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# Response of African eggplant (*Solanum macrocarpon* L.) cultivars produced in Benin Republic to salt stress at germination stage

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**Abstract**

In this study, the response of seed germination of six African eggplant cultivars produced in Benin Republic (*Dangbo, Kpinman*, *Adja-Ouèrè*, *Togan*, *Côte d'Ivoire* and *Kombara* F1) to salt stress was investigated with the aim to determine their relative salt resistance level. The experiment was laid out in a completely randomized design with four replications. Seeds were subjected in Petri dishes to five NaCl concentrations (0; 30; 60; 90 and 120 mM). Seed germination was checked every day during twenty days incubation period. Germination index (GI), percentage of final germination (PFG) and salt tolerance index (STI) were calculated for each cultivar. Salt stress induced a significant reduction of GI($P < 0.001$) and PFG ($P < 0.05$) with a difference among cultivars. A significant difference ($P < 0.001$) was observed among cultivars STI: cultivar *Togan* showed the highest STI (0.96) followed by *Adja-Ouèrè* (0.89) and Dangbo (0.76) whereas Côte d'Ivoire (0.38) and *Kombara* F1 (0.35) showed the weakest STI values. Thus cultivar *Togan* appeared as the most salt resistant whereas *Côte d'Ivoire* and *Kombara F1*were the most salt sensitive. For the first time, we demonstrated a variability of relative salinity resistance among local African eggplant cultivars at germination stage.

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## Introduction

Global climatic change disturbs ecological fitness and induces several abiotic stresses, which are considered as the significant constraints for crop productivity, namely, drought, water logging/flooding, salinity, extreme temperature (high and low), toxic metals/metalloids, etc. (Hasanuzzaman et al., 2020). Many authors reported that salinity is considered as one of the most common abiotic stresses reducing the productivity and fruit quality of crop plants (Shahid et al., 2020). Salt-affected soils occur in more than 100 countries, and their worldwide extent is estimated at about 1 billion hectares (FAO, 2016). Currently, it is one of the most severe abiotic factors in many agronomic and horticultural crops (Nasrin and Mannan, 2019). This resulted in a reduction in cultivated land size, crop productivity, quality and biomass, especially in arid and semi-arid irrigated areas (Shahbaz and Ashraf, 2013).

In the progress of plant development, germination is a critical stage where many factors such as temperature, light, water potential, and salinity affect the process (An and Zhou, 2017). Salinity disrupts crop establishment by decreasing the germination percentage and delaying seedling emergence (Siddiky et al., 2014) and decreases the yield at a later stage (Rahman et al., 2018). Salt tolerance can therefore be assessed by the earliness of germination. The degree of salt tolerance varies among species, with the stage of plant development as well as with environmental factors such as soil fertility, irrigation and climate, experiencing a reduction in output from excess soil salinity (Tanji and Kielen, 2002; Fontes, 2005 ; Dias et al., 2015).

Horticultural products in general and vegetables in particular, occupy a prominent place in the food production of Benin and are mainly cultivated in the coastal zone where they are exposed to salt stress (Ezin et al., 2012). Climate change which tends to increase sea level further aggravates the phenomenon (Ezin et al., 2012). African eggplant (*Solanum macrocarpon*) is a popular vegetable in West Africa, where the leaves are a regular part of the diet (Fern, 2020). The plant also supplies an edible fruit and has a range of local medicinal uses.

In Benin, this plant is part of the crops grown in market gardening as leafy vegetable. It is known for its high nutritional value due to its high protein, fat, ash, crude fiber and moisture (Oboh et al., 2005). Very few studies address the decline in its productivity and they generally focus only on biotic factors, pests and disease (FAO, 2004). In a recent study, we have demonstrated that the some African eggplant cultivars cultivated in Benin differed in their salinity resistance at young plants stage (Sounou et al., 2020). However, no study was addressed the response of these cultivars to salt stress at germination stage. As it is well known that plant response to salt stress varied greatly according to the developmental stage, the purpose of the present study is to evaluate the effects of salt stress on seed germination in six cultivars produced in the country with the aim to determine the relative level of salt resistance of these cultivars at the germination stage.

## Materials and methods

### Plant material

Six (06) African eggplant (*Solanum macrocarpon* L.) cultivars including five local (*Adja-ouèrè*, *Côte d'Ivoire* (*CI*), *Dangbo*, *Kpinman* and *Togan*) and one imported variety (*Kombara F1*) were used. Seeds of cultivars *CI*and *Kpinman* were provided the National Institute of Agricultural Research of Benin (INRAB) while cultivars *Dangbo*, *Adja-ouèrè* and *Togan* were obtained from the Regional Agriculture Development Agency of Plateau (ATDA / Plateau, Republic of Benin). Seeds of *Kombara F1* hybrid were bought from the company *BENIN SEMENCES* on the recommendation of ATDA / Plateau.

### NaCl effect on seed germination

Seeds were incubated in 10 cm Petri dishes on one layer of filter paper moistened with 20 ml of water solutions of 0–120 mM NaCl with an increment of 30. Seed germination was checked every day during 20 days incubation. The experiment was laid out as a completely randomized design with four replications (40 seeds each). The seeds were incubated in darkness at 26°C. A seed was considered as germinated when the radicle emerged from the seed coat according to Kinsou et al., (2019). Salt effect on seed germination was evaluated using germination kinetics, germination index and final germination rate. Cultivars were distinguished according to their salt resistance using the Salt Tolerance Index (STI) calculated according toa modified method of Tabatabaei et al., (2012).

### Statistical analysis

For all parameters, each value is presented as the mean ± standard error with four replicates per treatment. The analysis of the main effects of stress intensity was based on 1-way analysis of variance (ANOVA) and the means were compared using the Turkey test. Analysis was performed using "JM *P* Pro 12" software (SAS Institute. JMP® 12, 2009).

## Results and discussion

### Effect of salt stress on seed germination kinetics

Figures 1, 2, 3, 4, 5 and 6 present the effect of NaCl on seed germination rate after 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 days in the presence of NaCl at 0, 30, 60, 90 and 120 mM, respectively for cultivars *Adja-Ouèrè*, *Côte d'Ivoire*, *Dangbo*, *KombaraF1*, *Kpinman* and *Togan*. In the absence of stress, the reaction of cultivars were different: after 2 days: the germination percentages were 4.37%, 5%, 3.75%, 1.87% and 45% respectively for cultivars *Adja-Ouèrè*, *Dangbo*, *Kombara*, *Kpinman* and *Togan* whereas no seed of cultivar Côte d'Ivoire germinated. After 4 days, germination started for cultivar *Côte d'Ivoire*. The percentages of seed germination were about 84.37%, 63.75%, 63.75%, 60.62%, 88.12% and 20% respectively for cultivars *Adja-Ouèrè*, *Dangbo*, *Kombara F1*, *Kpinman* and *Togan* and *Côte d'Ivoire*. Thus, the germination started from the 2nd day or from the 4th day in the absence of stress according to the cultivar. At day 6,percentages of seed germination were about 88.75%, 76.25%, 69.37%, 77.5%; 93.12% and 52.5% respectively for cultivars *Adja-Ouèrè*, *Dangbo*, *Kombara F1*, *Kpinman*, *Togan* and *Côted'Ivoire*.

The time to maximum germination rate varied depending on the cultivar. Cultivar *Dangbo* reached its maximum (85%) after ten days, cultivar *Kpinman* (84.37%) after twelve days, cultivar *Kombara F1* (76.5%) after eighteen days, and *Togan* (96.87%) reached it after fourteen days. The remaining cultivars obtained their maximum rate of 91.87% for *Adja-Ouèrè*, and 80.25% for *Côte d'Ivoire*, respectively after sixteen and eighteen days of germination.

In the presence of NaCl, a variable response was observed according to the cultivar and the time (Figures 1 to 6).

For cultivar *Adja-Ouèrè*(fig. 1), the percentage of seed germination after 2 days passed from 4.37% to 4.37% and 2.5% respectively at 30 and 60 mM NaCl; no seed of this cultivar germinated at 90 and 120 mM NaCl. After four days, the germination percentages were 84.37%; 69.37%, 74.37%; 58.12% and 31.25% respectively for the control; 30, 60; 90 and 120 mM NaCl. At day 6, germination percentages decreased from 88.75% in the control to 80%; 85.62%; 76.25% and 61.87% respectively at 30; 60, 90 and 120 mM NaCl. Similar result was observed from the 8th day to the end of the experiment. The maximum germination rates were 91.87%; 84.37%, 88.12%, 83.75% and 70.62% respectively for the control; 30; 60; 90 and 120 mM NaCl. They were obtained at the 16th day for the control; the 8th day for 30 and 60 mM NaCl; at the 14th day for 90 mM NaCl; and at the 10th day for 120 mM NaCl. Thus, a germination reduction was observed under salt stress from the 2ndday.

For cultivar *Côte d'Ivoire* (fig. 2), at the 2nd day, seed germination started only for 30 and 90 mM NaCl with 0.62 % each. At the 4th day, germination percentage decreased from 20 % in the control to 16.87%; 2.5%; 3.12% and 0.62% respectively for 30; 60; 90 and 120 mM NaCl. At the 6th day, germination percentage decreased from 52.5% in the control to 35%; 19.37%; 11.25% and 1.87% respectively for 30; 60; 90 and 120 mM NaCl. Similar result was observed from the 8th day to the end of the experiment. The maximum germination rates were 80.25%; 60.87%, 38.75%, 19.37%and 3.12% respectively for the control; 30; 60; 90 and 120 mM NaCl. They were obtained at the 18th day for the control, 30 and 60 mM NaCl; at the 16th day for 90 mM NaCl; and at the 10th day for 120 mM NaCl. Thus, a germination reduction was observed under salt stress from the 4th day.

For cultivar *Dangbo* (fig. 3), at the 2nd day, no seed germinated in the presence of NaCl. At the 4th day, germination percentage decreased from 63.75% in the control to 50.62% ; 46.25% ; 31.87% and 11.87% respectively for 30; 60; 90 and 120 mM NaCl. At day 6, germination percentage decreased from 76.25% in the control to 68.12%, 61.25%; 52.5% and 42.5% respectively at 30, 60; 90 and 120 mM NaCl. Similar tendency was observed from the 8th day to the end of the experiment. The maximum germination rates were 85%; 75.62%, 67.5%, 60.62% and 53.12% respectively for the control; 30; 60; 90 and 120 mM NaCl. They were obtained from the 10th day for all NaCl concentrations except for 30 mM NaCl (14th day). Thus, a regular reduction was observed from the 4th day. However, the magnitude of the decrease is greater in the fourth early days compared to the last days of germination.

For variety *Kombara F1* (fig. 4), at the 2nd day, no seed germinated in the presence of NaCl except for 30 mM NaCl (0.625). At the 4th day, germination percentage decreased from 63.75% in the control to 37.5%; 28.12% ; 5.62% and 0.62% respectively for 30; 60; 90 and 120 mM NaCl. At the 6th day, germination percentage decreased from 69.37% in the control to 43.12%; 31.87%; 6.87% and 1.25% respectively for 30; 60; 90 and 120 mM NaCl. Similar tendency was observed from the 8th day to the end of the experiment.

The maximum germination rates were 76.5%; 54.37%, 41.87%, 11.25% and 1.25% respectively for the control, 30; 60; 90 and 120 mM NaCl. They were obtained from the 18th day for the control; from the 14th day for30 and 60 mM NaCl; from the 16th day for 90 mM NaCl and from the 6thday for 120 mM NaCl. Thus, a germination reduction was observed from the 4th day.

For cultivar *Kpinman* (fig. 5), at the 2nd day, no seed germinated in the presence of NaCl. At the 4th day, the germination percentages were 60.62% ; 53.12% ; 23.75% ; 8.75% and 1.87% respectively for the control, 30; 60; 90 and 120 mM NaCl. At day 6, the germination percentages were77.5%; 78.75%; 63.75%; 37.5% and 11.87% respectively for the control, 30, 60; 90 and 120 mM NaCl. Similar tendency was observed from the 8th day to the end of the experiment. The maximum germination rates were 85%; 84.37%, 71.87%, 48.12% and 30% respectively for the control; 30; 60; 90 and 120 mM NaCl. They were obtained from the 12th day for the control; from the 10th day for 30 mM NaCl; from the 14th day for 60 mM NaCl and from the 12th day for 90 and 120 mM NaCl. Thus, a germination reduction was observed under salt stress from the 4th day.

For cultivar *Togan* (fig. 6), at 2nd day, the percentage of seed germination after 2 days passed from 45 % in the control to 25.62%; 18.12% and 2.5 % respectively at 30; 60 and 90 mM NaCl; no seed of this cultivar germinated at 120 mM NaCl. At the 4th day, germination percentage decreased from 88.12% in the control to 86.25% ; 85% ; 73.75% and 66.25% respectively for 30; 60; 90 and 120 mM NaCl. At day 6, germination percentage decreased from 93.12% in the control to 90%, 91.25%; 86.25% and 80% respectively at 30, 60; 90 and 120 mM NaCl. Similar tendency was observed from the 8th day to the end of the experiment.

The maximum germination rates were 96.87%; 93.75%, 98.12%, 92.50 and 89.37% respectively for the control; 30; 60; 90 and 120 mM NaCl. They were obtained from 14th day for the control; 30 and 60 mM NaCl; and from 16th day for 90 and 120 mM NaCl. Thus, a germination reduction was observed under salt stress from the 2nd day.

Based on the time for maximum germination percentage, cultivars could be classified in three groups: Cultivars that reached the maximum germination at the same time for the control and the highest NaCl concentrations (*Kpinman* and *Dangbo*); cultivars that reached the maximum germination under salt stress earlier than the control (*Kombara F1*, *CI* and *Adja-Ouèrè*) and cultivars that reached the maximum germination under salt stress later than the control (*Togan*). It is important to notice that no seed of cultivar *Kombara F1* germinated after the 6th day at 120 mM NaCl whereas that of other NaCl concentrations continues their germination until the 14th-16th. The same observation can be made for cultivar *Côte d'Ivoire* after the 10th day for seed at 120 mM NaCl whereas that of other NaCl concentrations continues their germination until the 16th-18th.

### Effect of sodium chloride on germination index (GI)

In the absence of NaCl, the germination index were 3.41; 2.5; 3.47; 3.41; 3.37 and 4.06; respectively for cultivars *Adja-Ouèrè*, *Côte d'Ivoire*, *Dangbo*, *Kombara F1*, *Kpinman* and *Togan* (Table 1). Salt stress induced a significant decrease ($P<0.05$) in cultivar *Togan* from 30 mM NaCl; cultivars *Adja-Ouèrè* and *Kpinman* from 90 mM NaCl; and *Kombara F1* at 120 mM NaCl; cultivar *Dangbo* was not affected. Thus, the decrease of GI under salt stress was more marked in cultivar *Togan* than the other cultivars; *Dangbo* was the least affected.

### Effect of sodium chloride on final germination percentage

Figure 7 illustrates the effect of stress on the final germination percentage of the six African eggplant cultivars. In the absence of stress, the final germination percentages were 91.87%, 80.62%, 85%, 76.87%, 85% and 96.87% respectively for cultivars *Adja-Ouèrè*, *Côte d'Ivoire*, *Dangbo*, *Kombara F1*, *Kpinman* and *Togan*. Cultivar *Togan* has the highest final germination percentage and cultivar *Kombara F1* has the lowest.

Salt stress caused a reduction in the final germination percentage in almost all cultivars with a different response depending on the cultivar. Cultivar *Kombara F1* was affected significantly ($P<0.001$) from 30 mM NaCl, while the effect was significant ($P<0.001$) for cultivar Côte d'Ivoire from 60 mM NaCl. Cultivars *Dangbo* and *Kpinman* were significantly affected ($P<0.01$) from 90 mM NaCl. Cultivar *Adja-Ouèrè* was significantly affected ($P<0.01$) only at 120 mM NaCl while cultivar *Togan* was not significantly affected by the NaCl concentrations used. Thus, cultivar *Togan*, followed by *Adja-Ouèrè* were the least affected by salt stress whereas *Kombara F1*was the most affected, followed by *Côte d'Ivoire*.

**Table 1.** Germination index of six African eggplant cultivars as affected by different concentrations of NaCl: *Values are means ± standard errors*

| Cultivars | NaCl concentrations (mM) | | | | |
|---|---|---|---|---|---|
| | **0** | **30** | **60** | **90** | **120** |
| Adja-Ouere | 3.41±0.03a | 3.45±0.04ab | 3.39±0.02ab | 3.33±0.00b | 3.33±0.00b |
| Ci* | 2.50±0.83a | 3.75±0.41a | 0.83±0.83a | 2.08±1.25a | 0.83±0.83a |
| Dangbo | 3.47±0.02a | 3.33±0.00a | 3.33±0.00a | 3.33±0.00a | 2.50±0.83a |
| Kombara F1 | 3.41±0.04a | 3.36±0.02a | 3.33±0.00a | 2.50±0.83ab | 0.83±0.83b |
| Kpinman | 3.37±0.02a | 3.33±0.00a | 3.33±0.00a | 0.83±0.83b | 0.00±0.00b |
| Togan | 4.06±0.05a | 3.73±0.07b | 3.61±0.06b | 3.38±0.01c | 3.33±0.00c |

Means followed by different letters in the same line differ significantly ($P < 0.001$). *: Côte d'Ivoire

**Table 2.** Salt Tolerance Indexof sixAfrican eggplant cultivars at germination stage under five NaCl concentrations (0; 30; 60; 90 and 120 mM).

| Cultivars | | | | | |
|---|---|---|---|---|---|
| **Adja-Ouèrè** | **Côte d'ivoire** | **Dangbo** | **Kombara F1** | **Kpinman** | **Togan** |
| 0.89±0.02ab | 0.38±0.07c | 0.76±0.04ab | 0.35±0.07c | 0.69±0.06b | 0.96±0.01a |

Values are means ± standard errors (n=4). Means followed by different letters differ significantly ($P < 0.001$).

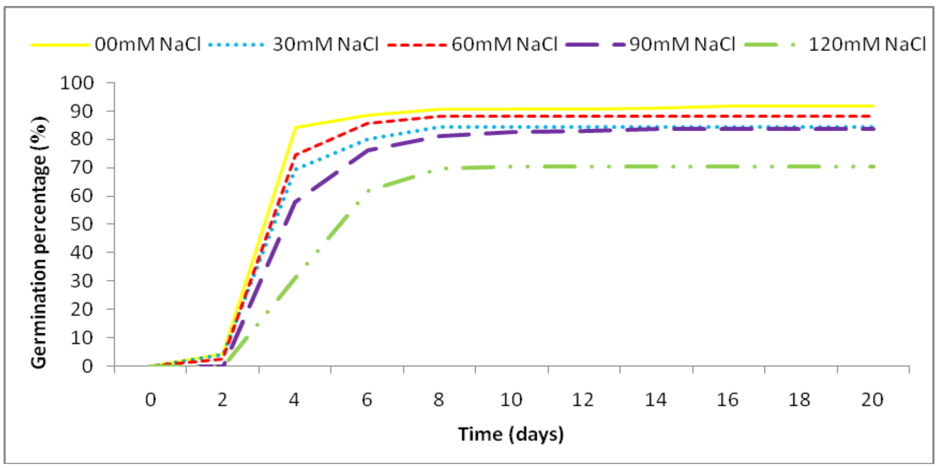


**Fig. 1:** Rate of germination of African eggplant seeds under saline conditions: Cultivar *Adja-Ouèrè*

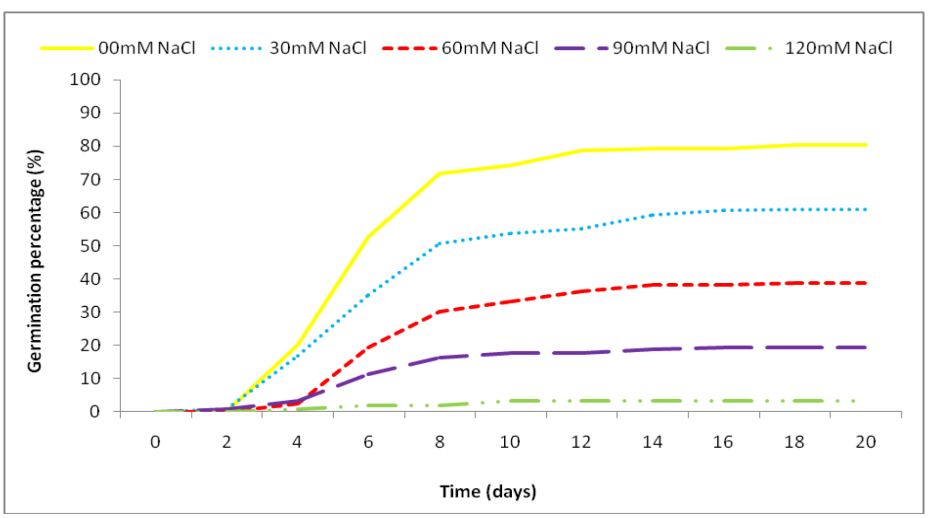


**Fig. 2:** Rate of germination of African eggplant seeds under saline conditions: cultivar *Côte d'Ivoire*

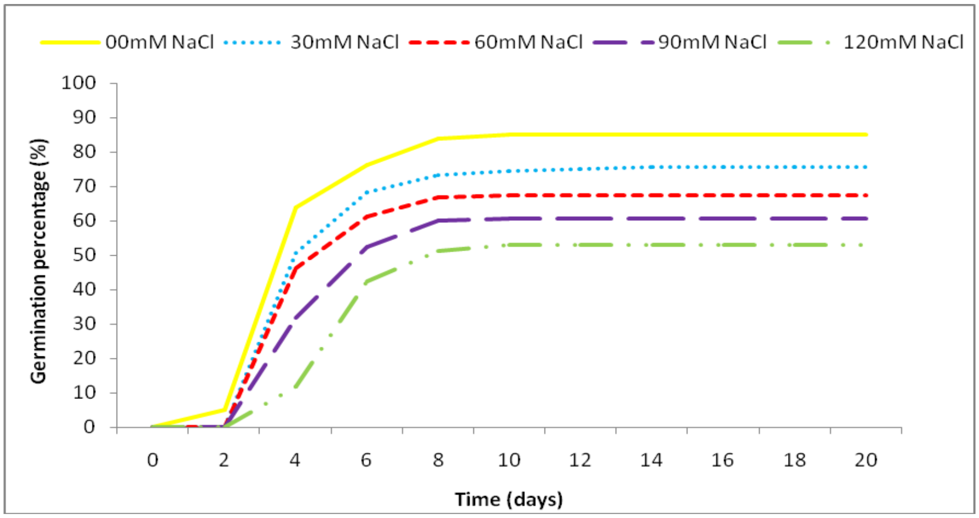


**Fig. 3:** Rate of germination of African eggplant seeds under saline conditions: cultivar *Dangbo*

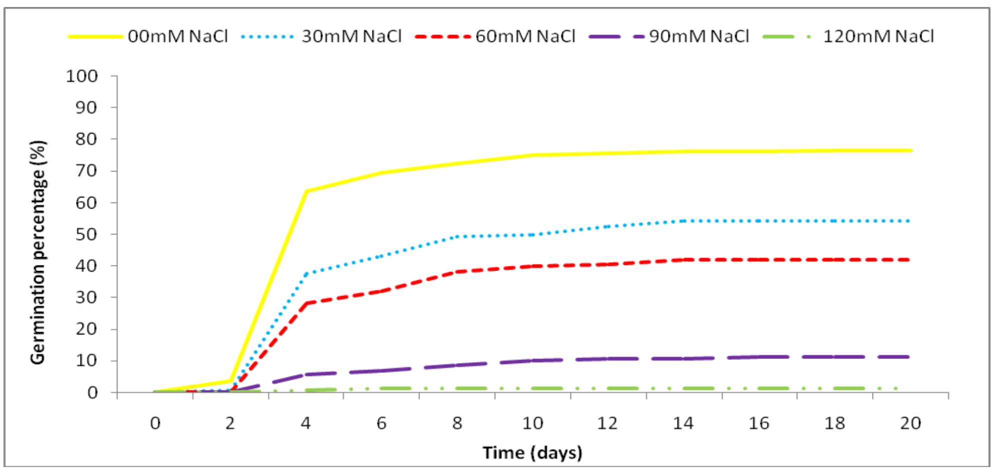


**Fig. 4:** Rate of germination of African eggplant seeds under saline conditions: cultivar *Kombara F1*

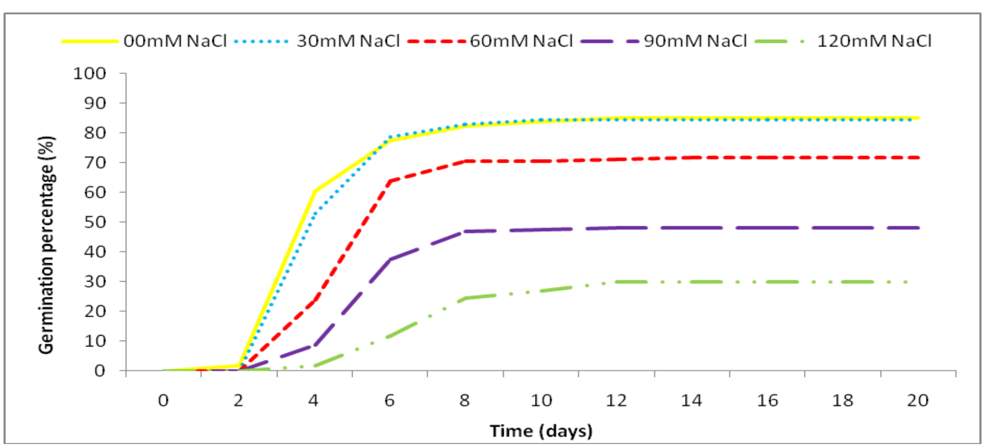


**Fig. 5:** Rate of germination of African eggplant seeds under saline conditions: Cultivar *Kpinman*

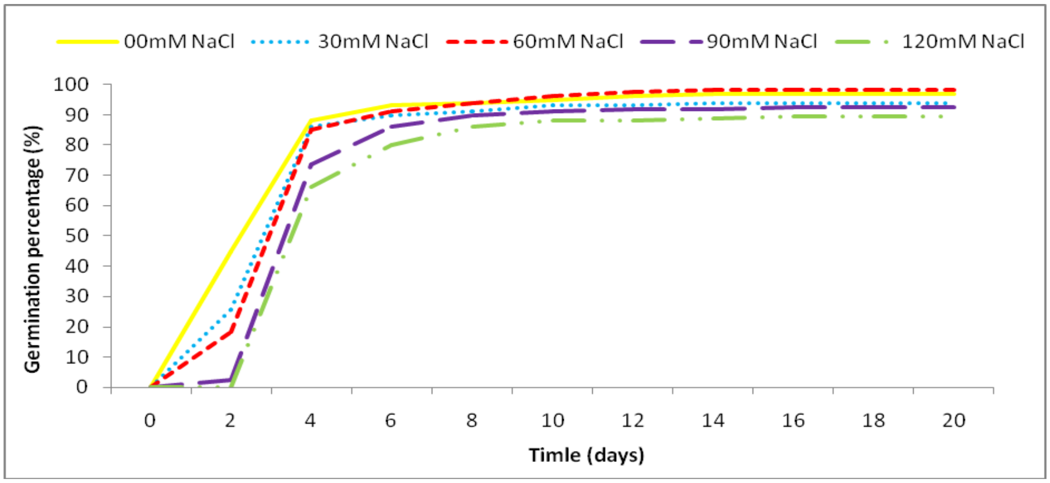


**Fig. 6:** Rate of germination of African eggplant seeds under saline conditions: Cultivar *Togan*

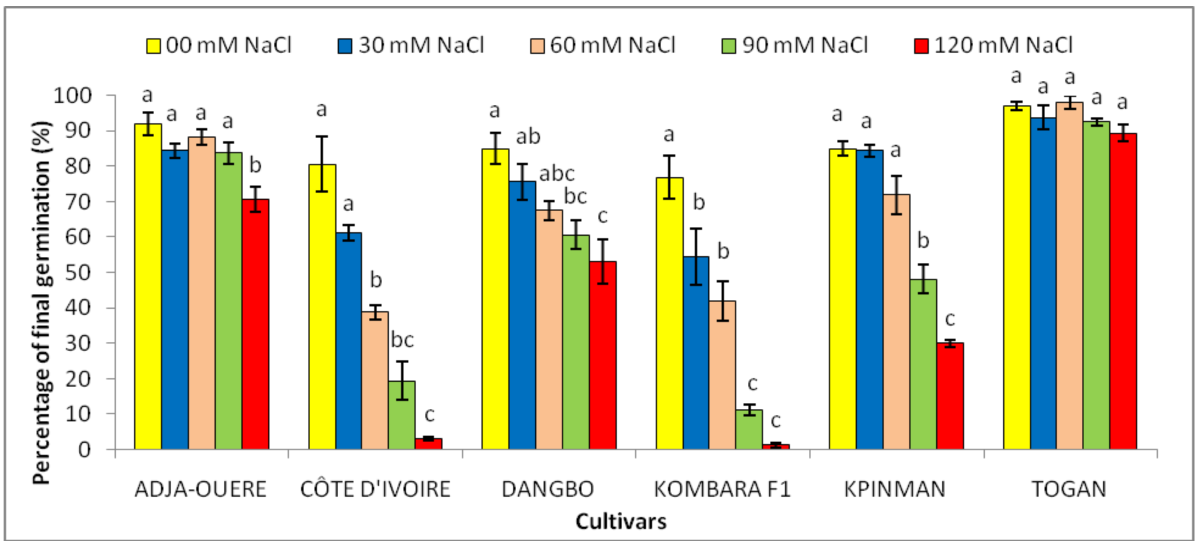


**Fig. 7:** Effect of different concentrations of NaCl on final germination percentage of six African eggplant cultivars, Vertical bars are standard error of means of four replications. Means followed by different letters for each cultivar differ significantly (P < 0.05)

## Salt Tolerance Index (STI) of the African eggplant cultivars

A significant difference ($P$<0.001) was observed among cultivars Salt Tolerance Index (Table 2). Cultivar *Togan* showed the highest STI (0.96) followed by cultivars *Adja-Ouèrè* (0.89) and *Dangbo* (0.76). Cultivars *Côte d'Ivoire* (0.38) and *Kombara F1* (0.35) showed the weakest STI values. Cultivar *Kpinman* was intermediary (0.69).

## Effect of salt stress on seed germination kinetics

Results revealed that the germination started from the 2$^{nd}$ day for all cultivars except for cultivar *CI* in the absence of stress and that in the presence of NaCl and particularly with the highest NaCl concentrations, germination started from the 4$^{th}$day indicating that salt stress delays seed germination. Moreover, results from the magnitude of decrease of germination percentage revealed that salt stress delayed germination mainly in cultivars *Adja-Ouéré*, *Dangbo*, *Kpinman* and *Togan*, corroborating previous reports in several vegetable species including amaranth (Wouyou et al., 2016) and tossa jute (Loko et al., 2020). However, the fact that this delay occurred only in four cultivars from the six evaluated seems to indicate that the germination delay under salt stress is not systematic but depends on cultivars.The time required for maximum seed germination percentage varied from the 6$^{th}$ day to the

18th day according to the cultivar either in the absence of stress or in the presence of salt stress. This result indicates that NaCl effect on African eggplant seeds final germination rate couldn't be studied before 18 days of stress. In other vegetables, variable duration was used to study salt stress effect on final germination percentage: 6 days incabbage (Jamil et al., 2007), 7 days (Cunhua et al., 2012), 8 days (Abdel-Farid et al., 2020) and 14 days (Sardoei and Mohammadi 2014) in tomato; 7 days in amaranth (Idris et al., 2020); 8 days in cucumber (Abdel-Farid et al., 2020), 14 days in chilli (Aloui et al., 2014) and 41 days in tossa jute (Mukul et al., 2021). These findings indicated that the accurate duration to study salt stress effect on germination varied greatly according to the species and the varieties considered.

## Effect of sodium chloride on germination index

According to Tadesse et al., (1999), the germination index quantifies the speed with which the seeds perform their germination indicating whether the seeds quickly germinate and synchronously. Our results revealed that salt stress significantly reduced the germination index in African eggplant cultivars from 30 mM NaCl indicating that salt stress reduced from lower concentration the speed of seed germination. In other vegetable species, Ben Yakoub et al., (2018) and Adilu and Gebre (2021) reported that increasing salt concentrations in the plant cultivation medium reduced the speed of germination. Similar results were reported in chickpeas (Noor-Ullah et al., 2018) and tomato (Chakma et al., 2019).

Our results also pointed out a significant difference among cultivars with cultivars *Côte d'Ivoire* and *Dangbo*as the least affected and cultivar *Togan* the most affected revealing variability among African eggplant cultivars behavior based on germination index. These findings corroborated those reported in chili pepper (Kpinkoun et al., 2018) and tossa jute (Loko et al., 2020).

## Effect of sodium chloride on final germination percentage

The cultivars tested in this study present different capacities of seed germination after 20 days in absence of salt stress. Similar trend was observed in different genotypes of the same vegetable species in chili (Newell et al., 2013; Kpinkoun et al., 2018); tomato (Kinsou et al., 2019) and tossa jute (Loko et al., 2020).Salinity induced a significant reduction in the percentage of final germination (after 20 days) in the cultivars tested except for cultivar Togan. The reduction of final germination percentage by NaCl has been reported in several vegetable species including chili pepper (Demir and Mavi, 2008; Bojović et al., 2010; Aloui et al., 2014), sugar beet (Zare et al., 2012), Black nightshade (*Solanum nigrum*) (Elhaak et al., 2015), eggplant (Hannachi and Van Labeke., 2018), carrot (Simon and Bolton, 2019)and pumpkin (Tarchoun et al., 2022). A variability was observed in the response of the six cultivars tested as previously reported by several authors. Cultivar *Togan*, followed by *Adja-Ouèrè* were the least affected by salt stress whereas *Kombara F1* was the most affected, followed by *Côte d'Ivoire*.

## Salt Tolerance Index (STI) of the African eggplant cultivars

Variability was observed among cultivars' Salt Tolerance Index. Cultivar *Togan* showed the highest STI followed by cultivars *Adja-Ouèrè* and *Dangbo*; cultivars *Côte d'Ivoire* and *Kombara F1* showed the weakest STI values. This criterion was used by Kpinkoun et al., (2018) and Kinsou et al., (2019) to classify respectively chili pepper and tomato cultivars according to their salt resistance level. Based on this criterion, cultivar *Togan* was the most salt resistant at germination level followed by *Adja-Ouèrè* and *Dangbo*; whereas cultivars *Côte d'Ivoire* and *Kombara F1* were the most salt sensitive; cultivar *Kpinman* was intermediate.

This study showed that NaCl salt stress delayed seed germination and reduced the percentage of final germination in African eggplant cultivars. It underlined the variability of relative salt-stress resistance for some local African eggplant cultivars at germination stage. Among the six cultivars tested, *Togan* was the most salt resistant with the highest STI the highest STI (0.96) followed by cultivars *Adja-Ouèrè* and *Dangbo*; cultivars *Côte d'Ivoire* and *Kombara F1* were the most salt sensitive with STI of 0.38 and 0.35 respectively. For the first time, we showcased a variability of salt resistance among local African eggplant cultivars at germination stage.

## Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this article.

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