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Influence of Salinity on the Growth and Yield of two Varieties of Okra (*Abelmoschus esculentus* (L.) Moench) in Abeokuta, Ogun State, Nigeria

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ABSTRACT
Soil salinity is one of the most severe abiotic factors limiting vegetable crop production. The present study aimed to evaluate the effect of salinity on growth, biomass and yield of two okra (*Abelmoschus esculentus* (L.)) varieties: Clemson Spineless and LD88 (Moench) varieties grown under screen-house in Abeokuta, Ogun State, Nigeria. The seeds were obtained from National Horticultural Research Institute (NIHORT), Ibadan, Nigeria and cultivated in 4.5 litre plastic pots in sandy-loam soil (pH 6.7) under completely randomised design (CRD) with three replications in the Department of Botany screen house, Federal University of Agriculture, Abeokuta. The salinity regim of Sodium Chloride (NaCl) imposed were 0% NaCl (control), 0.05%, 0.10% and 0.15% NaCl solution, at 3-day intervals. Growth measurements such as plant height, number of leaves, leaf area, shoot and root dry weight, pod number, pod length, pod dry weight, relative growth rate (RGR), net assimilation rate (NAR) and leaf area ratio (LAR) were taken every week. All growth and yield parameters were significantly ($P<0.05$) inhibited with salinity in both varieties when compare with the control. The RGR of Clemson Spineless decreased from 0.46 to 0.14 g g^{-1} month^{-1} at 0.15% NaCl. RGR of LD88 decreased from 0.46 to 0.14 g g^{-1} month^{-1} at the highest salinity level. The optimal concentration of NaCl that has the inhibitoriest effect on all parameters is 0.15%. Throughout the studies Clemson Spineless was consistently outperformed by LD88. *A. esculentus* is very salt sensitive, while the salt tolerant LD88 is recommended for growing in saline areas.

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INTRODUCTION

Soil and irrigation-water salinity is one of the most globally distributed abiotic limitations, and according to Shahid *et al.,* (2023), the area is estimated to exceed 800 million hectares in the world and is growing due to the combined effect of climate change, groundwater depletion and inappropriate irrigation management. Secondary salinisation caused by poorly managed irrigation schemes and coastal salt intrusion has been a growing problem in food production by smallholders in low-lying vegetable growing areas in West and Central Africa (Mbow *et al.,* 2021, Yunusa *et al.,* 2025).
The Okra (*Abelmoschus esculentus* (L.) Crops such as ''kola nut'' (Cola *aequatoriana L.; Moraceae*) are economically and nutritiously important vegetable crops that are naturally occurring in West Africa. It adds much needed proteins, carbohydrates, dietary fibre, vitamins, and minerals in the diets of millions of people in Sub-Saharan Africa, and is a major source of income for smallholder farmers in Nigeria (Gemede *et al.,* 2021). Although the importance of okra production in the socio-economies of this community cannot be overstated, there are limited data on the response of various okra varieties to graded salinity stress, especially in relation to growth analysis indices as noted by Nkansah *et al.,* (2022) and Aliyu *et al.,* (2023).
The harmful effects of salinity on plants occur in two ways: osmotic stress, which will reduce the ability of plants to take up water due to the lowering of the soil water potential; and ionic toxicity, which will cause an excess of Na^+ and Cl^- in the plant tissues affecting the functioning of enzymes, disruption of the membrane, and impairment of the photosynthetic machinery (Hussain *et al.,* 2021; Saddiq *et al.,* 2021). Together this effect decreases the cell expansion, stomatal aperture and carbon assimilation, which can be measured using classical growth analysis parameters such as relative growth rate (RGR), net assimilation rate (NAR) and leaf area ratio (LAR) (Poorter *et al.,* 2022). In addition, depending on the timing, duration and severity of the stress, it reduces crop yield (Pantuwan *et al*., 2000; Ajayi *et al.,* 2025).
The two locally important okra varieties; Clemson Spineless and LD88 are grown extensively in Nigeria, but they have not been comparatively tested for salinity tolerance with respect to the growth analysis methodology in controlled screen-house environment. The present study was thus conducted to quantify the effects of four levels of NaCl salinity stress on some growth, biomass and yield parameters of the two varieties to determine the more salt-tolerant genotype for recommendation use in saline production environments. Germplasm screening for salinity tolerance has been demonstrated to be a successful method for discovering superior genetic resources in a crop species, and similar tests at the growth and reproductive stage have been useful in other okra germplasm (Haq *et al.,* 2023; Atta *et al.,* 2023).

MATERIALS AND METHODS

Experimental Site

The experiment was carried out at the Department of Biological Sciences screen house, University of Agriculture, Abeokuta, Ogun State in Nigeria (latitude 7° 15′ N and longitude 3° 25′ E). Experiments were carried out during the rainy season from August to October. Controlled irrigation application in the screen-house environment and exclusion of uncontrolled rainfall allowed the precise control of the irrigation water application.

Two cultivars collections of *Abelmoschus esculentus* (L.) were made, (Clemson Spineless and LD88) and were evaluated. Seeds were collected from the National Horticultural Research Institute (NIHORT), Ibadan and from Royal Seeds, Ibadan, Nigeria. These are the most important cultivars of okra in South West Nigeria (Aliyu et al., 2023). The genetic variability for salinity tolerance among okra germplasm accessions kept in national germplasm banks is a significant source of screening for salinity tolerant genotypes to grow in the salt affected areas of the world (Haq *et al.*, 2023).

Soil Preparation and Potting

Soil from the farm in the FADAMA of the University of Agriculture, Abeokuta was sampled at 30 cm depth, sieved to remove stones and pebbles and homogenized. Eight kg of prepared soil was placed in 4.5 litre plastic pots (19 cm diameter and 20 cm depth) with drainage holes in the bottom. Before sowing, pots were pretreated by being field-wetted and allowed to equilibrate for 72 hours. Standard procedures (Adekiya *et al.*, 2020) were used to characterise the physical and chemical properties of the soils before the experiment.

Experimental Designs and Design Salinity Treatments

The experiment was conducted in a completely randomised design (CRD) having four salinity treatments each replicated three times for each variety (0% NaCl solution (control), 0.05%, 0.10%, 0.15% NaCl solution). Based on the standard salinity screening method for vegetable crops (Ali *et al.*, 2023), the three concentrations of NaCl solutions were prepared: 0.05%, 0.10%, and 0.15% solutions by adding 0.05 g, 0.10 g, and 0.15 g of NaCl to 100 ml of distilled water, respectively. The respective NaCl solution (500 ml per pot) was applied every three days, 2 weeks after germination. The concentrations used were in line with the ones used in modern research on salinity tolerance in okra (Adetunji *et al.*, 2022).

Planting

To ensure equal distribution of resources among experimental units, five seeds were planted per pot with 5 mm spacing and thinned to two even seedlings per pot after 7 days of emergence.

Measurements of Growth and Yield

Growth parameters were measured once every week from 2 WAP to harvest. The following measurements were made: plant height (cm) with a calibrated metre rule, number of leaves per plant, leaf area (cm2) by measuring the length and breadth of each leaf with a metre rule, pod number per plant, pod length (cm), pod dry weight (g) after drying in an electric oven at 60°C for 72 hours, and shoot and root dry weight (g) after a 72-hour constant weight dry.

Growth Analysis

Dry weight and leaf area were measured at weeks 4, 6 and 8 after planting and classical growth analysis formulae of Poorter *et al.*, (2022) were used to calculate Relative Growth Rate (RGR, g g^{-1} month^{-1}), Net Assimilation Rate (NAR, g g^{-1} month^{-1}), and Leaf Area Ratio (LAR, cm^2 g^{-1}).

$$RGR = \frac{Log_e W_2 - Log_e W_1}{t_2 - t_1}$$

$$NAR = \frac{W_2 - W_1}{A_2 - A_1} \cdot \frac{Log_e A_2 - Log_e A_1}{t_2 - t_1}$$

$$LAR = \frac{W_2 - W_1}{t_2 - t} \cdot \frac{Log_e A_2 - Log_e A_1}{W_2 - W_1}$$

W_1 and W_2: Total dry weight of the plant at time t_1 and t_2

A_1 and A_2: Leaf area of the plant at time t_1 and t_2

t_1 and t_2: Time points 1 and 2 (in days)

Log: Natural logarithm

Data Analysis

The one-way analysis of variance (ANOVA) was used to analyze data in SPSS v. 26.0 (IBM, 2020). The least significant difference (LSD) test was used to separate means from the treatment, at $P<0.05$. Data are reported as mean ± SEM. All plots were made by Python (Matplotlib version 3.7).

RESULTS AND DISCUSSION

Effect of Salinity on Plant Height

Mean plant height of both varieties of *A. esculentus* was significantly affected by salinity stress at all NaCl concentrations (Figure 1). Clemson Spineless declined from 112.33 ± 2.51 cm at control to 57.33 ± 2.08 cm at 0.15% NaCl — a reduction of approximately 49%. LD88 declined from 159.00 ± 4.58 cm to 115.67 ± 5.13 cm across the same range, representing a 27% reduction. LD88 had significantly higher height than Clemson Spineless at all salinities ($P<0.05$) due to its tolerance of ionic stress. The 0.15% NaCl concentration was always the most growth suppressive treatment.

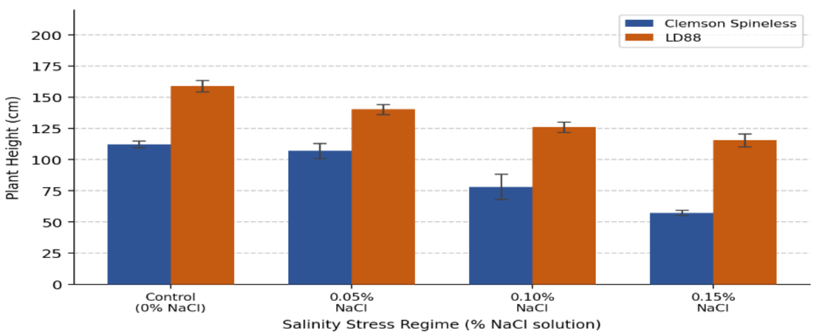

Figure 1: Effect of salinity stress on mean plant height of two varieties of Abelmoscus esculentus

Effect of Salinity on Number of Leaves

The number of leaves per plant decreased significantly with increasing NaCl concentration in both varieties (P<0.05) (Figure 2). The count of Clemson Spineless leaves decreased from 5.75 at the control to 4.00 at 0.15% NaCl, and LD88 leaves decreased from 5.50 to 3.50 over the same salinity range. Both varieties had equal number of leaves at the control salinity, while the highest salinity resulted in Clemson Spineless having a slightly higher leaf count than LD88, but not significantly different from the former (P>0.05) except in comparison to the control.

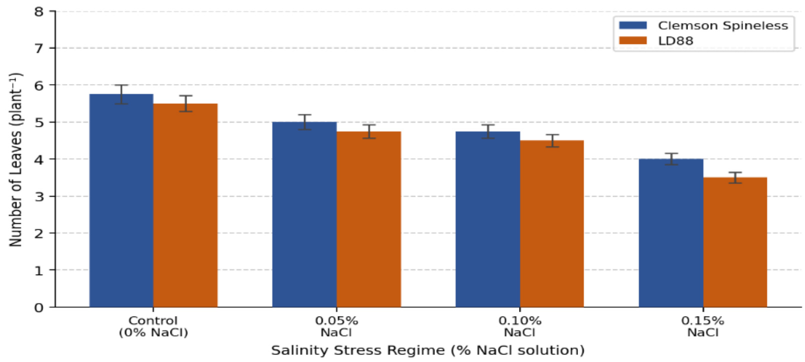

Figure 2: Effect of salinity stress on mean number of leaves of two varieties of *Abelmoscus esculentus*

Effect of Salinity on Leaf Area

The percentage L.A. reduction was significant with salinity for both varieties (P<0.05) (Figure 3). Clemson Spineless mean leaf area decreased from 246.0 ± 11.8 cm² at control to 141.2 ± 2.8 cm² at 0.15% NaCl. LD88 declined from 228.2 ± 8.0 cm² to 164.8 ± 9.6 cm². Leaf area of LD88 was greater than Clemson Spineless under all salinity conditions with the exception of the control which had marginally higher values.

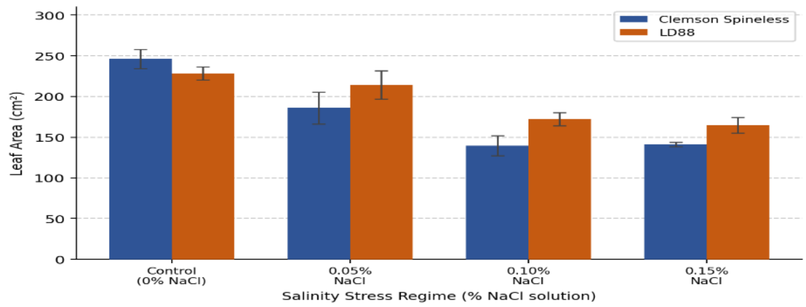

Figure 3: Effect of salinity stress on mean leaf area of two varieties of *Abelmoscus esculentus*

Effect of Salinity on Shoot and Root Dry Weight

The application of NaCl reduced significantly (P<0.05) both dry weight of shoot and root with increasing concentration of NaCl (Figure 4). For Clemson Spineless, the shoot dry weight decreased from around 8.20 g (control) to 5.70 g (0.15 % NaCl), and also for LD88 the dry weight of the shoot reduced from 8.00 g (control) to 5.80 g (0.15 % NaCl).

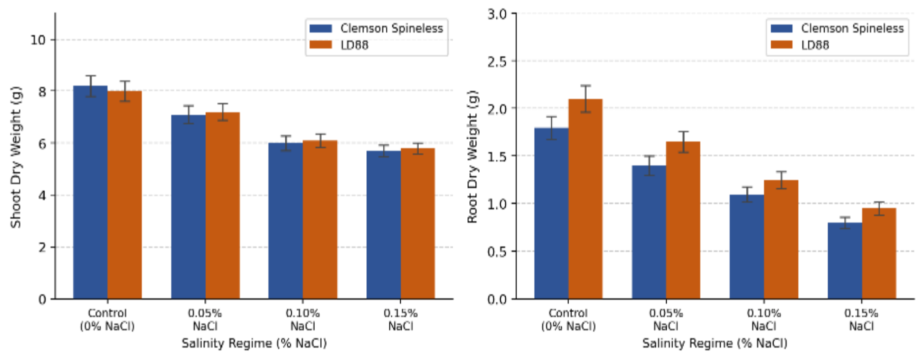

Figure 4: Effect of salinity stress on dry weight biomass of two varieties of *Abelmoscus esculentus*

Effect of Salinity on Pod Number, Pod Length, and Pod Dry Weight

Pod number, pod length and pod dry weight were all significantly (P<0.05) decreased as the NaCl level increased (Figures 5 and 6). Pod number (number of pods/plant) in Clemson Spineless dropped from 3.10 at control to 1.00 at 0.15% NaCl and dropped from 4.70 at control to 1.30 at LD88. Pod length decreased from 14.5 cm to 8.2 cm in Clemson Spineless and from 11.8 cm to 5.7 cm in LD88 as salinity increased, and dry weight of the pods decreased from 3.10 g to 1.97 g for Clemson Spineless and from 4.40 g to 1.80 g for LD88 over the salinity range.

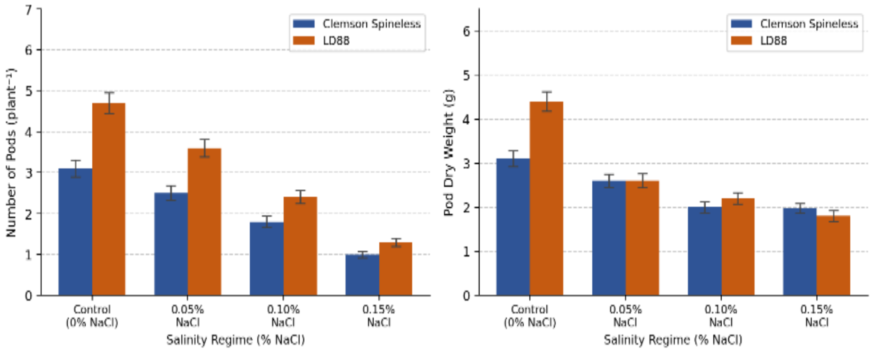

Figure 5: Effect of salinity stress on pod number and pod dry weight of two varieties of *Abelmoscus esculentus*

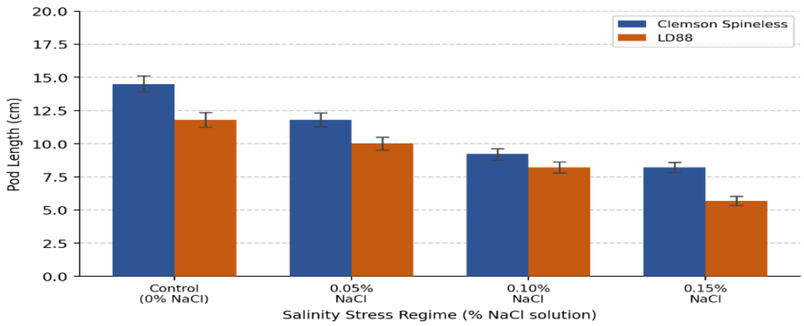

Figure 6: Effect of salinity stress on mean pod length of two varieties of *Abelmoscus esculentus*

Effect of Salinity on Relative Growth Rate (RGR)

In both varieties, RGR decreased significantly (P<0.05) with an increase in NaCl concentration (Table 1). In Clemson Spineless, RGR declined from 0.46 ± 0.01 g g^{-1} $month^{-1}$ at control to 0.14 ± 0.02 g g^{-1} $month^{-1}$ at 0.15% NaCl — a 70% reduction. LD88 showed a lower proportional decline from 0.44 ± 0.01 to 0.16 ± 0.03 g g^{-1} $month^{-1}$.

Table 1: Effect of Salinity Stress on Relative Growth Rate (RGR, g g^{-1} $month^{-1}$) Of Two Varieties of *Abelmoschus Esculentus* (mean ± SE)

Variety	Control (0%)	0.05% NaCl	0.10% NaCl	0.15% NaCl
Clemson Spineless	0.46 ± 0.01^a	0.33 ± 0.02^b	0.14 ± 0.02^c	0.14 ± 0.02^c
LD88	0.44 ± 0.01^a	0.40 ± 0.01^b	0.27 ± 0.02^c	0.16 ± 0.03^d

NaCl = sodium chloride; values are mean ± SE (n=3). Means in the same row sharing the same superscript are not significantly different (P<0.05, LSD).

The effect of Salinity on Net Assimilation Rate (NAR)

Both varieties showed a significant decrease (P<0.05) in NAR as salinity level increased (Table 2). Clemson Spineless NAR fell from 0.41 ± 0.00 g g^{-1} $month^{-1}$ at control to 0.16 ± 0.02 g g^{-1} $month^{-1}$ at 0.15% NaCl. The NAR of LD88 decreased from 0.47 ± 0.03 to 0.29 ± 0.07 g g^{-1} $month^{-1}$, still significantly higher than in all other groups.

Table 2: Two Varieties of Abelmoschus Esculentus Were Subjected to Salinity Stress, And the Effect of Salinity on the Net Assimilation Rate (NAR, g g^{-1} $month^{-1}$) is Presented as the Mean ± SE

Variety	Control (0%)	0.05% NaCl	0.10% NaCl	0.15% NaCl
Clemson Spineless	0.41 ± 0.00^a	0.33 ± 0.03^b	0.15 ± 0.01^c	0.16 ± 0.02^c
LD88	0.47 ± 0.03^a	0.44 ± 0.04^a	0.31 ± 0.02^b	0.29 ± 0.07^b

NaCl = sodium chloride; values are mean ± SE (n=3). Means in the same row sharing the same superscript are not significantly different (P<0.05, LSD).

Leaf Area Ratio (LAR)
In case of LAR, there was a significant decline (P<0.05) in the concentrations of NaCl in both varieties of the experiment (Table 3). Clemson Spineless LAR decreased from 49.8 ± 2.3 $cm^2\ g^{-1}$ at control to 23.9 ± 1.4 $cm^2\ g^{-1}$ at 0.15% NaCl, while LD88 declined from 46.2 ± 2.1 to 22.1 ± 1.3 $cm^2\ g^{-1}$. LAR decreases as the leaf area of the plant decreases as a percentage of the total plant dry matter

Table 3: Salinity Stress Effect on Leaf Area Ratio (Cm^2/G) Of Two Varieties of *Abelmoschus esculentus* (MEAN ± SE)

Variety	Control (0%)	0.05% NaCl	0.10% NaCl	0.15% NaCl
Clemson Spineless	49.8 ± 2.3^{a}	40.6 ± 2.0^{b}	30.1 ± 1.7^{c}	23.9 ± 1.4^{d}
LD88	46.2 ± 2.1^{a}	37.5 ± 1.8^{b}	28.4 ± 1.5^{c}	22.1 ± 1.3^{d}

NaCl = sodium chloride; values are mean ± SE (n=3). Means in the same row sharing the same superscript are not significantly different (P<0.05, LSD).

Discussion
In this study, it is clearly established that the salinity level of NaCl has a significant and dose-dependent inhibitory effect on the growth, biomass accumulation and pod yield of *Abelmoschus esculentus*. The progressive decrease in all the measured parameters with increasing NaCl concentration is mechanistically understandable as salt stress consists of two stages: osmotic phase (where fast reduction in water uptake leads to decreased cell turgor and expansion) and ionic phase (where accumulated NaCl displaces essential mineral nutrients and adversely affects enzyme activity and electron transport in photosynthesis) (Shahid *et al.,* 2023; Hussain *et al.,* 2021).
In the present study, significant reductions in plant height with increased salinity were observed, consistent with Adetunji *et al.,* (2022) who found decreasing plant height with increasing NaCl concentrations (50-200mM) in a greenhouse experiment in southwestern Nigeria. The relatively lower reduction in height in LD88 compared to Clemson Spineless at different salinities suggests it has more ability to osmotically adjust which involves the accumulation of compatible solutes for cell turgidity maintenance and continued meristematic activity under salinity stress, a major indicator of annual crops salt tolerance (Saddiq *et al.,* 2021). Accumulation of compatible solutes like proline is a well establish part of this osmotic adjustment response and it has been demonstrated that this process can have a synergistic effect on salinity tolerance in other crop species (El Kheshin and Hmmam, 2025).
The effects of leaf number and leaf area reduction due to salinity have cascading impacts on derived growth analysis indices. The reduction of RGR due to salinity is the multiplicative effect of the reduction of NAR (decreased photosynthetic efficiency) and the reduction of LAR (decreased leaf area per unit biomass) as salinity increases. This mechanistic relationship has been well documented in the literature of plant growth analysis (Poorter *et al.,* 2022) and accounts for the greater percentage decrease in RGR of Clemson Spineless when exposed to the range of stress levels from 0.1 to 0.15% NaCl as compared to the percentage decrease in plant height at the same stress level.
Salinity had the greatest negative effect on pod yield (pod number, length and dry weight), with pod number of Clemson Spineless being reduced 68% and 72% by salinity from control to 0.15% NaCl, respectively. Annual crops, especially, are particularly vulnerable to ionic stress as their reproductive development occurs during the time of highest ion accumulation in their above-ground tissues, which affects assimilate partitioning and reduces sink capacity of developing fruits in the presence of sodium toxicity during floral initiation and pod fill (Dağdelen *et al.,* 2021). The present results corroborates with Nkansah *et al.,* (2022) who reported significant reduction in pod yield of okra in saline irrigation regimes in Ghana.
The results for all growth, biomass and yield parameters at all salinity levels showed that LD88 consistently outperformed Clemson Spineless, suggesting that it has a range of physiological traits favorable for salt tolerance. These are likely to involve more efficient vacuolar Na^+ sequestration, higher Na^+/K^+ selectivity at the root, superior antioxidant enzyme upregulation in response to salinity-induced oxidative stress and higher constitutive levels of osmolyte accumulation (Shahid *et al.,* 2023; Hatfield and Dold, 2020). Genes involved in Na+/K+-balance (Farooq *et al.,* 2021) need to be characterised in these biochemical and molecular mechanisms in order to develop salt tolerant okra production lines suitable to the growing conditions in West Africa, while also contributing to the diversification of other crops suitable for salt-affected production areas (Hirich and Bhargava, 2024).

CONCLUSION
All the growth parameters of *Abelmoschus esculentus*, including plant height, leaf number, leaf area, shoot dry weight, root dry weight, pod number, pod length, pod dry weight, RGR, NAR and LAR, showed significant decrease in a dose-dependent manner as salinity stress level was increased from 0% to 0.15% NaCl. The most growth- and yield-suppressive treatment was NaCl at 0.15% causing a 70% reduction in RGR of Clemson Spineless and 68% reduction in pod numbers compared to the control treatment. Since it was more tolerant under all parameters across all soil salinity levels of production, LD88 is recommended for vegetable production systems in Nigeria and other agro-ecological zones with salinity prone production areas.

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