkahtani J., AlMunqedhi B.M., Song C. (2024). Genetic variability for salinity tolerance of tomato (Solanum lycopersicon Mill.) genotypes determined by stress tolerance indices. Journal of King Saud University - Science, 36: 103386.

Zuzunaga-Rosas J., Silva-Valdiviezo D., Calone R., Lupuţ I., Ibáñez-Asensio S., Boscaiu M., Moreno-Ramón H., Vicente O. (2023). Biochemical responses to salt stress and biostimulant action in tomato plants grown in two different soil types. Horticulturae, 9: 1209.

References