

**Germination, Growth and Root Responses of Selected Kenyan Cowpea Varieties under Salt Stress**

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**Abstract**

Soil salinity limits crop establishment and productivity in semi-arid environments. Cowpea (*Vigna unguiculata* L. Walp.) is an important crop in the semi-arid parts of Kenya, but its response to salt stress is poorly documented. Seventeen Kenyan cowpea varieties were screened in the greenhouse under six NaCl treatments (electrical conductivity, EC, of 0, 4, 8, 12, 14 and 15 dS m<sup>-1</sup>). Plants were harvested 40 days after planting. We measured germination, plant height, leaf number, shoot fresh and dry weight, root number and total root length. Salinity above 8 dS m<sup>-1</sup> delayed germination and reduced germination percentage, biomass and root development, and no seeds germinated at 15 dS m<sup>-1</sup>. Between the control and 14 dS m<sup>-1</sup>, mean germination time rose from 5.7 to 18.5 days and germination percentage fell from 98.7% to 55.6%. Across varieties, mean plant height at 14 dS m<sup>-1</sup> was about 80% lower than in the control. Kunde Kubwa and Ken Kunde ranked consistently among the best performers. At 14 dS m<sup>-1</sup>, Kunde Kubwa had the highest shoot fresh weight (2.29 g) and kept 80% germination, and Ken Kunde had the tallest plants (12.1 cm). Kunde Mboga, Kunde Faulu, Black Kunde, Khaki and M 66 performed poorly across several traits at 14 dS m<sup>-1</sup>. These results show substantial variation in salt response among Kenyan cowpea varieties. They also show that combining establishment, growth, biomass and root traits gives a stronger basis for early-stage salinity screening than any single indicator. Kunde Kubwa and Ken Kunde are recommended for validation under saline field conditions.

**Keywords:** *Vigna unguiculata*; salt resistance; germination; biomass; root development

**Introduction**

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important legume across sub-Saharan Africa, where it supports food and nutritional security in smallholder farming systems (Abraha, 2025). Its short growth cycle, tolerance of heat and low rainfall, and ability to fix atmospheric nitrogen make it especially valuable in marginal environments (Affrifah et al., 2022). The leaves, immature pods and seeds are all widely eaten (Arifuddin & Al Banna, 2025). In Kenya, cowpea is a source of food and income in the arid and semi-arid areas. These areas are often prone to soil salinization, which threatens crop establishment and growth. Salinity is a major constraint on crop production because it limits water availability and disrupts ion balance across cell membranes. It develops as soluble salts accumulate under high evaporation, poor drainage or saline irrigation water. The resulting fall in the osmotic potential of the soil solution makes water uptake harder. Accumulated ions, especially Na<sup>+</sup>, can also cause ionic toxicity and interfere with the uptake of nutrients such as K<sup>+</sup>. Salt stress can further drive excess production of reactive oxygen species, which damage proteins, lipids and membranes (Munns & Tester, 2008).

Salt stress can reduce germination percentage, lengthen mean germination time and lower seedling vigour. Final germination percentage alone may not capture a genotype's response, because seeds that germinate under salt stress may do so much later (Rai et al., 2025). Germination traits therefore give complementary information on how quickly a genotype can establish under adverse conditions. In cowpea, the response to salinity also shifts with developmental stage, and some concentrations have little effect on germination itself (Afonso et al., 2025).

Salt-stressed plants usually grow less. Substrate salinity causes apparent plant water stress, which reduces cell turgor and expansion. Reduced expansion impairs photosynthesis and limits shoot growth, while ionic imbalance and oxidative stress further constrain carbon assimilation and nutrient acquisition (Murillo-Amador et al., 2006). The root is the first organ exposed to soil salinity. Salinity can restrict root elongation and branching, which reduces the soil volume explored for water and nutrients. Maintaining root length, root number and related traits is therefore associated with salt tolerance (Karahara & Horie, 2021). Evaluating shoot and root responses together gives a more complete picture of tolerance than above-ground growth alone.

Cowpea is generally considered hardy, but its response to salinity varies widely among varieties and growth stages (Jayawardhane et al., 2022). This variation offers a chance to identify locally adapted genotypes that keep growing under saline conditions. Information on the salt response of Kenyan cowpea genotypes is limited, particularly where germination, vegetative growth, biomass and root architecture are considered together. This study evaluated 17 Kenyan cowpea varieties under increasing salinity. It assessed germination, plant height, leaf number, shoot biomass, root length and root number. The aim was to identify varieties that maintain establishment, growth and physiological function under saline conditions.

## Materials and Methods

### Study Site and Plant Material

The study was conducted in a greenhouse at the University of Eldoret, Uasin Gishu County, Kenya, under natural daylight (about 12 h), daytime temperatures of 30–35 °C and relative humidity of 60–70%. Seventeen cowpea varieties were sourced from the Kenya Agricultural and Livestock Research Organization (KALRO) and the Kenya Seed Company (Table 1).

### Salt Treatments and Experimental Design

Sodium chloride (NaCl) solutions were prepared in distilled water to give electrical conductivity (EC) levels of 0 (control), 4, 8, 12, 14 and 15 dS m<sup>-1</sup>, which span non-saline to high-salinity conditions (Munns & Tester, 2008). EC was verified at 25 °C with a Pen Type P-312 EC meter (Shanghai Yoke Instrument Co. Ltd.). Five seeds of each variety were sown in 4.5-kg plastic pots with perforated bases, each holding 4 kg of washed, heat-sterilized river sand (1.5–2.0 mm). A volume of 500 mL of the corresponding salt solution was added to bring the sand to field capacity. Pots were arranged in a completely randomized design with six replicates, and each pot stood in its own tray to catch leachate. Diammonium phosphate (DAP) was applied at half rate at planting to supply starter nitrogen and phosphorus. Calcium ammonium nitrate (CAN) was top-dressed 20 days after planting to support vegetative growth. Seedlings were later thinned to three uniform plants per pot.

### Germination

Germination was monitored daily for 14 days, and emergence of the shoot above the substrate counted as germination. Germination percentage (GP) and mean germination time (MGT) were calculated following Islam et al. (2019) and Tanyeer et al. (2010), respectively:

$$\text{MGT} = \Sigma(T_i N_i) / \Sigma N_i \quad \dots\dots\dots (1)$$

where  $N_i$  is the number of seeds newly germinated on day  $T_i$ , and

$$\text{GP (\%)} = (\text{number of germinated seeds} / \text{number of seeds sown}) \times 100 \quad \dots\dots (2)$$

### Growth Measurements

At harvest (40 days after planting, DAP), plant height, leaf number, shoot fresh and dry weight, and total root number and length were determined. Plant height was measured from the substrate surface to the tip of the youngest mature leaf. Roots were recovered carefully, washed and scanned with an HP ICT SJ-300 scanner. Root number and total root length were quantified with RhizoVision Explorer®. Shoot and root fresh weights were recorded immediately after washing and blotting dry. Shoots and roots were then oven-dried at 70 °C to constant weight to obtain dry biomass.

### Statistical Analysis

All analyses were done in R v4.5.0 (R Core Team, 2025). Data were first checked for normality with the Shapiro–Wilk test and fitted to a linear model (lm), and global validation checks were run before ANOVA. Where the data did

not meet the assumptions of the linear model, a mixed-effects model (nlme::lme) was used instead, with variety and salinity level as fixed factors and replicate as a random factor. Tukey's HSD test separated means at the 95% confidence level.

## Results and Discussion

### Germination

Salinity delayed germination and reduced germination percentage (Table 1). Averaged across varieties, mean germination time rose significantly ( $P < 0.05$ ) from 5.7 days in the control to 18.5 days at 14 dS m<sup>-1</sup>. Germination percentage fell significantly from 98.7% to 55.6% over the same range. No seeds germinated at 15 dS m<sup>-1</sup>. Varieties differed numerically, but the variety  $\times$  salinity interaction was not significant for either trait ( $P > 0.05$ ). At 14 dS m<sup>-1</sup>, germination percentage ranged from 20.0% in Kunde Faulu to 90.0% in Kat Kunde, followed by Kunde Kubwa (80.0%) and K-80 (76.7%). Mean germination time at that level ranged from 14.3 days in Kunde Kubwa to 24.3 days in Kaltex 7. Ken Kunde took 14.9 days.

**Table 1. Mean germination time and germination percentage of selected cowpea varieties as affected by salt stress**

| Variety       | Mean germination time (days) |                      |                      |                       |                       | Germination percentage (%) |                      |                      |                       |                       |
|---------------|------------------------------|----------------------|----------------------|-----------------------|-----------------------|----------------------------|----------------------|----------------------|-----------------------|-----------------------|
|               | Control                      | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> | Control                    | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> |
| Kat Kunde     | 5.0 <sup>a</sup>             | 9.0 <sup>b-i</sup>   | 11.8 <sup>g-v</sup>  | 12.7 <sup>k-w</sup>   | 19.7 <sup>f-z</sup>   | 100.0 <sup>i</sup>         | 96.7 <sup>h-i</sup>  | 96.7 <sup>h-i</sup>  | 93.3 <sup>h-i</sup>   | 90.0 <sup>e-i</sup>   |
| Kunde Tamu    | 5.5 <sup>ab</sup>            | 10.0 <sup>e-o</sup>  | 12.1 <sup>h-w</sup>  | 13.0 <sup>l-x</sup>   | 17.2 <sup>z-f</sup>   | 100.0 <sup>i</sup>         | 96.7 <sup>h-i</sup>  | 90.0 <sup>e-i</sup>  | 83.3 <sup>d-i</sup>   | 60.0 <sup>b-h</sup>   |
| Kunde Tumaini | 5.7 <sup>abc</sup>           | 10.0 <sup>e-o</sup>  | 11.8 <sup>g-v</sup>  | 13.3 <sup>m-y</sup>   | 17.1 <sup>z-f</sup>   | 96.7 <sup>h-i</sup>        | 96.7 <sup>h-i</sup>  | 91.7 <sup>f-i</sup>  | 80.0 <sup>c-i</sup>   | 46.7 <sup>a-d</sup>   |
| K-80          | 6.0 <sup>a-d</sup>           | 9.0 <sup>b-i</sup>   | 11.1 <sup>f-s</sup>  | 13.5 <sup>n-z</sup>   | 16.4 <sup>x-f</sup>   | 100.0 <sup>i</sup>         | 100.0 <sup>i</sup>   | 96.7 <sup>h-i</sup>  | 93.3 <sup>g-i</sup>   | 76.7 <sup>c-i</sup>   |
| Kunde Soko    | 6.0 <sup>a-d</sup>           | 10.0 <sup>e-o</sup>  | 11.8 <sup>g-v</sup>  | 13.5 <sup>n-z</sup>   | 17.1 <sup>z-f</sup>   | 96.7 <sup>h-i</sup>        | 93.3 <sup>g-i</sup>  | 83.3 <sup>d-i</sup>  | 73.3 <sup>b-i</sup>   | 60.0 <sup>b-h</sup>   |
| Kunde Faulu   | 7.0 <sup>a-e</sup>           | 10.5 <sup>e-r</sup>  | 11.8 <sup>g-v</sup>  | 13.4 <sup>m-y</sup>   | 15.6 <sup>w-zc</sup>  | 100.0 <sup>i</sup>         | 83.3 <sup>d-i</sup>  | 76.7 <sup>c-i</sup>  | 56.7 <sup>a-g</sup>   | 20.0 <sup>a</sup>     |
| Kaltex 14     | 6.0 <sup>a-d</sup>           | 8.6 <sup>a-h</sup>   | 12.5 <sup>i-w</sup>  | 13.7 <sup>n-z</sup>   | 17.4 <sup>z-g</sup>   | 100.0 <sup>i</sup>         | 93.3 <sup>g-i</sup>  | 83.3 <sup>d-i</sup>  | 80.0 <sup>c-i</sup>   | 60.0 <sup>b-h</sup>   |
| Kaltex 7      | 6.0 <sup>a-d</sup>           | 10.0 <sup>e-o</sup>  | 11.7 <sup>g-v</sup>  | 13.8 <sup>n-z</sup>   | 24.3 <sup>z-i</sup>   | 100.0 <sup>i</sup>         | 93.3 <sup>g-i</sup>  | 88.3 <sup>c-i</sup>  | 80.0 <sup>c-i</sup>   | 73.3 <sup>b-i</sup>   |
| M 66          | 5.8 <sup>abc</sup>           | 9.0 <sup>b-i</sup>   | 11.4 <sup>f-u</sup>  | 13.9 <sup>q-z</sup>   | 16.8 <sup>y-f</sup>   | 100.0 <sup>i</sup>         | 83.3 <sup>d-i</sup>  | 83.3 <sup>d-i</sup>  | 76.6 <sup>c-i</sup>   | 43.3 <sup>abc</sup>   |
| Ken Kunde     | 5.0 <sup>a</sup>             | 8.0 <sup>a-f</sup>   | 10.4 <sup>e-q</sup>  | 10.8 <sup>f-s</sup>   | 14.9 <sup>t-ze</sup>  | 100.0 <sup>i</sup>         | 100.0 <sup>i</sup>   | 83.3 <sup>d-i</sup>  | 73.3 <sup>b-i</sup>   | 66.7 <sup>b-i</sup>   |
| Kunde Mboga   | 6.0 <sup>a-d</sup>           | 11.0 <sup>f-s</sup>  | 14.1 <sup>r-d</sup>  | 15.3 <sup>v-z</sup>   | 23.5 <sup>z-i</sup>   | 100.0 <sup>i</sup>         | 83.3 <sup>d-i</sup>  | 73.3 <sup>b-i</sup>  | 70.0 <sup>b-i</sup>   | 51.7 <sup>a-e</sup>   |
| Kang'au       | 5.7 <sup>abc</sup>           | 10.0 <sup>e-o</sup>  | 12.6 <sup>i-w</sup>  | 13.3 <sup>m-y</sup>   | 19.9 <sup>z-h</sup>   | 96.7 <sup>h-i</sup>        | 86.7 <sup>e-i</sup>  | 86.7 <sup>e-i</sup>  | 70.0 <sup>b-i</sup>   | 46.7 <sup>a-d</sup>   |
| Kunde Kubwa   | 5.0 <sup>a</sup>             | 8.4 <sup>a-g</sup>   | 10.8 <sup>f-s</sup>  | 12.6 <sup>i-w</sup>   | 14.3 <sup>s-z</sup>   | 100.0 <sup>i</sup>         | 96.7 <sup>h-i</sup>  | 96.7 <sup>h-i</sup>  | 90.0 <sup>e-i</sup>   | 80.0 <sup>c-i</sup>   |
| Khaki         | 5.7 <sup>abc</sup>           | 8.5 <sup>a-g</sup>   | 11.4 <sup>f-u</sup>  | 13.1 <sup>m-x</sup>   | 20.8 <sup>z-g</sup>   | 100.0 <sup>i</sup>         | 93.3 <sup>g-i</sup>  | 93.3 <sup>g-i</sup>  | 91.7 <sup>f-i</sup>   | 36.7 <sup>ab</sup>    |
| Kunde Ndogo   | 5.5 <sup>ab</sup>            | 10.0 <sup>e-o</sup>  | 12.6 <sup>i-w</sup>  | 14.9 <sup>n-z</sup>   | 18.3 <sup>z-g</sup>   | 96.7 <sup>h-i</sup>        | 96.7 <sup>h-i</sup>  | 93.3 <sup>g-i</sup>  | 63.3 <sup>b-i</sup>   | 43.3 <sup>abc</sup>   |
| Purple Pod    | 5.0 <sup>a</sup>             | 9.4 <sup>d-l</sup>   | 11.3 <sup>f-t</sup>  | 13.5 <sup>n-z</sup>   | 19.9 <sup>z-h</sup>   | 100.0 <sup>i</sup>         | 93.3 <sup>g-i</sup>  | 63.3 <sup>b-i</sup>  | 53.3 <sup>a-f</sup>   | 53.3 <sup>a-f</sup>   |
| Black Kunde   | 6.0 <sup>a-d</sup>           | 10.2 <sup>e-p</sup>  | 10.9 <sup>f-s</sup>  | 11.6 <sup>g-u</sup>   | 22.0 <sup>z-i</sup>   | 91.7 <sup>f-i</sup>        | 86.7 <sup>e-i</sup>  | 86.7 <sup>e-i</sup>  | 86.7 <sup>e-i</sup>   | 36.7 <sup>ab</sup>    |

Values followed by the same letter are not significantly different at  $P = 0.05$ .

Salinity delayed emergence as well as reducing it. At 14 dS m<sup>-1</sup>, seeds needed 14.3 to 24.3 days to germinate, against 5 to 7 days in the control. Similar reductions in cowpea germination with rising NaCl have been reported (Afonso et al., 2025; Thiam et al., 2013). The delay is best explained by restricted water uptake. Higher salt concentrations lower the water potential of the medium, and adequate hydration is needed to activate enzymes, mobilize reserves and support embryo growth (Dadlani & Yadava, 2023). At higher salinity, Na<sup>+</sup> and Cl<sup>-</sup> accumulation probably adds to this by disturbing cellular ion balance and metabolism (Manono, 2026; Munns & Tester, 2008).

The wide spread among varieties at 14 dS m<sup>-1</sup> is useful for identifying promising genotypes, in line with earlier reports of large genetic variation in cowpea salt tolerance at germination (Ravelombola et al., 2017). Some varieties showed a sharp threshold. Khaki, for example, still germinated at 91.7% at 12 dS m<sup>-1</sup> but only 36.7% at 14 dS m<sup>-1</sup>. Because the variety  $\times$  salinity interaction was not significant, these rankings are indicative and not conclusive. Tolerance at germination also does not always carry over into later growth. A cultivar can keep germinating under NaCl and still suffer a large reduction in seedling growth (Tavares et al., 2021). For this reason, germination was combined here with vegetative, biomass and root traits.

## Plant Height and Leaf Number

Plant height fell significantly ( $P < 0.05$ ) with rising salinity in every variety (Table 2). Mean height across varieties dropped from 34.1 cm in the control to 25.3, 21.6, 16.4 and 6.6 cm at 4, 8, 12 and 14 dS m<sup>-1</sup>, which is a reduction of about 80% at the highest level. Leaf number also declined significantly in all varieties, from a mean of 4.5 leaves per plant to 0.4. At 14 dS m<sup>-1</sup>, ten varieties had no leaves and seven had one. Ken Kunde (12.1 cm) and Kunde Kubwa (11.3 cm) kept the greatest height, and both still had one leaf. Kunde Mboga (1.6 cm), Kunde Faulu (1.9 cm), M 66 (2.0 cm), Black Kunde (2.1 cm) and Khaki (2.5 cm) were the shortest.

**Table 2. Plant height and leaf number of cowpea varieties as affected by salt stress at 40 days after sowing (DAS)**

| Variety       | Plant height (cm)   |                      |                      |                       |                       | Number of leaves |                      |                      |                       |                       |
|---------------|---------------------|----------------------|----------------------|-----------------------|-----------------------|------------------|----------------------|----------------------|-----------------------|-----------------------|
|               | Control             | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> | Control          | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> |
| Kat Kunde     | 31.6 <sup>b-z</sup> | 24.6 <sup>j-z</sup>  | 22.6 <sup>f-z</sup>  | 15.8 <sup>a-p</sup>   | 9.2 <sup>a-j</sup>    | 4 <sup>e-i</sup> | 4 <sup>e-i</sup>     | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>      | 1 <sup>a-d</sup>      |
| Kunde Tamu    | 35.6 <sup>w-z</sup> | 25.4 <sup>m-z</sup>  | 21.6 <sup>f-y</sup>  | 15.7 <sup>a-p</sup>   | 7.6 <sup>a-h</sup>    | 5 <sup>f-i</sup> | 4 <sup>e-i</sup>     | 2 <sup>a-f</sup>     | 2 <sup>a-f</sup>      | 1 <sup>a-d</sup>      |
| Kunde Tumaini | 31.0 <sup>b-z</sup> | 23.8 <sup>i-z</sup>  | 22.1 <sup>f-z</sup>  | 16.2 <sup>a-q</sup>   | 3.1 <sup>a-e</sup>    | 4 <sup>e-i</sup> | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>     | 2 <sup>a-f</sup>      | 0 <sup>a</sup>        |
| K-80          | 32.3 <sup>t-z</sup> | 25.2 <sup>k-z</sup>  | 21.6 <sup>f-y</sup>  | 18.9 <sup>e-v</sup>   | 9.3 <sup>a-k</sup>    | 5 <sup>f-i</sup> | 4 <sup>e-i</sup>     | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>      | 0 <sup>a</sup>        |
| Kunde Soko    | 36.8 <sup>x-z</sup> | 26.9 <sup>n-z</sup>  | 23.7 <sup>i-z</sup>  | 18.4 <sup>d-u</sup>   | 9.4 <sup>a-l</sup>    | 5 <sup>f-i</sup> | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>     | 2 <sup>a-f</sup>      | 0 <sup>a</sup>        |
| Kunde Faulu   | 34.3 <sup>v-z</sup> | 25.6 <sup>m-z</sup>  | 24.2 <sup>i-z</sup>  | 16.5 <sup>a-r</sup>   | 1.9 <sup>ab</sup>     | 4 <sup>e-i</sup> | 4 <sup>e-i</sup>     | 4 <sup>e-i</sup>     | 3 <sup>b-i</sup>      | 0 <sup>a</sup>        |
| Kaltex 14     | 32.6 <sup>w-z</sup> | 26.5 <sup>n-z</sup>  | 22.2 <sup>f-z</sup>  | 17.0 <sup>e-t</sup>   | 9.7 <sup>a-m</sup>    | 4 <sup>e-i</sup> | 3 <sup>b-i</sup>     | 2 <sup>a-f</sup>     | 2 <sup>a-f</sup>      | 0 <sup>a</sup>        |
| Kaltex 7      | 33.9 <sup>u-z</sup> | 25.3 <sup>l-z</sup>  | 23.6 <sup>i-z</sup>  | 18.6 <sup>e-v</sup>   | 9.4 <sup>a-l</sup>    | 3 <sup>b-i</sup> | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>     | 2 <sup>a-f</sup>      | 1 <sup>a-d</sup>      |
| M 66          | 31.2 <sup>b-z</sup> | 23.4 <sup>h-z</sup>  | 18.6 <sup>e-v</sup>  | 14.4 <sup>a-o</sup>   | 2.0 <sup>abc</sup>    | 5 <sup>f-i</sup> | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>     | 2 <sup>a-f</sup>      | 0 <sup>a</sup>        |
| Ken Kunde     | 31.1 <sup>b-z</sup> | 24.2 <sup>j-z</sup>  | 23.2 <sup>h-z</sup>  | 16.8 <sup>a-s</sup>   | 12.1 <sup>a-n</sup>   | 4 <sup>e-i</sup> | 4 <sup>e-i</sup>     | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>      | 1 <sup>a-d</sup>      |
| Kunde Mboga   | 37.0 <sup>x-z</sup> | 22.4 <sup>f-z</sup>  | 18.9 <sup>e-v</sup>  | 15.6 <sup>a-p</sup>   | 1.6 <sup>a</sup>      | 5 <sup>f-i</sup> | 4 <sup>e-i</sup>     | 4 <sup>e-i</sup>     | 2 <sup>a-f</sup>      | 0 <sup>a</sup>        |
| Kang'au       | 33.7 <sup>u-z</sup> | 25.8 <sup>n-z</sup>  | 23.5 <sup>h-z</sup>  | 18.1 <sup>d-u</sup>   | 6.8 <sup>a-g</sup>    | 4 <sup>e-i</sup> | 4 <sup>e-i</sup>     | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>      | 1 <sup>a-d</sup>      |
| Kunde Kubwa   | 37.7 <sup>z</sup>   | 25.7 <sup>n-z</sup>  | 20.8 <sup>f-w</sup>  | 18.0 <sup>d-u</sup>   | 11.3 <sup>a-n</sup>   | 5 <sup>f-i</sup> | 4 <sup>e-i</sup>     | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>      | 1 <sup>a-d</sup>      |
| Khaki         | 37.6 <sup>z</sup>   | 27.0 <sup>n-z</sup>  | 23.3 <sup>h-z</sup>  | 14.9 <sup>a-o</sup>   | 2.5 <sup>a-d</sup>    | 5 <sup>f-i</sup> | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>      | 0 <sup>a</sup>        |
| Kunde Ndogo   | 32.8 <sup>x-z</sup> | 28.9 <sup>o-z</sup>  | 18.1 <sup>d-u</sup>  | 13.6 <sup>a-o</sup>   | 6.7 <sup>a-f</sup>    | 5 <sup>f-i</sup> | 4 <sup>e-i</sup>     | 3 <sup>b-i</sup>     | 3 <sup>b-i</sup>      | 0 <sup>a</sup>        |
| Purple Pod    | 38.9 <sup>ab</sup>  | 26.1 <sup>n-z</sup>  | 21.0 <sup>f-x</sup>  | 15.7 <sup>a-p</sup>   | 8.2 <sup>a-i</sup>    | 5 <sup>f-i</sup> | 4 <sup>e-i</sup>     | 3 <sup>b-i</sup>     | 2 <sup>a-f</sup>      | 1 <sup>a-d</sup>      |
| Black Kunde   | 32.1 <sup>q-z</sup> | 22.7 <sup>h-z</sup>  | 17.6 <sup>b-t</sup>  | 14.6 <sup>a-o</sup>   | 2.1 <sup>a-c</sup>    | 5 <sup>f-i</sup> | 4 <sup>e-i</sup>     | 4 <sup>e-i</sup>     | 4 <sup>e-i</sup>      | 0 <sup>a</sup>        |

Values followed by the same letter are not significantly different at  $P = 0.05$ .

Height, leaf number and shoot biomass declined together. This suggests that salinity reduced the general capacity for vegetative growth and not any single trait. Similar reductions in shoot growth have been reported in cowpea under NaCl and saline irrigation, with the size of the effect depending on variety (Dong et al., 2019; Santos et al., 2025). The first constraint on shoot growth is usually osmotic. Salt in the root zone lowers its osmotic potential and makes water uptake harder even when water is present, which reduces plant water status and turgor (Lu & Fricke, 2023). Cell expansion depends on turgor, so developing leaves and stems are especially sensitive early on. This is the rapid osmotic phase described by Munns and Tester (2008), when young-leaf growth is inhibited before much ion accumulates in older tissue.

Root-to-shoot hormonal and hydraulic signals may add to this effect. They can restrict leaf expansion and stomatal conductance before toxic Na<sup>+</sup> builds up in leaves (Munns & Tester, 2008; Zou et al., 2022). Leaves are the main photosynthetic surface, so fewer and smaller leaves mean less light interception and CO<sub>2</sub> assimilation. Salt can reduce photosynthesis further through stomatal closure and, under severe stress, through damage to the photosynthetic machinery (Jan et al., 2025). The loss of leaves at 14 dS m<sup>-1</sup> therefore probably reflects a reduced capacity to produce the assimilates needed for growth, as well as a visible growth response.

## Shoot Fresh and Dry Weight

Shoot fresh weight did not differ significantly among most varieties in the control. It fell significantly with increasing salinity, from a mean of 15.2 g in the control to 6.3 g at 8 dS m<sup>-1</sup> and 1.1 g at 14 dS m<sup>-1</sup> (Table 3). Shoot dry weight followed the same trend, with little varietal difference in the control and a significant decline as salinity rose, from a mean of 2842 mg to 126 mg. At 14 dS m<sup>-1</sup>, Kunde Kubwa had the highest shoot fresh weight (2.29 g), followed by Ken Kunde (2.06 g) and Kaltex 14 (1.91 g). Shoot dry weight was highest in Kaltex 14 (265 mg), Kunde Soko (263 mg) and Kunde Kubwa (248 mg). Ken Kunde had 193 mg. The lowest shoot fresh weights were in Kunde Faulu and

Kunde Mboga (0.28 g each), Khaki (0.37 g), M 66 (0.38 g) and Black Kunde (0.40 g). The lowest shoot dry weights were in Black Kunde (15 mg), Kunde Mboga and Kunde Faulu (23 mg each), M 66 (28 mg) and Khaki (38 mg).

**Table 3. Shoot fresh weight and shoot dry weight of cowpea varieties as affected by salt stress at 40 DAS**

| Variety       | Shoot fresh weight (g) |                      |                      |                       |                       | Shoot dry weight (mg) |                      |                      |                       |                       |
|---------------|------------------------|----------------------|----------------------|-----------------------|-----------------------|-----------------------|----------------------|----------------------|-----------------------|-----------------------|
|               | Control                | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> | Control               | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> |
| Kat Kunde     | 12.67 <sup>h-w</sup>   | 12.30 <sup>f-w</sup> | 5.35 <sup>a-m</sup>  | 2.93 <sup>a-c</sup>   | 1.27 <sup>ab</sup>    | 2580 <sup>a-c</sup>   | 2582 <sup>a-c</sup>  | 887 <sup>l-q</sup>   | 568 <sup>l-q</sup>    | 132 <sup>pq</sup>     |
| Kunde Tamu    | 15.97 <sup>f-w</sup>   | 15.70 <sup>q-w</sup> | 6.53 <sup>a-p</sup>  | 5.03 <sup>a-m</sup>   | 1.26 <sup>ab</sup>    | 2890 <sup>a-c</sup>   | 2002 <sup>c-k</sup>  | 837 <sup>l-q</sup>   | 820 <sup>l-q</sup>    | 128 <sup>pq</sup>     |
| Kunde Tumaini | 14.60 <sup>n-w</sup>   | 8.60 <sup>a-u</sup>  | 5.70 <sup>a-n</sup>  | 4.20 <sup>a-m</sup>   | 0.71 <sup>a</sup>     | 2820 <sup>a-c</sup>   | 2002 <sup>c-k</sup>  | 935 <sup>l-q</sup>   | 383 <sup>l-q</sup>    | 63 <sup>pq</sup>      |
| K-80          | 15.83 <sup>f-w</sup>   | 12.40 <sup>g-w</sup> | 6.87 <sup>a-r</sup>  | 4.37 <sup>a-k</sup>   | 1.18 <sup>ab</sup>    | 2260 <sup>b-g</sup>   | 2093 <sup>c-i</sup>  | 838 <sup>l-q</sup>   | 740 <sup>l-q</sup>    | 143 <sup>pq</sup>     |
| Kunde Soko    | 17.10 <sup>i-w</sup>   | 12.30 <sup>f-w</sup> | 7.20 <sup>a-s</sup>  | 1.77 <sup>abc</sup>   | 1.69 <sup>ab</sup>    | 2840 <sup>a-c</sup>   | 2085 <sup>d-i</sup>  | 1293 <sup>f-m</sup>  | 570 <sup>l-q</sup>    | 263 <sup>m-q</sup>    |
| Kunde Faulu   | 12.90 <sup>i-w</sup>   | 11.47 <sup>e-w</sup> | 8.05 <sup>a-t</sup>  | 4.97 <sup>a-m</sup>   | 0.28 <sup>a</sup>     | 2780 <sup>a-c</sup>   | 2072 <sup>d-j</sup>  | 1220 <sup>b-o</sup>  | 850 <sup>l-q</sup>    | 23 <sup>q</sup>       |
| Kaltex 14     | 15.10 <sup>o-w</sup>   | 13.43 <sup>k-w</sup> | 6.70 <sup>a-q</sup>  | 4.28 <sup>a-j</sup>   | 1.91 <sup>abc</sup>   | 2970 <sup>a-c</sup>   | 2487 <sup>a-c</sup>  | 927 <sup>l-q</sup>   | 882 <sup>l-q</sup>    | 265 <sup>m-q</sup>    |
| Kaltex 7      | 13.07 <sup>i-w</sup>   | 11.33 <sup>d-w</sup> | 8.93 <sup>a-v</sup>  | 6.37 <sup>a-p</sup>   | 1.30 <sup>ab</sup>    | 3060 <sup>a-d</sup>   | 2087 <sup>d-i</sup>  | 1085 <sup>i-p</sup>  | 843 <sup>l-q</sup>    | 153 <sup>pq</sup>     |
| M 66          | 12.43 <sup>f-w</sup>   | 10.20 <sup>b-w</sup> | 8.57 <sup>a-u</sup>  | 5.52 <sup>a-h</sup>   | 0.38 <sup>a</sup>     | 2250 <sup>b-h</sup>   | 2187 <sup>b-h</sup>  | 1237 <sup>g-n</sup>  | 665 <sup>l-q</sup>    | 28 <sup>q</sup>       |
| Ken Kunde     | 13.57 <sup>i-w</sup>   | 13.20 <sup>i-w</sup> | 5.62 <sup>a-n</sup>  | 5.20 <sup>a-m</sup>   | 2.06 <sup>abc</sup>   | 2857 <sup>a-c</sup>   | 2270 <sup>b-f</sup>  | 905 <sup>l-q</sup>   | 983 <sup>k-q</sup>    | 193 <sup>opq</sup>    |
| Kunde Mboga   | 16.07 <sup>s-w</sup>   | 13.67 <sup>m-w</sup> | 6.15 <sup>a-o</sup>  | 2.10 <sup>abc</sup>   | 0.28 <sup>a</sup>     | 3077 <sup>a-d</sup>   | 2513 <sup>a-c</sup>  | 1383 <sup>f-l</sup>  | 383 <sup>l-q</sup>    | 23 <sup>q</sup>       |
| Kang'au       | 17.83 <sup>vw</sup>    | 17.23 <sup>uvw</sup> | 7.63 <sup>a-s</sup>  | 6.06 <sup>a-o</sup>   | 1.28 <sup>ab</sup>    | 3182 <sup>ab</sup>    | 2908 <sup>a-c</sup>  | 1307 <sup>f-l</sup>  | 717 <sup>l-q</sup>    | 128 <sup>pq</sup>     |
| Kunde Kubwa   | 17.30 <sup>o-w</sup>   | 14.87 <sup>o-w</sup> | 5.53 <sup>a-n</sup>  | 6.33 <sup>a-p</sup>   | 2.29 <sup>a-d</sup>   | 2613 <sup>a-c</sup>   | 2430 <sup>a-c</sup>  | 1043 <sup>j-q</sup>  | 783 <sup>l-q</sup>    | 248 <sup>n-q</sup>    |
| Khaki         | 16.77 <sup>i-w</sup>   | 11.67 <sup>e-w</sup> | 5.00 <sup>a-m</sup>  | 4.09 <sup>a-i</sup>   | 0.37 <sup>a</sup>     | 3063 <sup>a-d</sup>   | 2103 <sup>c-i</sup>  | 822 <sup>l-q</sup>   | 712 <sup>l-q</sup>    | 38 <sup>q</sup>       |
| Kunde Ndogo   | 15.67 <sup>q-w</sup>   | 13.37 <sup>j-w</sup> | 4.46 <sup>a-l</sup>  | 2.00 <sup>abc</sup>   | 1.33 <sup>ab</sup>    | 3350 <sup>a</sup>     | 2232 <sup>b-h</sup>  | 757 <sup>l-q</sup>   | 580 <sup>l-q</sup>    | 130 <sup>pq</sup>     |
| Purple Pod    | 18.23 <sup>w</sup>     | 15.33 <sup>p-w</sup> | 4.40 <sup>a-k</sup>  | 3.43 <sup>a-g</sup>   | 1.39 <sup>ab</sup>    | 3122 <sup>abc</sup>   | 2323 <sup>a-f</sup>  | 730 <sup>l-q</sup>   | 447 <sup>l-q</sup>    | 175 <sup>pq</sup>     |
| Black Kunde   | 12.67 <sup>h-w</sup>   | 10.83 <sup>c-w</sup> | 4.65 <sup>a-m</sup>  | 3.21 <sup>a-f</sup>   | 0.40 <sup>a</sup>     | 2603 <sup>a-c</sup>   | 2287 <sup>b-f</sup>  | 818 <sup>l-q</sup>   | 462 <sup>l-q</sup>    | 15 <sup>q</sup>       |

Values followed by the same letter are not significantly different at  $P = 0.05$ . Control shoot dry weights of the first nine varieties were originally reported in g and are converted to mg here.

Fresh weight reflects tissue structure and water content, whereas dry weight reflects net accumulation of organic matter. Both fell together, so salinity affected water relations and dry-matter production at the same time. Reduced carbon assimilation, impaired nutrient uptake and the metabolic cost of osmotic adjustment all reduce the assimilate available for growth (Munns & Tester, 2008). With longer exposure, the ionic component becomes more important.  $\text{Na}^+$  entering through  $\text{K}^+$  uptake pathways can upset the cellular  $\text{K}^+/\text{Na}^+$  balance and interfere with enzyme activation, osmotic regulation and stomatal function (Hasanuzzaman et al., 2021). In cowpea, rising salinity has been linked to more  $\text{Na}^+$  and less  $\text{K}^+$  in leaves (Le et al., 2021).

Ken Kunde and Kunde Kubwa kept more shoot growth under severe salinity than most varieties. Possible reasons include better control of plant water status, tighter restriction of  $\text{Na}^+$  movement into shoots, sustained  $\text{K}^+$  nutrition and protection of photosynthetic tissue, as seen in tolerant cowpea material (Murillo-Amador et al., 2006). Ion concentrations, photosynthesis and water relations were not measured here. These explanations therefore remain plausible and not demonstrated. The agreement among height, leaf number and both biomass traits makes the performance of these two varieties stronger evidence of tolerance than any single trait would be. It also fits the view of salinity tolerance as a composite trait built from osmotic adjustment, ion exclusion or compartmentation, and sustained tissue function (Munns & Tester, 2008).

### Root Number and Root Length

Root production differed significantly ( $P < 0.05$ ) among varieties even in the control, and salinity reduced root number significantly in every variety (Table 4). Mean root number fell from 104 in the control to 52 at 8 dS m<sup>-1</sup>, 16 at 12 dS m<sup>-1</sup> and 7 at 14 dS m<sup>-1</sup>. Mean root length fell from 878 mm to 318 mm at 8 dS m<sup>-1</sup> and to 8 mm at 12 dS m<sup>-1</sup>. Varietal differences in root length were significant in the control and at 4 and 8 dS m<sup>-1</sup>. They disappeared at 12 and 14 dS m<sup>-1</sup>, where root length was below 10 mm in every variety. Kunde Kubwa had the most roots in the control and at 4 dS m<sup>-1</sup> (158 and 157) and the longest roots at 4 dS m<sup>-1</sup> (983 mm). By 8 dS m<sup>-1</sup>, however, it had lost 66% of its roots and 77% of its root length, more than the means of 48% and 63%. Ken Kunde kept the longest roots at 8 dS m<sup>-1</sup> (550 mm) and the most roots at 14 dS m<sup>-1</sup> (12).

**Table 4. Root number and root length of 40-day-old cowpea plants as affected by salt stress.**

| Variety   | Number of roots  |                      |                      |                       |                       | Root length (mm)     |                      |                      |                       |                       |
|-----------|------------------|----------------------|----------------------|-----------------------|-----------------------|----------------------|----------------------|----------------------|-----------------------|-----------------------|
|           | Control          | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> | Control              | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> |
| Kat Kunde | 88 <sup>vw</sup> | 63 <sup>pq</sup>     | 40 <sup>jk</sup>     | 16 <sup>gh</sup>      | 11 <sup>b-h</sup>     | 787.8 <sup>g-m</sup> | 622.1 <sup>b-m</sup> | 346.4 <sup>a-h</sup> | 5.9 <sup>a</sup>      | 1.6 <sup>a</sup>      |

| Variety       | Number of roots    |                      |                      |                       |                       | Root length (mm)     |                      |                      |                       |                       |
|---------------|--------------------|----------------------|----------------------|-----------------------|-----------------------|----------------------|----------------------|----------------------|-----------------------|-----------------------|
|               | Control            | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> | Control              | 4 dS m <sup>-1</sup> | 8 dS m <sup>-1</sup> | 12 dS m <sup>-1</sup> | 14 dS m <sup>-1</sup> |
| Kunde Tamu    | 98 <sup>z</sup>    | 63 <sup>pq</sup>     | 57 <sup>nop</sup>    | 15 <sup>gh</sup>      | 9 <sup>a-g</sup>      | 723.7 <sup>c-m</sup> | 653.5 <sup>b-m</sup> | 406.0 <sup>a-i</sup> | 6.0 <sup>a</sup>      | 1.2 <sup>a</sup>      |
| Kunde Tumaini | 100 <sup>z</sup>   | 70 <sup>z</sup>      | 62 <sup>opq</sup>    | 16 <sup>gh</sup>      | 4 <sup>a-d</sup>      | 817.4 <sup>s-m</sup> | 728.4 <sup>d-m</sup> | 231.2 <sup>a-e</sup> | 8.0 <sup>a</sup>      | 1.0 <sup>a</sup>      |
| K-80          | 106 <sup>z</sup>   | 86 <sup>vw</sup>     | 75 <sup>st</sup>     | 15 <sup>gh</sup>      | 10 <sup>a-h</sup>     | 748.6 <sup>c-m</sup> | 738.9 <sup>c-m</sup> | 398.5 <sup>a-i</sup> | 7.0 <sup>a</sup>      | 2.2 <sup>a</sup>      |
| Kunde Soko    | 90 <sup>v-z</sup>  | 84 <sup>u-v</sup>    | 27 <sup>i</sup>      | 15 <sup>gh</sup>      | 11 <sup>b-h</sup>     | 887.4 <sup>s-m</sup> | 706.7 <sup>c-m</sup> | 468.4 <sup>a-l</sup> | 7.0 <sup>a</sup>      | 1.6 <sup>a</sup>      |
| Kunde Faulu   | 93 <sup>w-ab</sup> | 89 <sup>v-y</sup>    | 60 <sup>n-q</sup>    | 16 <sup>gh</sup>      | 2 <sup>a</sup>        | 778.3 <sup>f-m</sup> | 746.5 <sup>c-m</sup> | 437.7 <sup>a-j</sup> | 8.9 <sup>a</sup>      | 0.4 <sup>a</sup>      |
| Kaltex 14     | 116 <sup>z</sup>   | 93 <sup>w-ab</sup>   | 68 <sup>qrs</sup>    | 15 <sup>gh</sup>      | 10 <sup>a-h</sup>     | 930.0 <sup>t-m</sup> | 689.6 <sup>b-m</sup> | 349.4 <sup>a-h</sup> | 8.0 <sup>a</sup>      | 2.9 <sup>a</sup>      |
| Kaltex 7      | 86 <sup>vw</sup>   | 67 <sup>qrs</sup>    | 46 <sup>kl</sup>     | 15 <sup>gh</sup>      | 7 <sup>a-f</sup>      | 909.7 <sup>i-m</sup> | 681.6 <sup>b-m</sup> | 230 <sup>a-e</sup>   | 9.6 <sup>a</sup>      | 1.1 <sup>a</sup>      |
| M 66          | 129 <sup>z</sup>   | 66 <sup>qr</sup>     | 56 <sup>m-p</sup>    | 16 <sup>gh</sup>      | 2 <sup>a</sup>        | 991.7 <sup>lm</sup>  | 577.4 <sup>b-m</sup> | 447.0 <sup>a-k</sup> | 8.4 <sup>a</sup>      | 4.5 <sup>a</sup>      |
| Ken Kunde     | 142 <sup>z</sup>   | 68 <sup>qrs</sup>    | 61 <sup>opq</sup>    | 15 <sup>gh</sup>      | 12 <sup>d-h</sup>     | 1083.5 <sup>m</sup>  | 787.5 <sup>g-m</sup> | 550.1 <sup>b-k</sup> | 8.8 <sup>a</sup>      | 2.8 <sup>a</sup>      |
| Kunde Mboga   | 77 <sup>tu</sup>   | 77 <sup>tu</sup>     | 40 <sup>ik</sup>     | 17 <sup>gh</sup>      | 3 <sup>abc</sup>      | 608.0 <sup>b-m</sup> | 412.1 <sup>a-i</sup> | 238.0 <sup>a-f</sup> | 6.3 <sup>a</sup>      | 0.3 <sup>a</sup>      |
| Kang'au       | 134 <sup>z</sup>   | 121 <sup>z</sup>     | 52 <sup>lmn</sup>    | 15 <sup>gh</sup>      | 11 <sup>b-h</sup>     | 986.3 <sup>k-m</sup> | 907.8 <sup>i-m</sup> | 299.1 <sup>a-g</sup> | 8.8 <sup>a</sup>      | 1.8 <sup>a</sup>      |
| Kunde Kubwa   | 158 <sup>z</sup>   | 157 <sup>z</sup>     | 54 <sup>mno</sup>    | 17 <sup>gh</sup>      | 9 <sup>a-g</sup>      | 1039.0 <sup>m</sup>  | 983.0 <sup>k-m</sup> | 243 <sup>a-f</sup>   | 8.1 <sup>a</sup>      | 3.0 <sup>a</sup>      |
| Khaki         | 88 <sup>vw</sup>   | 61 <sup>opq</sup>    | 45 <sup>kl</sup>     | 13 <sup>c-h</sup>     | 3 <sup>abc</sup>      | 926.1 <sup>i-m</sup> | 720.2 <sup>c-m</sup> | 185.3 <sup>a-c</sup> | 8.2 <sup>a</sup>      | 0.8 <sup>a</sup>      |
| Kunde Ndogo   | 107 <sup>z</sup>   | 95 <sup>z</sup>      | 40 <sup>ik</sup>     | 18 <sup>h</sup>       | 5 <sup>a-c</sup>      | 704.7 <sup>c-m</sup> | 633.9 <sup>b-m</sup> | 239.1 <sup>a-f</sup> | 5.8 <sup>a</sup>      | 2.3 <sup>a</sup>      |
| Purple Pod    | 77 <sup>tu</sup>   | 56 <sup>m-p</sup>    | 48 <sup>klm</sup>    | 15 <sup>gh</sup>      | 9 <sup>a-g</sup>      | 962.0 <sup>j-m</sup> | 671.0 <sup>b-m</sup> | 190.7 <sup>a-d</sup> | 6.4 <sup>a</sup>      | 2.0 <sup>a</sup>      |
| Black Kunde   | 74 <sup>rst</sup>  | 73 <sup>rst</sup>    | 53 <sup>m-p</sup>    | 17 <sup>gh</sup>      | 4 <sup>a-d</sup>      | 1044.8 <sup>m</sup>  | 635.9 <sup>b-m</sup> | 154.0 <sup>ab</sup>  | 6.6 <sup>a</sup>      | 0.4 <sup>a</sup>      |

Values followed by the same letter are not significantly different at  $P = 0.05$ .

Roots are the first organs to meet changes in the osmotic and ionic environment, so reductions there can occur early and affect the whole plant (Karahara & Horie, 2021). The initial restriction is closely tied to osmotic stress. As external water potential becomes more negative, roots must lower their internal water potential to keep absorbing water, through compatible-solute accumulation and ion regulation. When the stress becomes too severe, root cells cannot maintain turgor, and cell division and expansion decline (Munns, 2002). The drop in root number likely reflects impaired root initiation and branching. Lateral roots need cell division in the pericycle, followed by expansion and differentiation, and all of these need energy, assimilates, water and minerals. Reduced shoot photosynthesis limits the carbohydrate that reaches developing roots, so salinity can restrict branching both directly and through the shoot.

Root elongation is also vulnerable because it depends on cell expansion in the elongation zone. Reduced turgor limits expansion, and excess  $\text{Na}^+$  can interfere with ion homeostasis and compete with  $\text{K}^+$  (Hasanuzzaman et al., 2021). The decline in root length therefore probably reflects reduced cell expansion, impaired root metabolism and rising ionic stress acting together. Shrinking root systems explore less substrate, which can set up a feedback loop. Salinity restricts roots, the smaller root system limits uptake, and the resulting resource shortage further constrains the shoot. The close match between declining root and shoot growth here suggests that the two responses were physiologically linked. Roots may also help regulate how much  $\text{Na}^+$  reaches the shoot. Tolerant cowpea material has been shown to retain more  $\text{Na}^+$  in roots and accumulate less in shoots than sensitive material (Murillo-Amador et al., 2006).

The stronger root development of Ken Kunde and Kunde Kubwa under low to moderate salinity fits their stronger shoot performance. A functional root system may have helped them access more water and nutrients while limiting  $\text{Na}^+$  movement to sensitive shoot tissue.  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Cl}^-$  concentrations, xylem ion loading and root ion compartmentation were not measured. It would therefore be premature to attribute their performance to superior  $\text{Na}^+$  exclusion, and this remains a priority for follow-up work. The collapse in root growth at 12 and 14 dS m<sup>-1</sup> suggests that the stress then exceeded the capacity of all varieties to sustain active root growth. The narrow gap among varieties at these levels probably reflects this shared ceiling and not an absence of genuine varietal differences. Root number and root length together describe the below-ground response, since number reflects development and branching and length reflects elongation and exploration. Even so, root traits are best read alongside shoot growth and biomass, because salt tolerance is a whole-plant trait (Ravelombola et al., 2018).

### Overall Varietal Performance

Kunde Kubwa and Ken Kunde ranked consistently among the best varieties across germination, height, leaf number, shoot biomass and root traits. Kunde Mboga, Kunde Faulu, Black Kunde, Khaki and M 66 performed poorly across several traits at 14 dS m<sup>-1</sup>. Kunde Tumaini also performed poorly in height (3.1 cm), leaf number and shoot weight. The ranking has limits. Many differences among varieties at 14 dS m<sup>-1</sup> were not statistically separable, and some varieties led in single traits, such as Kat Kunde in germination and Kaltex 14 in shoot dry weight. The study was a



single greenhouse trial in sand, and salinity was imposed from sowing with NaCl only. The results are therefore an early-stage screen, and field validation is needed.

The root results also guide the choice of screening level. At 12 dS m<sup>-1</sup> and above, root traits no longer separated the varieties. At 8 dS m<sup>-1</sup>, salinity had already cut root length by about 63% on average, yet significant differences among varieties remained. A level of about 8 dS m<sup>-1</sup> is therefore a sensible candidate for root-based screening.

### Conclusion and Recommendations

Salt stress reduced germination, plant growth, biomass production and root development in all 17 Kenyan cowpea varieties tested. Varieties differed clearly in how well they withstood increasing salinity. Kunde Kubwa and Ken Kunde showed the greatest tolerance across several traits and are the most promising candidates from this screen.

Three recommendations follow. First, about 8 dS m<sup>-1</sup> should be used as a candidate screening level for root-based discrimination among varieties in follow-up experiments. Second, Kunde Kubwa and Ken Kunde should be evaluated in saline soils and then under field conditions typical of salt-affected cowpea-growing areas, to test whether the tolerance seen here holds up. Third, follow-up work should measure tissue Na<sup>+</sup>, K<sup>+</sup> and Cl<sup>-</sup> concentrations and photosynthetic performance to test the mechanisms suggested here.

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### References

- Abraha, R. H. (2025). The promoting underutilized legumes for food security to small-scale farming communities: Evidence from developing countries and genetic diversity perspectives: Underutilized legumes for food security to small-scale farming communities. *African Journal of Rural Development*, 10(2), 206–227.
- Affrifah, N. S., Phillips, R. D., & Saalia, F. K. (2022). Cowpeas: Nutritional profile, processing methods and products—A review. *Legume Science*, 4(3), e131.
- Afonso, P., Castro, I., & Carvalho, M. (2025). Salt-resilient cowpeas: Early identification through growth parameters and gene expression at germination stage. *International Journal of Molecular Sciences*, 26(5), 1892.
- Arifuddin, W., & Al Banna, M. Z. (2025). Phytochemical profiling and nutritional assessment of indigenous cowpea (*Vigna unguiculata* L.) cultivars from Bulukumba, South Sulawesi, Indonesia. *Chempublish Journal*, 9(2), 300–312.
- Dadlani, M., & Yadava, D. K. (2023). *Seed science and technology: Biology, production, quality* (p. 430). Springer Nature.
- Dong, L., Ravelombola, W., Weng, Y., Qin, J., Bhattarai, G., Zia, B., ... Shi, A. (2019). Seedling salt tolerance for above ground-related traits in cowpea (*Vigna unguiculata* (L.) Walp). *Euphytica*, 215(3), 53.
- Hasanuzzaman, M., Raihan, M. R. H., Masud, A. A. C., Rahman, K., Nowroz, F., Rahman, M., ... Fujita, M. (2021). Regulation of reactive oxygen species and antioxidant defense in plants under salinity. *International Journal of Molecular Sciences*, 22(17), 9326.
- Islam, M. M., Haque, M. S., & Sarwar, A. G. (2019). Salt tolerance of cowpea genotypes during seed germination and seedling growth: Salt tolerance in cowpea genotypes in Bangladesh. *Journal of the Bangladesh Agricultural University*, 17(1), 39–44.
- Jan, S., Ashraf Bhat, M., Kumar, A., Altaf Wani, M., Ahmad Bhat, F., Kanth, R. H., ... Naik, Z. A. (2025). Plants response to different abiotic stresses. *Journal of Crop Health*, 77(5), 139.
- Jayawardhane, J., Goyali, J. C., Zafari, S., & Igamberdiev, A. U. (2022). The response of cowpea (*Vigna unguiculata*) plants to three abiotic stresses applied with increasing intensity: Hypoxia, salinity, and water deficit. *Metabolites*, 12(1), 38.
- Karahara, I., & Horie, T. (2021). Functions and structure of roots and their contributions to salinity tolerance in plants. *Breeding Science*, 71(1), 89–108.
- Le, L. T. T., Kotula, L., Siddique, K. H., & Colmer, T. D. (2021). Na<sup>+</sup> and/or Cl<sup>-</sup> toxicities determine salt sensitivity in soybean (*Glycine max* (L.) Merr.), mungbean (*Vigna radiata* (L.) R. Wilczek), cowpea (*Vigna unguiculata* (L.) Walp.), and common bean (*Phaseolus vulgaris* L.). *International Journal of Molecular Sciences*, 22(4), 1909.
- Lu, Y., & Fricke, W. (2023). Salt stress—Regulation of root water uptake in a whole-plant and diurnal context. *International Journal of Molecular Sciences*, 24(9), 8070.
- Manono, B. O. (2026). Effects of salinity on seed germination: Mechanisms, impacts, and mitigation strategies. *Seeds*, 5(1), 1.
- Munns, R. (2002). Comparative physiology of salt and water stress. *Plant, Cell & Environment*, 25(2), 239–250.
- Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, 59, 651–681.



- University of Eldoret, Kenya, Mount Kenya University, Kenya, Chukwuemeka Odumegwu Ojukwu University, Nigeria, Kyambogo University, Uganda and University of Makeni, Sierra Leone
- Murillo-Amador, B., Troyo-Diéguez, E., García-Hernández, J. L., López-Aguilar, R., Avila-Serrano, N. Y., Zamora-Salgado, S., ... Kaya, C. (2006). Effect of NaCl salinity in the genotypic variation of cowpea (*Vigna unguiculata*) during early vegetative growth. *Scientia Horticulturae*, 108(4), 423–431.
- R Core Team. (2025). *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Rai, S. K., Kumar, R., Dayal, A., Reddy, M. L. S. S., & Gupta, N. (2025). Optimizing NaCl concentration for screening salt tolerance in cowpea (*Vigna unguiculata* L. Walp.) genotypes at germination stage using salt injury index. *Vegetable Science*, 52(01), 77–83.
- Ravelombola, W. S., Shi, A., Weng, Y., Clark, J., Motes, D., Chen, P., & Srivastava, V. (2017). Evaluation of salt tolerance at germination stage in cowpea [*Vigna unguiculata* (L.) Walp]. *HortScience*, 52(9), 1168–1176.
- Ravelombola, W., Shi, A., Weng, Y., Mou, B., Motes, D., Clark, J., ... Sugihara, Y. (2018). Association analysis of salt tolerance in cowpea (*Vigna unguiculata* (L.) Walp) at germination and seedling stages. *Theoretical and Applied Genetics*, 131(1), 79–91.
- Santos, A. S. D., Neto, M. F., Melo, H. Y. D. A., Filho, R. A. R., Oliveira, F. D. C. D., Medeiros, J. F. D., ... Sá, F. V. D. S. (2025). Growth, physiology and yield of traditional cowpea varieties under salt stress using exogenous magnesium. *Plants*, 14(22), 3524.
- Tanyeer, [initials], et al. (2010). [Full reference to be added by the authors.]
- Tavares, D. S., Fernandes, T. E. K., Rita, Y. L., Rocha, D. C., Sant'Anna-Santos, B. F., & Gomes, M. P. (2021). Germinative metabolism and seedling growth of cowpea (*Vigna unguiculata*) under salt and osmotic stress. *South African Journal of Botany*, 139, 399–408.
- Thiam, M., Champion, A., Diouf, D., & Ourèye SY, M. (2013). NaCl effects on in vitro germination and growth of some Senegalese cowpea (*Vigna unguiculata* (L.) Walp.) cultivars. *International Scholarly Research Notices*, 2013(1), 382417.
- Zou, Y., Zhang, Y., & Testerink, C. (2022). Root dynamic growth strategies in response to salinity. *Plant, Cell & Environment*, 45(3), 695–704.