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Salinity Resistance of Five Amaranth (*Amaranthus cruentus*) Cultivars at Young Plants Stage

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Authors' contributions

This work was carried out in collaboration between all authors. Author AW designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors AW and CBG managed the literature searches. Authors AW, CBG and FAK contributed to the protocol writing and managed the analyses of the study. Author DM performed the statistical analysis. Authors ASZ, SL and SLG contributed to the protocol writing. All authors read and approved the final manuscript.

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ABSTRACT

Aims: In this study, salt resistance level of five amaranth (*Amaranthus cruentus*) cultivars: *AA-04-028*, *AA-04-017*, *Locale*, *Rouge* and *Red-Sudan,* was evaluated at young plants stage.
Study Design: The experiment was laid out as a Randomized Complete Block Design (RCBD) with four replications.
Place and Duration of Study: The experiment was carried out in a screen house at Center of

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Agricultural Research of Agonkanmey, Commune of Abomey-Calavi, Republic of Benin from July to September 2016.

Methodology: Three weeks old plants of the five cultivars were submitted in pots containing a mixture of potting soil and sand to four NaCl concentrations: 0, 30, 60 and 90 mM NaCl corresponding respectively to an electric conductivity of 0, 1.915, 4.815 and 8.39 $dS.m^{-1}$ by irrigation every two days. Plant growth parameters were evaluated after two weeks.

Results: Salt effect caused a reduction of young plant growth whatever the growth parameter considered with a significant difference among cultivars. The growth reduction due to NaCl is lower and non significant in cultivar *Rouge* for all growth parameters except root fresh mass, whereas this reduction is higher and significant (*p*=.05) in cultivars *Locale* and *AA-04-028* for all growth parameters. For cultivars *Red-Sudan* and *AA-04-017*, the reduction due to NaCl was significant (p= .05) only for leaf number and plant height. The results indicated that cultivar *Rouge* was the less affected by NaCl, followed by *AA-04-017, Red-Sudan* and *AA-04-028*; cultivar *Locale* was the most affected.

Conclusion: Plant height, leaf number and root length appeared as the most suitable growth parameters for studying salt stress effect in *Amaranthus cruentus.* For the first time, we demonstrated that there is a variability of relative salt-stress resistance among *A. cruentus* cultivars at young plant stage. Among the five cultivars, *Rouge* appeared as the most salt resistant whereas cultivar *Locale* was the most salt sensitive at young plants stage.

Keywords: Cultivars discrimination; leaf vegetable; NaCl salt-stress; root growth; shoot growth.

ABBREVIATIONS

PRHG : Plant Relative Height Growth
RLNG : Relative Leaf Number Growth
SFM : Shoot Fresh Mass
SDM : Shoot Dry Mass
RRLG : Root Relative Length Growth
RFM : Root Fresh Mass
RDM : Root Dry Mass

1. INTRODUCTION

Salt stress is one of the major environmental constraints limiting agricultural productivity [1,2]. More than 900 million hectares are affected by high salt concentration in the substrate [3] including half of irrigated areas [4]. Plant growth is compromised by salinity at all developmental stages, but sensitivity varies greatly at different stages [5,6,7]. Crop production in saline areas largely depends upon successful germination, seedling emergence and establishment and efficient reproductive phase [8]. Although most, if not all cultivated plants are glycophyte species, their overall responses to increasing NaCl dose appear to be species-specific [9,10,11,12,13,14]. Moreover, within a given species, a substantial variation in salt sensitivity may occur among cultivars [9,2,10].

Amaranthus, collectively known as amaranth, is a cosmopolitan genus of annual, short-lived or perennial plants. Some amaranth species are cultivated as leaf vegetables, pseudocereals, and ornamental plants. Amaranth (*Amaranthus sp*.) is a promising crop for semi-arid regions. It exhibits a high nutritive value but also a fascinating ability to adapt to diverse harsh environments [15]. As a tropical leafy vegetable, it is acquiring increasing importance as a potential subsidiary food crop for its excellent quality of protein and endogenous micronutrients content [16,17]. Presently some amaranth species were cultivated in semiarid regions, where problem of salinity is acute [8]. Vegetable crops are predominantly cultivated in the south of Benin, in urban and suburban areas and in the valley of *Ouémé* [18]. In Benin, amaranth species are mainly cultivated as leaf vegetable in the cultivable lands of the coastal areas where soil and irrigation water's salinity constitute real problems hampering crop production.

In this respect, the prospects for future cultivation of salt-tolerant, high-yielding genotypes of amaranth are of paramount importance [19]. However, despite a substantial amount of literature on responses of plants to salinity stress, data on the tolerance of amaranth to salinity stress are lacking [19,15]. Moreover, there is almost no information about salt resistance between cultivars of a given amaranth species. Moreover, only little research work has focused on salt resistance of amaranth cultivars produced in Benin. In our previous study, we have demonstrated that there is a variability of relative salt-stress resistance among *Amaranthus cruentus* cultivars at the germination stage [20]. Since salt-resistance at the germination stage is not necessarily correlated with salinity resistance at subsequent developmental stages, the present study aims at evaluating NaCl stress effects on young plant growth of five amaranth cultivars grown in Benin.

2. MATERIALS AND METHODS

2.1 Plant Material

Five *Amaranthus cruentus* cultivars, produced in Benin were used (*AA-04-028*, *Locale*, *AA-04-017*, *Rouge* and *Red-Sudan*). Species identification was performed by the team at the National Herbarium of Benin. Cultivars were obtained from the Market Gardening Crops Program of the Benin National Institute for Agricultural Research (INRAB).

2.2 Experimental Conditions

The experiment was carried out in a screen house at Center of Agricultural Research of Agonkanmey (Abomey-Calavi, Republic of Benin) from July to September 2016. Plants were cultivated at a temperature of 26 ℃/22 day/night with natural light and a relative humidity of 55%.

Seeds were incubated for germination in tanks filled with potting moistened soil for two weeks. Young seedlings were then transferred to earthen small pots of 5.8 cm diameter and 6 cm height containing a mixture of potting soil and sandy loam soil 50:50 (one plant/pot) and cultivated for one week before stress application. Plants of the five cultivars were submitted to salt stress in earthen big pots of 11.3 cm diameter and 14 cm height filled with 3 kg of a same mixture. Treatments consisted of plant irrigation every two days with 100 ml/pot of salt solution of 0, 30, 60 or 90 mM NaCl corresponding respectively to an electric conductivity of 0; 1.91, 4.81, and 8.39 $dS.m^{-1}$ determined by a conductimeter (VWR; CO310). The experiment was laid out as a Randomized Complete Block Design (RCBD) with two factors and four replications. The two considered factors were cultivars (with five levels) and salt-concentrations (with four levels).

2.3 Experiment Evaluation

Plants height, leaf number and root length were measured before stress application (X_0); they were measured again after 2 weeks of treatment (X_1). Plants Relative Height Growth of (PRHG), Relative Leaf Number Growth and Relative Root Length Growth (RRLG) were calculated as $(X_1-X_0)/X_0$. Shoot and root fresh mass were determined after two weeks. Samples were then transferred to an oven at 80℃ for 72 hours for dry mass determination.

2.4 Statistical Analysis

All the experiments were performed twice independently. For all parameters, each value was presented in the form of mean ± standard error with a reading of four independent samples per treatment. The analysis of the main effects of stress intensity and/or cultivars was based on a one-way and two-ways analysis of variance (ANOVA). The differences among the means were compared through Students, Newman and Keuls (SNK) test. All statistical analyses were performed by GenStat discovery [21].

3. RESULTS

3.1 Effect of NaCl on Plant Aerial Part Growth

3.1.1 NaCl effect on plant height

The Fig. 1 presents NaCl effect on PRHG (plants relative height growth) after two weeks of stress. In the absence of stress, the PRHG after two weeks was 1.49, 1.213, 1.953, 1.338 and 1.438 respectively for cultivars *AA-04-017*, *AA-04-028*, *Locale*, *Red-Sudan* and *Rouge*. Cultivar *AA-04-028* presented the lowest PRHG whereas *Locale* showed the highest PRHG. NaCl effect resulted in a reduction of plants PRHG but the five cultivars showed different behaviors. Cultivar *Rouge* was less affected by NaCl than the other cultivars. It exhibited a PRHG of 1.192, 1.19 and 0.71 in the presence of 30; 60 and 90 mM of NaCl respectively. Statistical analysis revealed that NaCl effect was not significant ($p = .221$) on this cultivar. For cultivar *Locale*, salt PRHG inhibition was significant from 30 mM NaCl ($p = .001$) with PRHG values of 0.78, 0.66 and 0.57 respectively at 30, 60 and 90 mM NaCl. For cultivar *Red-Sudan*, salt PRHG inhibition was significant from 60 mM NaCl ($p = .01$) with PRHG values of 1.13, 0.73 and 0.62 respectively at 30, 60 and 90 mM NaCl. NaCl PRHG inhibition was significant only at 90 mM NaCl for cultivar *AA-04-028* ($p = .01$) and AA-04-017 ($p = .05$) with PRHG values of 1.11, 0.71 and 0.047 for *AA-04-028*; for AA-04-017, RHG values were 1.427, 1.147 and 0.415 in the presence of 30, 60 and 90 mM of

NaCl respectively. Thus, salt effect on plant height inhibition was the most important on cultivar *Locale* and the least marked on cultivar *Rouge*.

3.1.2 NaCl effect on leaf number

In the absence of stress, the RLNG after 15 days was 0.927, 0.925, 1.042, 1.375 and 0.88 respectively for cultivars *AA-04-017*, *AA-04-028*, *Locale*, *Red-Sudan* and *Rouge* (Fig. 2). Cultivar *Rouge* presented the lowest RLNG whereas *Red-Sudan* showed the highest RLNG. NaCl effect resulted in a reduction of plants RLNG but the five cultivars showed different behaviors. Cultivar *Rouge* was less affected by NaCl than the other cultivars. It exhibited a RLNG of 0.67, 0.627 and 0.357 in the presence of 30, 60 and 90 mM of NaCl respectively. Statistic analysis revealed that NaCl effect was not significant (p=.064) on this cultivar. NaCl RLNG inhibition was significant from 30 mM NaCl for cultivar *Locale* (p=.001) and *Red-Sudan* (p=.01) with RLNG values of 0.517, 0.35 and 0.25 for *Locale*. For *Red-Sudan*, RLNG values were 0.895, 0.632 and 0.575 in the presence of 30, 60 and 90 mM of NaCl respectively. For cultivar *AA-04-028*, salt RLNG inhibition was significant from 60 mM NaCl (p=.001) with RLNG values of 0.742, 0.59 and 0.2 respectively at 30, 60 and 90 mM NaCl. For cultivar AA-04-017, salt RLNG inhibition was significant only at 90 mM NaCl (p=.05) with RLNG values of 0.915, 0.715 and 0.345 respectively at 30, 60 and 90 mM NaCl. Thus, salt effect on leaf number inhibition was the most important on cultivars *Locale* and *Red-Sudan* and the lowest on cultivar *Rouge*.

3.1.3 NaCl effect on shoot fresh mass

The Fig. 3 presents NaCl effect on plants shoot fresh mass (SFM) after two weeks of stress. In absence of stress, the SFM after 15 days was 5.87, 4.12, 6.63, 2.6 and 7.7 g respectively for cultivars *AA-04-017*, *AA-04-028*, *Locale*, *Red-Sudan* and *Rouge*. Cultivar *Red-Sudan* presented the lowest SFM whereas *Rouge* showed the highest SFM. NaCl effect resulted in a reduction of plants SFM but the five cultivars showed different behaviors. Cultivars *Rouge, AA-04-017* and *Red-Sudan* remained unaffected by NaCl concentrations used in this experiment.

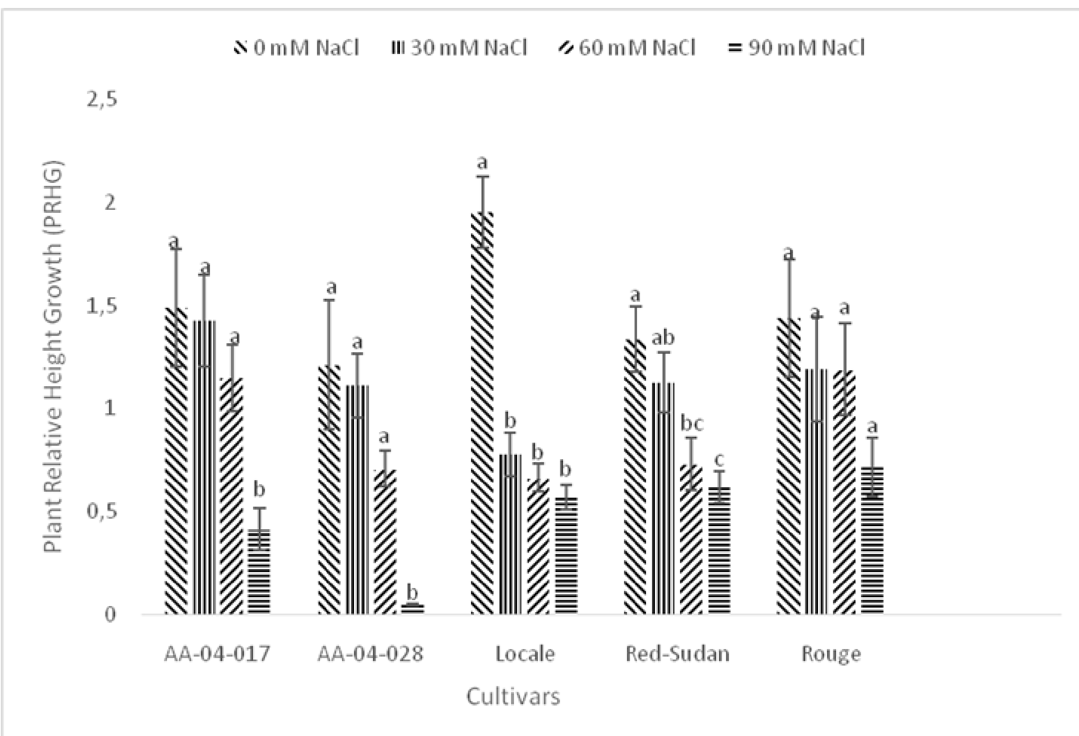

Fig. 1. Plant Relative height growth (PRHG) of five *Amaranthus cruentus* cultivars under different NaCl concentrations (n = 4; vertical bars are standard errors)

Values within cultivar with same letter are not significantly different at p=.05

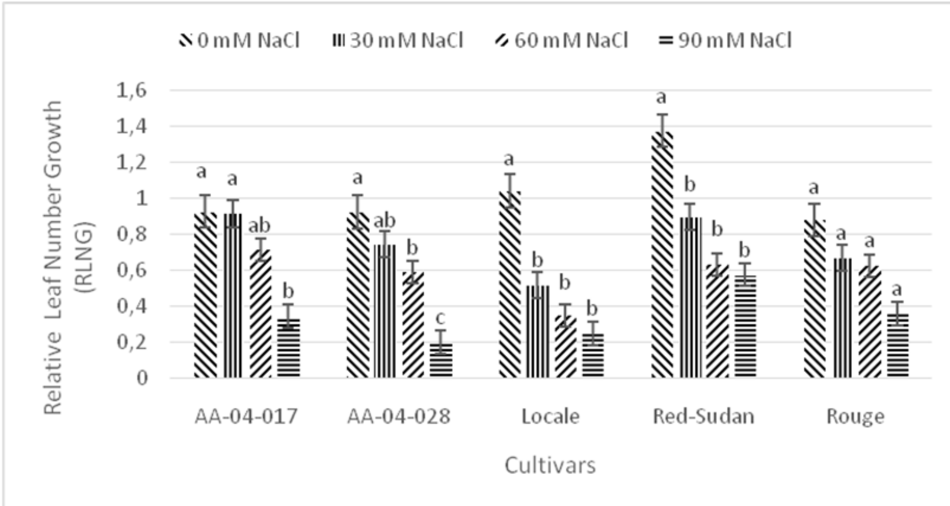

Fig. 2. RLNG (Relative Leaf number growth) of five *Amaranthus cruentus* cultivars under different NaCl concentrations (n = 4; vertical bars are standard errors)

Values within cultivar with same letter are not significantly different at p<.05

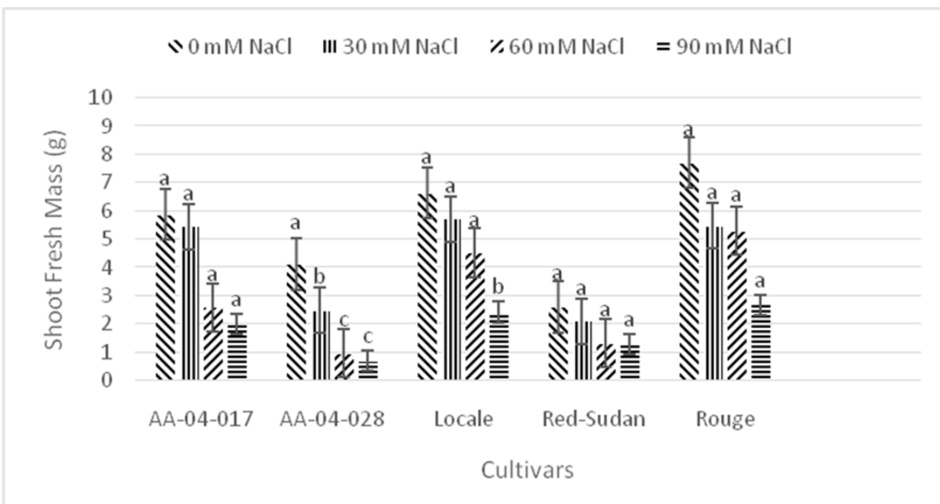

Fig. 3. SFM (Shoot Fresh Mass) of five *Amaranthus cruentus* cultivars under different NaCl concentrations (n = 4; vertical bars are standard errors)

Values within cultivar with same letter are not significantly different at p=.01

However, cultivar *AA-04-028* was the most affected by salt stress with a shoot fresh mass of 2.48, 0.96 and 0.69 g in the presence of 30, 60 and 90 mM of NaCl respectively. The salt-induced decrease of the shoot fresh mass was significant (p=.01) already at 30 mM NaCl. For cultivar *Locale*, SFM was significantly affected (p=.01) only at 90 mM NaCl with a value of 5.71, 4.51 and 2.42 g. Thus, salt effect on shoot fresh mass inhibition was more accentuated on cultivar *AA-04-028* and less accentuated on cultivar *Rouge*, *Red-Sudan* and *AA04-017*.

3.1.4 NaCl effect on shoot dry mass

The Fig. 4 presents NaCl effect on plants shoot dry mass (SDM) after two weeks of stress. In absence of stress, the SDM after 15 days was 1.001, 0.532, 0.939, 0.248 and 1.127 g respectively for cultivars *AA-04-017*, *AA-04-028*, *Locale*, *Red-Sudan* and *Rouge*. Cultivar *Red-Sudan* presented the lowest SDM whereas *Rouge* showed the highest SDM. NaCl effect resulted in a reduction of plants SDM but the five cultivars showed different behaviors. Cultivars

Rouge, AA-04-017 and *Red-Sudan* were not affected by NaCl concentrations used in this experiment as revealed by statistical analysis that revealed that NaCl effect was not significant (p>.05) on these cultivars. However, cultivar *AA-04-028* was the most affected by salt stress with a shoot dry mass of 0.261, 0.195 and 0.073 g in the presence of 30, 60 and 90 mM of NaCl respectively; the reduction of shoot dry mass due to NaCl was significant (p=.01) from 30 mM NaCl. For cultivar *Locale*, SDM was significantly affected (p=.05) only at 90 mM NaCl with a value of 0.918, 0.490 and 0.233 g. Thus, salt effect on shoot fresh mass inhibition was more accentuated on cultivar *AA-04-028* and less accentuated on three other cultivars.

3.2 Effect on NaCl on Roots Growth

3.2.1 NaCl effect on root length

In absence of stress, cultivars *AA-04-028* and *Rouge* presented the lowest RRLG (Root relative length growth (2.64 and 2.67 g) whereas *Red-Sudan* showed the highest RRLG (4.67 g) (Table 1). NaCl effect resulted in a reduction of RRLG but the five cultivars showed different behaviors. Cultivars *Rouge* and *AA-04-017* were less affected by NaCl than the other cultivars. Cultivar *Rouge* exhibited a RRLG of 2.513, 2.368 and 0.73 whereas for cultivar *AA-04-017* RRLG was 2.678, 2.133 and 0.298 in the presence of 30, 60 and 90 mM of NaCl respectively. Statistical analysis revealed that NaCl effect on RRLG was not significant (p>.05) in these cultivars. Cultivars *Locale* and *Red-Sudan* were the most affected by NaCl. RRLG inhibition was significant from 30 mM NaCl (p=.01) for cultivar *Locale* and for *Red-Sudan* (p=.001). RRLG values were 1.948, 1.77 and 0.768 for *Locale*; and 2.793, 0.998 and 0.935 for *Red-Sudan* respectively at 30, 60 and 90 mM NaCl. For cultivar *AA-04-028*, RRLG inhibition was significant (p=.001) from 60 mM NaCl with RRLG values of 2.3, 0.96 and 0.408 in the presence of 30, 60 and 90 mM of NaCl respectively. Thus, salt effect on root length inhibition was more accentuated on cultivars *Locale* and *Red-Sudan,* and less accentuated on cultivar *Rouge* and *AA04-017*.

3.2.2 NaCl effect on root fresh mass

Cultivar *Red-Sudan* presented the lowest root fresh mass (RFM) (0.21 g) whereas *Rouge* showed the highest RFM (0.912 g) (Table 2). NaCl effect resulted in a reduction of RFM but the five cultivars showed different behaviors. RFM of cultivars *AA-04-017* and *Red-Sudan* were not affected by NaCl concentrations used in this experiment as shown by statistical analysis that revealed a non significant effect of NaCl (p>.05) on RFM of these cultivars. However, cultivars *Locale* and *AA-04-028* were the most affected by salt stress with a reduction significant (p=.01) from 60 mM NaCl. Root fresh mass were 0.582, 0.477 and 0.267 for cultivar *Locale* ; and 0.209, 0.107 and 0.081 for cultivar *AA-04-028* in the presence of 30, 60 and 90 mM of NaCl respectively. For cultivar *Rouge*, RFM inhibition by NaCl was significant (p=.05) only at 90 mM NaCl. Thus, salt effect on root fresh mass inhibition was more accentuated on cultivars *Locale* and *AA-04-028* and less accentuated on *AA-04-017* and *Red-Sudan; Rouge* was intermediary.

3.2.3 NaCl effect on root dry mass

Cultivar *Red-Sudan* presented the lowest root dry mass (RDM) (0.022 g) whereas *Rouge* showed the highest RFM (0.078 g) (Table 3). NaCl effect resulted in a reduction of RDM but the five cultivars showed different behaviors. RDM of cultivars *Rouge*, *AA-04-017* and *Red-Sudan* were not affected by NaCl concentrations used in this experiment as shown by statistical analysis that revealed a non significant effect of NaCl (p>.05) on RDM of these cultivars. However, cultivars *Locale* and *AA-04-028* were the most affected by salt stress.

Table 1. Effect of different NaCl concentrations (0, 30, 60 and 90 mM) on root relative length growth of five *Amaranthus cruentus* cultivars after two weeks of stress

NaCl (mM)	Cultivars				
	AA-04-017	AA-04-028	Locale	Red-Sudan	Rouge
0	2.992±0.781a	2.643±0.453a	4.535±0.826a	4.675±1.467a	2.675±0,551a
30	2.6778±0.131a	2.3±0.291a	1.948±0.471b	2.793±0.724b	2.513±0,432a
60	2.133±0.54a	0.96±0.267b	1.77±0.35b	0.998±0.292b	2.368±0,276a
90	0.298±0.075a	0.408±0.137b	0.768±0.174b	0.935±0.529b	0.73±0,232a

Values are means ±SE (n = 4). Means with different letters within a column were significantly different (p=.01)

Table 2. Effect of different NaCl concentrations (0, 30, 60 and 90 mM) on root fresh mass of five *Amaranthus cruentus* cultivars after two weeks of stress

NaCl (mM)	Cultivars				
	AA-04-017	**AA-04-028**	**Locale**	**Red-Sudan**	**Rouge**
0	0.653±0.305a	0.314±0.075a	0.808±0.135a	0.21±0.055a	0.912±0.09a
30	0.512±0.12a	0.209±0.025ab	0.582±0.09ab	0.165±0.03a	0.521±0.155ab
60	0.294±0.055a	0.107±0.025b	0.477±0.045b	0.107±0.02a	0.521±0.155ab
90	0.241±0.045a	0.081±0.035b	0.267±0.025b	0.097±0.015a	0.268±0.045b

Values are means ±SE (n = 4). Means with different letters within a column were significantly different (p=.05)

Table 3. Effect of different NaCl concentrations (0, 30, 60 and 90 mM) on root dry mass of five *Amaranthus cruentus* cultivars after two weeks of stress

NaCl (mM)	Cultivars				
	AA-04-017	**AA-04-028**	**Locale**	**Red-Sudan**	**Rouge**
0	0.0528±0.021a	0.0355±0.01a	0.0753±0.011a	0.0225±0.008a	0.0785±0.019a
30	0.049±0.007a	0.0235±0.008ab	0.0743±0.01a	0.021±0.007a	0.0775±0.016a
60	0.0478±0.007a	0.0165±0.005ab	0.0622±0.005ab	0.021±0.002a	0.069±0.012a
90	0.0278±0.003a	0.0133±0.002b	0.0413±0.004b	0.012±0.002a	0.0595±0.0 03ab

Values are means ±SE (n = 4). Means with different letters within a column were significantly different (p=.05)

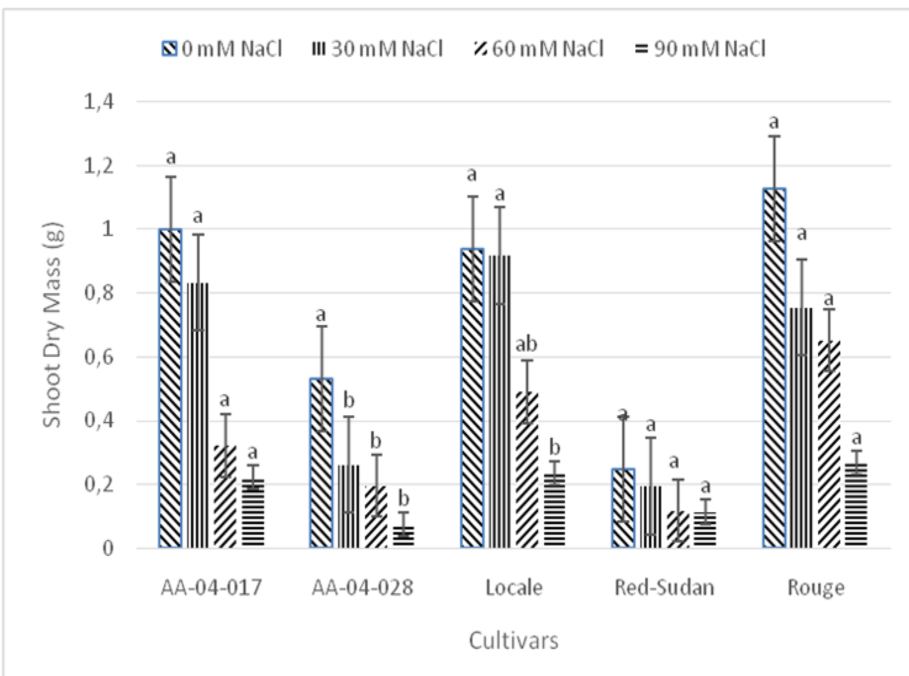

Fig. 4. SDM (Shoot Dry Mass) of five *Amaranthus cruentus* cultivars under different NaCl concentrations (n = 4; vertical bars are standard errors)

Values within cultivar with same letter are not significantly different at p=.05

RDM inhibition was significant at 90 mM NaCl (p=.01) for cultivar *Locale* and for *AA-04-028* (p=.05). Root dry mass were 0.077, 0.069 and 0.059 for cultivar *Rouge* ; 0.582, 0.477 and 0.267 for *Locale* ; and 0.209, 0.107 and 0.081 for *AA-04-028* in the presence of 30, 60 and 90 mM of NaCl respectively. Thus, salt effect on root dry mass inhibition was more accentuated on cultivars *Locale* and *AA-04-028* than the three other cultivars which showed the same behavior.

4. DISCUSSION

Salt stress caused an obvious inhibition on plant root and shoot growth. Such observation is commonly reported for glycophytes species such as rice [9], sugarcane [22,23,10,24], tomato [25,26] and pepper [27]. Similar results were also reported in barley and corn by Cramer [28] who found that salt stress reduced aerial part elongation. In amaranth, Omami et *al*. [15] and Omami and Hammes [29] reported that salt stress reduced plant growth of six amaranth genotypes including one genotype of *Amaranthus cruentus* using different morphological criteria such as plant height, leaf number, leaf area, leaf mass and stem mass. The same tendency was reported in several amaranth genotypes including *Amaranthus hybridus* [30], *A. tricolor* [31,32] and *A. hypochondriacus* [33]. The reduction in plant growth, in particular in biomass accumulation, could be the consequence of a water stress resulting from a decrease in external osmotic potential and/or the accumulation of toxic ions [34]. Further research is needed to determine which component of salt stress is the most toxic for *Amaranthus cruentus*.

Our results revealed a significant effect of NaCl concentrations for all growth parameters considered in this study, indicating that the response of *Amaranthus cruentus* cultivars to salt stress is concentration dependent. Amukali et al. [30] reported that NaCl concentrations lower or equal than 50 mM stimulated plant growth in *Amaranthus hybridus* mainly for root length, plant dry weight, dry matter, leaf area index and leaf number after eight weeks by watering the plants in potted bags with different salt concentrations on twelve hourly (12) bases. According to our data, this is not the case for *A. cruentus* cultivars since NaCl concentration as low as 30 mM significantly reduced shoot and root growth for some cultivars after two weeks as we used similar strategy for salt stress imposition. Ratnakar and Rai [35] revealed plant growth reduction by 20 mM, 40 mM and 60 mM NaCl after forty five days in *Amaranthus polygamous*. In other amaranth genotype, it was reported that the salt concentration of 4.5 dS m^{-1} in the irrigation water delayed amaranth flowering but did not affect dry biomass production [36].

It is well known that for plant species there is a substantial variation in salt sensitivity among cultivars of the same species [9,2,10]. Our data confirm that this is also the case for *Amaranthus cruentus* since a significant difference was observed among the tested cultivars. Except for roots fresh mass at 90 mM NaCl, the reduction of plant growth due to NaCl was not significant for cultivar *Rouge* whatever the parameter. Thus, this cultivar appeared as the most salt resistant among the five *Amaranthus cruentus* cultivars studied. In contrast, cultivars *Locale* and *AA-04-028* were significantly affected by the NaCl concentrations used whatever the parameter taken into account indicating that these two cultivars were clearly salt sensitive. Cultivars *Red-Sudan* and *AA-04-017* showed an intermediate behavior.

The cultivars' response depended on the considered growth parameter. Results revealed that plant height and leaf number were significantly affected by NaCl concentrations used in four of the five cultivars tested (*Red-Sudan*, *Locale*, *AA-04-028* and *AA-04-017*) at the lowest dose (30 mM NaCl) whereas shoot fresh and dry mass as well as root dry mass were significantly affected only for two cultivars (*Locale*, *AA-04-028*). Mean roots length (at 30 mM NaCl) and root fresh mass (at 60 mM NaCl) were significantly affected for three cultivars (*Locale*, *AA-04-028* and *Red-Sudan* or *Rouge*). Moreover, it is important to notice that plant height, leaf number and root length were significantly affected by the lowest NaCl concentration used (30 mM) in several cultivars. It is therefore logical to infer that plant height, leaf number and root length were the most sensitive parameters to salt stress in *Amaranthus cruentus* cultivars, followed by roots fresh mass, shoot fresh and dry mass. Thus, plant height, leaf number and root length appeared as the most suitable growth parameters for studying salt stress effect in *A. cruentus*.

Ratnakar and Rai [35] also reported that root and shoot lengths are discriminant parameters for studying salt stress. This is obvious as roots are in direct contact with soil salinity [30]. Based on root length and shoot height, cultivar *Rouge* growth was not significantly affected by NaCl concentrations used confirming the supposed salt resistance of this cultivar in comparison with the four other cultivars, followed by cultivar *AA-04-017* with a non significant effect on RRLG and a significant effect on PRHG only at 90 mM NaCl. Cultivars *Locale* was significantly affected from 30 mM NaCl confirming the putative salt sensitivity of this cultivar, followed by *Red-Sudan* with a significant effect on RRLI from 30 mM NaCl and a significant effect on PRHG from 60 mM NaCl. Cultivar *AA-04-028*, with a significant effect on RRLG from 60 mM NaCl and a significant effect on PRHG only at 90 mM NaCl, was intermediary between *AA-04-017* and *Red-Sudan*. Thus, there is variability of relative salt-stress resistance among *Amaranthus cruentus* cultivars at young plants stage.

In our previous study on the same cultivars at germination stage, we have demonstrated that cultivar *Red Sudan* was the most salt-resistant and that cultivar *Locale* was rather salt-sensitive and *Rouge* rather intermediary [20]. Thus, cultivar *Rouge* which was the most-salt résistant at young plants stage behaves as an intermidiary cultivar at germination stage and *Red Sudan* which was the most salt-resistant at germination stage behaves as an intermediary cultivar at young plant stage. These findings indicated that salinity tolerance at different development stages does not behave as an interdependent characteristic as reported in sugarcane [24]. Thus, salt resistance of a given cultivar at germination stage does not guarantee its salt resistance at whole-plant stage.

5. CONCLUSION

This study indicated that NaCl salt stress reduced young plant growth in *Amaranthus cruentus* cultivars. It underlined, for the first time, the variability of relative salt-stress resistance for some *A. cruentus* cultivars at young plant stage. Plant height, leaf number and root length appeared as the most suitable growth parameters for studying salt stress effect in *A. cruentus.* Among the five cultivars tested and whatever the parameter taken into account, cultivar *Rouge* is the most salt resistant cultivar whereas cultivar *Locale* is the most salt sensitive; cultivars *AA-04-028, Red-Sudan* and *AA-04-017* were intermediary.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Boyer JS. Plant productivity and environment. Science. 1982;218:443-448.
2. Wei W, Bilsborrow EP, Hooley P, Fincham AD, Lombi E, Forster PB. Salinity induced differences in growth, ion distribution and partitioning in barley between the cultivar Maythorpe and its derived mutant Golden Promise. Plant Soil. 2003;250:183-191.
3. Flowers TJ. Improving crop salt tolerance. J. Exp. Bot. 2004;55(396):307-319.
4. Zhu JK. Plant salt tolerance. Trends Plant Sci. 2001;6(2):66-71.
5. Caravajal M, Amor FM, Fernandez-Ballester G, Martinez V, Cerdia A. Time course of solute accumulation and water relations in muskmelon plants exposed to salt during different growth stages. Plant Sci. 1998;138:103–112.
6. Akram M, Hussain M, Akhtar S, Rasul E. Impact of NaCl salinity on yield components of some wheat accession/ variety. Int. J. Agric.Biol. 2002;4:156–158.
7. Akinci IE, Akinci S, Yilmaz K, Dikici H. Response of eggplant varieties (*Solanum melongena*) to salinity in germination and seedling stages. New Zeal. J. Crop Hort. Sci. 2004;32:193–200.
8. Bhattacharjee S. Triadimefon pretreatment protects newly assembled membrane system and causes up-regulation of stress proteins in salinity stressed *Amaranthus lividus* L. during early germination. J. Env. Biol. 2008;29(5):805-810.
9. Lutts S, Kinet JM, Bouharmont J. Changes in plant response to NaCl during development of rice (*Oryza sativa* L.) varieties differing in salinity resistance. J. Exp. Bot. 1995;46:1843-1852.
10. Gandonou CB, Gnancadja SL, Abrini J, Skali Senhaji N. Salinity tolerance of some sugarcane (*Saccharum sp*.) cultivars in hydroponic medium. Int. Sugar J. 2012; 114(1359):190-196.
11. Levitt J. Responses of the plants to environmental stress - Chilling, freezing and temperature stress. 2nd Edn; Acad. Press, New York; 1980.
12. Karikalan L, Rajan SN, Gopi R, Sujatha BM, Pannersevalam R. Induction of salt tolerance by triadimefon in pigeon pea (*Cajanus cajan* L.) Mill sp. Ind. J. Exp. Biol. 1999;37:825-829.
13. Lakra N, Mishra SN, Singh DB, Pushpa CT. Exogenous putrescine effect on cation concentration in leaf of *Brassica juncea* seedlings subjected to Cd and Pb along

with salinity stress. J. Environ. Biol. 2006; 27:263-269.

14. Chukwu LO, Okpe HA. Differential response of *Tilapia guineensis* fingerlings to inorganic fertilizer under various salinity regimes. J. Environ. Biol. 2006;27:687-690.
15. Omami EN, Hammes PS, Robbertse PJ. Differences in salinity tolerance for growth and water-use efficiency in some amaranth *(Amaranthus* spp.) genotypes. New Zealand J. Crop Hort. Sci. 2006;34(1):11-22.
16. Prakash OM, Zaidi PH. Effect of amaranth *(Amaranthus spinosus* L.) supplemented maize diet on blood haemoglobin and lipid metabolism in rats. Ann agric Res, New Delhi. 2000;21(2):223-232.
17. Devdas RP, Saroja S. Availability of iron and b-carotene from Amaranthus to children. Amaranthus Proc. 2001;15.
18. Adorgloh-Hessou RA. Guide for the development of production system and marketing of quality vegetables in the urban and suburban regions of southern Benin. Report of consultation. IITA-Benin. 2006;82.
19. Omami EN. Response of Amaranth to salinity stress, Ph. D Thesis, University of Pretoria, South Africa. 2005;235.
20. Wouyou A, Gandonou CB, Montcho D, Kpinkoun J, Kinsou E, Assogba Komlan F, et al. Salinity resistance of six Amaranth (*Amaranthus* sp.) cultivars cultivated in Benin at germination stage. Int. J. Plant Soil Sci. 2016;11(3):1-10.
21. GenStat. GenStat for Windows. Release 4.23 DE Discovery Edition. VSN International Ltd., Hemel Hempstead: UK; 2003.
22. Akhtar S, Wahid A, Rasul E. Emergence, growth and nutrient composition of sugarcane sprouts under NaCl salinity. Biol. Plant. 2003;46(1):113-116.
23. Hussain A, Khan ZI, Ashraf M, Rashid HM, Akhtar MS. Effect of salt stress on some growth attributes of sugarcane cultivars CP-77-400 and COJ-84. Int. J. Agric. Biol. 2004;6(1):188-191.
24. Gandonou GCB, Skali Senhaji N. Sugarcane (*Saccharum* sp.) salt tolerance at various developmental levels. In: Chakraborty U, Chakraborty B, Editors. Abiotic Stresses in Crop Plants, CABI Publishing, United Kingdom; 2015.
    ISBN-13: 978-1-78064-373-1.
25. Albacete A, Ghanem ME Martinez C, Jari A, Acosta M, Sanchez-Bravo J, et al. Hormonal changes in relation to biomass partitioning and shoot growth impairment in salinized tomato (*Solanum lycopersicum* L.) plants. J. Exp. Bot. 2008;59(15):4119–4131.
    DOI: 10.1093/jxb/ern251
26. Ould Mohamdi M, Bouya D, Ould Mohamed Salem A. Etude de l'effet du stress salin (NaCl) chez deux variétés de tomate (Campbell 33 et Mongal). Int. J. Biol. Chem. Sci. 2011;5(3):860-900.
27. R'him T, Tlili I, Hnan I, Ilahy R, Benali A, Jebari H. Effet du stress salin sur le comportement physiologique et métabolique de trois variétés de piment (*Capsicum annuum* L.). J. Appl. Bios. 2013;66:5060–5069.
28. Cramer GR. Differential effects of salinity on leaf elongation kinetics of three grass species. Plant Soil. 2003;253:233-244.
29. Omami EN, Hammes PS. Ameliorative effects of calcium on growth and mineral uptake of salt-stressed amaranth. S. Afr. J. Plant Soil. 2006;23(3):197-202.
30. Amukali O, Obadoni BO, Mensah JK. Effects of different NaCl concentrations on germination and seedlings growth of *Amaranthus hybridus* and *Celosia argentea*. Afr. J. Env. Sci. Technol. 2015; 9(4):301-306.
    DOI: 10.5897/AJEST2014.1819
31. Makus DJ. Salinity and nitrogen level affect agronomic performance, leaf color and leaf mineral nutrients of vegetable Amaranth. Subtrop. Plant Sci. 2003;55:1-6.
32. Qin L, Guo S, Ai W, Tang Y, Cheng Q, Chen G. Effect of salt stress on growth and physiology in amaranth and lettuce: Implications for bioregenerative life support system. Adv. Space Res. 2013;51:476–482.
33. Lavini A, Pulvento C, d'Andria R, Riccardi M. Effects of saline irrigation on yield and qualitative characterization of seed of an amaranth accession grown under Mediterranean conditions. J. Agric. Sci. 2016;154(5) :858-869.
    DOI:https://doi.org/10.1017/S0021859615000659

34. Odjegba VJ, Chukwunwike IC. Physiological responses of *Amaranthus hybridus* L. under salinity stress. Ind. J. Innov. Dev. 2012;1(10):742-748.
35. Ratnakar A, Rai A. Effect of NaCl salinity on B-carotene, thiamine, riboflavin and ascorbic acid contents in the leaves of *Amaranthus Polygamous* L. var. Pusa Kirti. Oct. J. Env. Res. 2013;1(3):211-216.
36. da Costa DMA, de Souza Melo HN, Ferreira SR, de Holanda JS. Growth and development of amaranth (*Amaranthus* ssp) under saline stress and mulch. Rev. Bras. Ciênc. Solo. 2008;32(1).

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