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Salinity tolerance at the germination stage of Senegalese varieties of peanut, cowpea, millet and sorghum

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Abstract

Salinization continues to increase in semi-arid areas like Senegal where it limits seed germination, a crucial phase in a plant's cycle. Adaptation to salinization, one of the great challenges of modern agriculture, is possible through the use of halotolerant varieties which could be selected early during seed germination.

The general objective of this study is to evaluate the effect of salinity on the germination of peanut, cowpea, millet and sorghum.

The effect of NaCl (0, 40, 80 and 120 mM) was tested on seed germination for one week at 30°C in a culture chamber. The parameters evaluated are: the final percentage of germination (FG), the germination vigor index (GVI), the coefficient of velocity of germination (CVG), the percentage reduction in germination compared to the control (PRG) and the daily average germination (DAG).

The FG, GVI and CVG of millet, cowpea, sorghum and peanut show significant differences ($p<0.01$) for each NaCl concentration. On the other hand, DAG and PRG give significant differences only at 80 mM and/or 120 mM NaCl. FG, CVG, DAG and GVI decreased with increasing salinity for all varieties unlike PRG. Cowpea (V4) are less sensitive to salinity than peanut (V3), which tolerate NaCl better than cereals. Millet (V5) is more resistant than sorghum (V7). The increase in NaCl led to a significant difference in germination.

Cowpea (V4) would be more osmotolerant than peanut (V3) which is more tolerant than cereals such as millet (V5) and sorghum (V7) to salinity. These varieties would be the most recommended for successful cultivation in a saline environment.

Keywords: Salinity; Germination; Peanut; Cowpea; Millet; Sorghum.

1. Introduction

In Senegal, the surface area of salty lands is constantly increasing [1]. It affects virtually all regions of Senegal to varying degrees [2]. It is more important in the peanut basin [3] where it is estimated at 20% [4]. It is linked to climatic conditions and human activities. Salinization reduces the productive potential of arable land and threatens the food security of vulnerable populations [5]. Sodium chloride (NaCl) is the main agent responsible for salinity and salt stress in plants.

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Tolerance to NaCl is a widely sought-after quality for the adaptation of plants of agronomic interest to very widespread and constantly increasing salinization in Senegal since 1994 ([3]; [6]). Salinity negatively affects the physiology of seed germination of cereals and legumes including millet, sorghum, peanut and cowpea. The salinity that plants can tolerate without much damage depends on families, genera, species and varieties [7].

Improving agricultural production in areas affected by salinity could be done through the selection and use of salt-tolerant varieties and genotypes [8].

Salinity is the main environmental stress reducing crop productivity negatively affecting plant vigor and seed germination ([9]; [10]). It inhibits the absorption of water necessary for seed germination [11]. Plant tolerance to salinity can be assessed in seeds during their germination [10]. Germination is the first and most critical step in the development cycle of a plant [12] sensitive to stress including salinity [13]. The success of the germination phase is decisive during the vegetative period [14]. The final germination rate constitutes the best means of identifying the salt concentration which shows the physiological limit of seed germination [15]. The germination rate and parameters could be considered as criteria for early selection of plant species tolerant to saline stress ([14]; [16]).

The general objective of this study is to evaluate the effect of salinity on the germination of peanut, cowpea, millet and sorghum.

2. Material and methods

2.1. Plant material

The plant material consists of the seeds of three varieties of peanut (*Arachis hypogaea* L.) (V1=55-33 from Bambey; V2=28-206 produced in Casamance; V3=73-33 from Kaffrine), a variety of cowpea (*Vigna unguiculata* L.) (V4= undetermined early cowpea variety grown in Gassane), two varieties of millet (*Pennisetum glaucum* (L.) R. Br.) (V5= undetermined millet variety grown in Gassane; V6 = Souna3 millet from Kaffrine) and a variety of sorghum (*Sorghum bicolor* L.) (V7= undetermined variety of Sorghum grown in Gassane). The seeds were first disinfected by soaking for 03 minutes in 05% sodium hypochlorite solution, then rinsed three times with sterile distilled water.

2.2. Experimental apparatus

Three concentrations of NaCl (40, 80 and 120 mM) were tested, distilled water was used as a control. The treatment consisted of three repetitions of twenty seeds each. Each batch placed on filter paper in a Petri dish received 15 ml of the corresponding solution. The boxes were incubated in a culture chamber at a temperature of 30°C for one week. Seeds were considered germinated if a radicle of at least 2 mm emerged [17]. Counting of germinated seeds was done daily.

2.3. Parameters measured

The germination parameters were determined with reference to the work of ([8]; [12]; [18]; [19]; [20])

• Final germination percentage (%FG): $\%FG = (Nf / S) \times 100$ (Equation 1)

In our case this is the germination rate on the sixth day of the test, determined by the number of germinations obtained at the end of the experiment (Nf), expressed as a percentage of the total number of seeds tested (S).

• Germination vigor index (GVI): $GVI = (a / 1 + b / 2 + c / 3 ... + z / n) \times 100 / S$ (Equation 2)

With a, b, c, ..., z being number of seeds that germinate each day; n being the number of days the experiment lasts; S: number of seeds tested.

• Coefficient of velocity of germination (CVG): $CVG = 100 \times (N1+N2+...+Nx) / (N1T1+ N2T2...+NxTx)$ (Equation 3)

With N: number of seeds germinated each day (the 1st, 2nd day , and so on until the last day 'x': otherwise it is the number of germination Ni counted at Ti minus the number of germinated seeds Ni-1 counted at Ti-1); T: duration in days corresponding to N.

• Daily average germination (DAG): $DAG = \% FG / x^{th}$ day of the test (Equation 4)

With xth day of the test: day when the number of germinations reaches its maximum for each repetition.

• Percentage reduction in germination (PRG) compared to the control: PRG = 100 x [1 - (Nx / N0)]. (Equation 5)

Nx: number of seeds germinated with the saline treatment at x mMNaCl; N0: number of seeds germinated in the control (0 mMNaCl).

2.4. Statistical analyzes

Statistical analyzes were performed with R software version 4.3.1. All data are subjected to the Shapiro-Wilk normality test. Statistical processing of normally distributed data are performed by adopting a parametric approach with analysis of variance (ANOVA). For data with non-normal distribution, a non-parametric approach is applied with an analysis of variance on the ranks of the means. The Tukey test at the 5% probability threshold is performed in order to compare and rank the means or ranks on the means of the variables evaluated.

3. Results

3.1. Influence of NaCl on the final germination percentage (%FG)

For the same concentration, the final germination percentage of the V1 peanut variety presents statistically very significant differences ($p<0.01$) at the 5% threshold compared to those of the V2 peanut varieties (28-206, Casamance) and V3 (73-33, Kaffrine), regardless of the salinity level (Figure 1). On the other hand, within the variety for the four NaCl concentrations, only two varieties (V1 and V3) show significant statistical differences ($p<0.05$). The final germination percentage decreased with salt content for all peanut varieties. The peanut variety V1 (55-33 from Bambey) gave the lowest germination rates while the highest were obtained with V3 (73-33 from Kaffrine) (Figure 1).

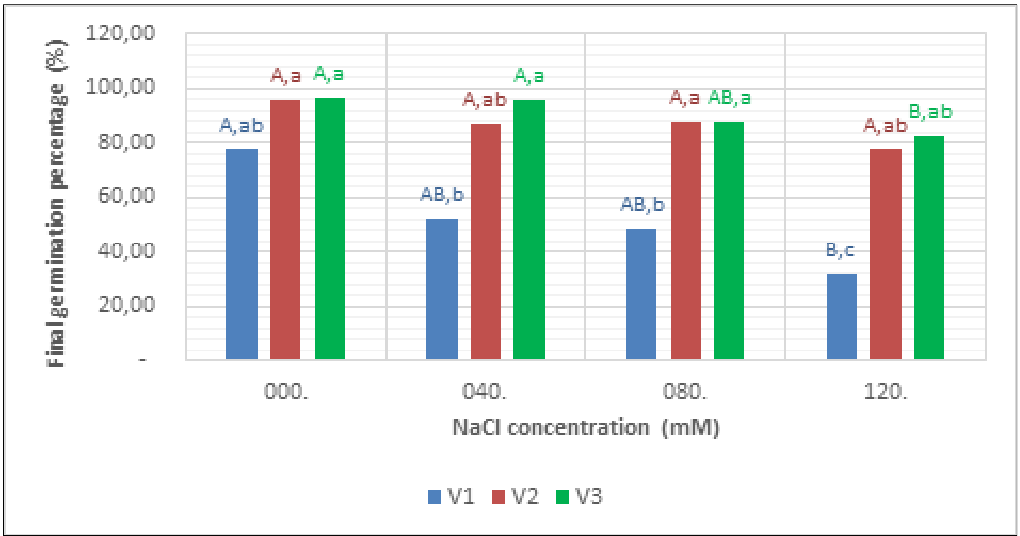

Figure 1 Final germination percentage of three peanut varieties (V1; V2; V3) as a function of NaCl concentration

Bars assigned the same capital letters do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the same variety. For each NaCl concentration, the bars assigned the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties.

The final germination percentage of the peanut variety V1 (55-33, Bambey) has a very statistically significant difference ($p<0.01$) compared to those of the peanut varieties V2 (28-206, Casamance) and V3 (73-33, Kaffrine) and the V4 variety (undetermined early cowpea variety grown in Gassane), for the same concentration and whatever the salinity level (Figure 2). Within the variety for the four NaCl concentrations, only two peanut varieties (V1 and V3) have significant statistical differences ($p<0.05$). Cowpea (V4) produced the highest germination percentages then the peanut varieties V3 and V2 respectively. The V1 variety (peanut 55-33 from Bambey) gave the lowest germination rates. Salt caused a reduction in the germination of peanut and cowpea (Figure 2).

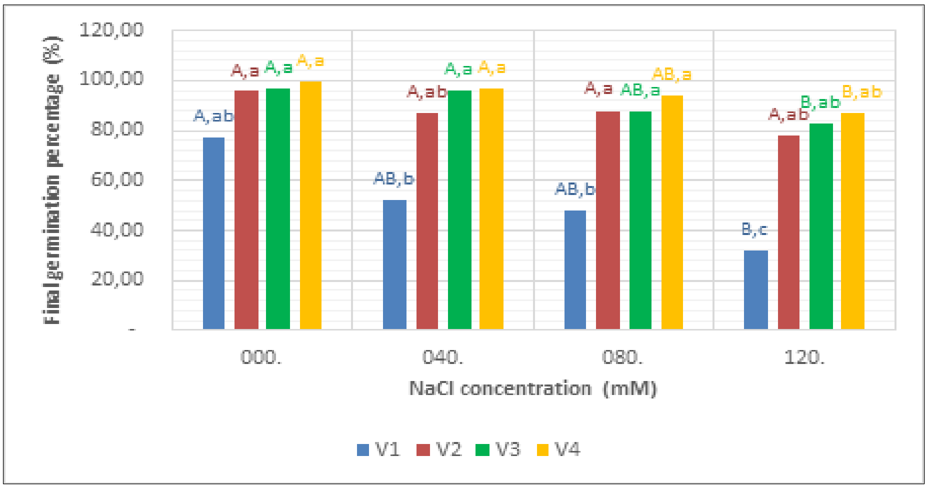

Figure 2 Final germination percentage of three peanut varieties (V1; V2; V3) and one cowpea variety (V4) as a function of NaCl concentration

Bars assigned the same capital letters do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the same variety. For each NaCl concentration, the bars assigned the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties.

Regardless of the salinity level, the seed germination rates of different varieties of millet, cowpea, sorghum and peanut are statistically different ($p<0.01$) at the 5% threshold (Figure). For salinity, within the same variety, significant statistical differences ($p<0.05$) are observed only for two varieties of peanut (V1 and V3). The highest germination rates are obtained with cowpea (V4= undetermined early cowpea variety grown in Gassane) followed by those of the two peanut varieties V3 (73-33, Kaffrine) and V2 (28-206, Casamance) . The weakest are given by the V1 peanut variety (55-33, Bambey). The two varieties of millet (*Pennisetum glaucum* (L.) R. Br.) (V5 = undetermined variety of millet grown in Gassane; V6 = Souna3 millet from Kaffrine) and a variety of sorghum (*Sorghum bicolor* L.) (V7 = undetermined variety of sorghum grown in Gassane) have intermediate and approximately similar germination rates. Overall, the final germination rate of millet, cowpea, sorghum and peanut seeds decreased with increasing NaCl concentration (Figure 3).

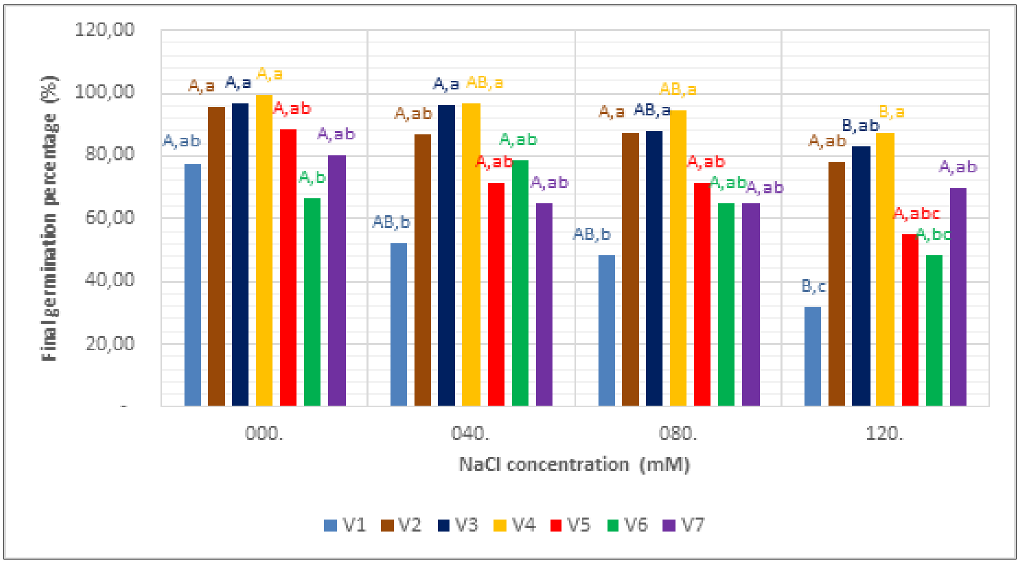

Figure 3 Final germination percentage of three varieties of peanut (V1; V2; V3), a variety of cowpea (V4), two varieties of millet (V5; V6) and a variety of sorghum (V7) as a function of NaCl concentration.

Bars assigned the same capital letters do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the same variety. For each NaCl concentration, the bars assigned the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties.

3.2. Effect of NaCl on the Germination Vigor Index (GVI)

Salinity led to a very significant reduction (p<0.001) in the peanut germination vigor index. The smallest indices are observed in V1 (55-33, Bambey) and the largest are produced by V3 (73-33, Kaffrine) (Table 1).

Table 1 Effect of salinity on the germination vigor index (GVI) of three peanut varieties (V1; V2; V3)

	NaCl concentration (mM)				
Varieties	**000**	**040**	**080**	**120**	**p-value**
V1	53.15_A b	28.49_B b	23.76_B b	13.38_B b	0.000661 ***
V2	88.40_A a	70.71_B a	66.23_B a	45.96_C a	0.000148 ***
V3	91.30_A a	81.57_A a	67.66_B a	47.25_C a	2.73e-05 ***
p-value	0.000148 ***	0.000275 ***	0.000173 ***	0.000264 ***	

For each variety on the same line, the numbers followed by the same capital letters in subscript do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the different concentrations of NaCl. For each NaCl concentration on the same column, the numbers followed by the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties. Meaning code: ns = non-significant difference, P ⩾ 0.05; * = significant difference, P < 0.05; ** = significant difference, P < 0.01; *** = significant difference, P < 0.001; On the column, averages with identical letters are statistically equivalent to 5%.

Whatever the concentration of NaCl, the germination vigor indices of the seeds of the different varieties of peanut (V1, V2 and V3), cowpea (V4), millet (V5 and V6) and sorghum (V7) show statistically significant differences (p<0.005) at the 5% threshold (Table 2). For salinity, very significant statistical differences (p<0.001) are observed within the same variety only for peanuts (V1, V2 and V3). Cowpea (V4) has the highest germination vigor index followed by the indexes of peanut varieties (V2 and V4). However, the V1 peanut variety gave the lowest germination index regardless of the NaCl concentration. For all seeds the index is reduced by increasing the salt concentration (Table 2).

Table 2 Germination vigor index (GVI) of three varieties of peanut (V1; V2; V3), one variety of cowpea (V4), two varieties of millet (V5; V6) and one sorghum variety (V7) depending on NaCl concentration

	NaCl concentration (mM)				
Varieties	**000**	**040**	**080**	**120**	**p-value**
V1	53.15_A b	28.49_B b	23.76_B b	13.38_B c	0.000661 ***
V2	88.40_A a	70.71_B a	66.23_B a	45.96_C ab	0.000148 ***
V3	91.30_A a	81.57_A a	67.66_B a	47.25_C ab	2.73e-05 ***
V4	91.02_A a	80.43_A a	70.40_A a	64.29_A a	0.06^{ns}
V5	78.06_A ab	63.61_{AB} ab	61.11_{AB} a	46.11_B ab	0.05^{ns}
V6	55.83_{AB} b	70.83_A b	55.83_{AB} a	35.83_B b	0.07^{ns}
V7	70.56_A ab	57.92_A ab	58.06_A a	57.50_A ab	0.71^{ns}
p-value	0.0011 **	0.00327 **	0.00133 **	5.96e-05 ***	

For each variety on the same line, the numbers followed by the same capital letters in subscript do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the different concentrations of NaCl. For each NaCl concentration on the same column, the numbers followed by the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties. Meaning code: ns = non-significant difference, P ⩾ 0.05; * = significant difference, P < 0.05; ** = significant difference, P < 0.01; *** = significant difference, P < 0.001; On the column, averages with identical letters are statistically equivalent to 5%.

3.3. Variation of the coefficient of velocity of germination (CVG) as a function of salinity

The coefficient of velocity of germination show significant statistical differences (p<0.05) at the 5% threshold for the different peanut varieties and within the same variety for all NaCl concentrations (Figure 4). Salinity led to a reduction in the coefficient for all varieties. This decrease varied depending on the peanut varieties and the salt concentration (Figure 4).

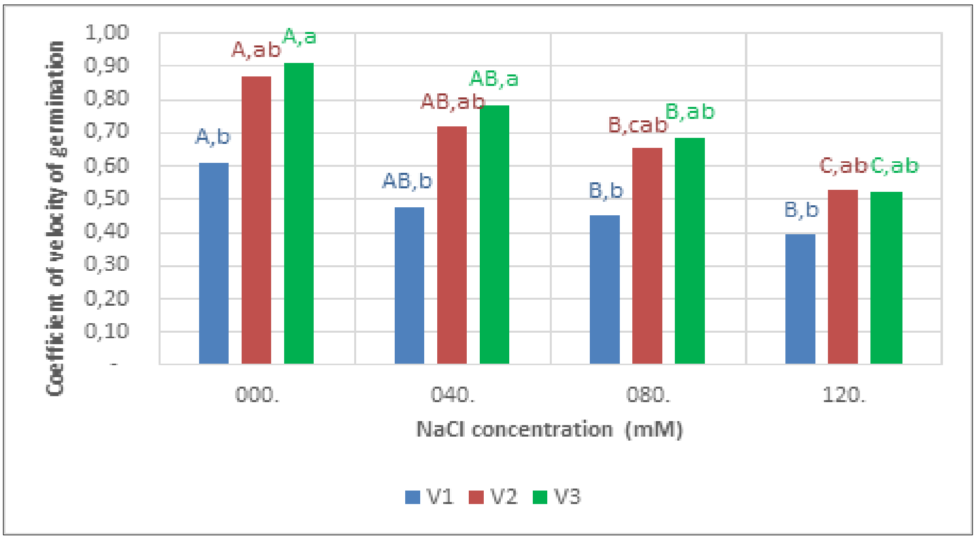

Figure 4 Coefficient of velocity of germination (CVG) of three peanut varieties (V1; V2; V3) as a function of salinity

Bars assigned the same capital letters do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the same variety. For each NaCl concentration, the bars assigned the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties.

The coefficient of velocity of germination of the cereals and legumes tested presents very statistically significant differences ($p<0.05$) at the 5% threshold regardless of the salinity level for the same concentration (Figure 5). On the other hand, for the four concentrations of NaCl, the coefficient of velocity of germination of the peanut varieties (V1, V2 and V3) and that of millet V6 show significant statistical differences ($p<0.05$) within the variety. The reduction in the coefficient of velocity of germination increased with salinity (Figure 5).

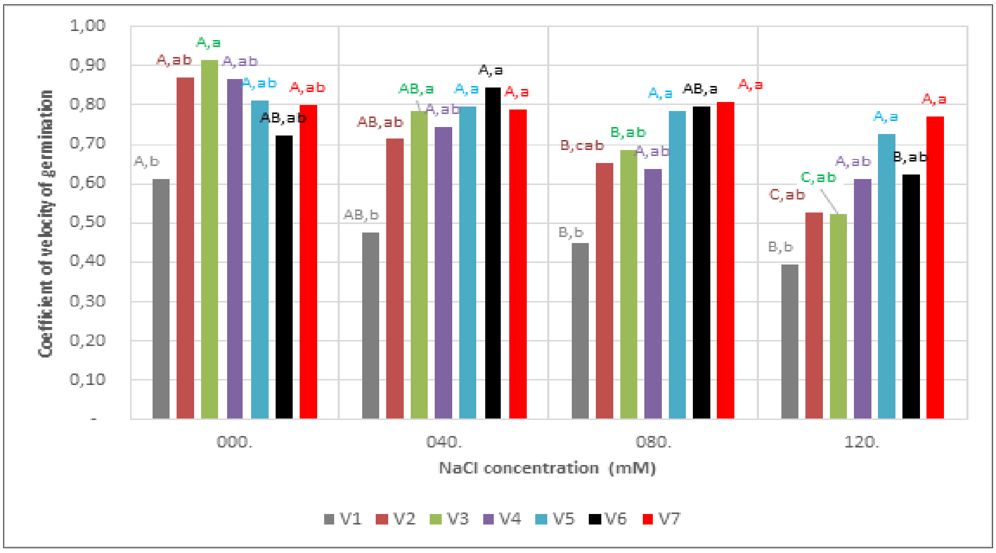

Figure 5 Coefficient of velocity of germination (CVG) of three varieties of peanut (V1; V2; V3), a variety of cowpea (V4), two varieties of millet (V5; V6) and a variety of sorghum (V7) as a function of NaCl concentration

Bars assigned the same capital letters do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the same variety. For each NaCl concentration, the bars assigned the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties.

3.4. Impact of salinity on daily average germination (DAG)

In the presence of NaCl, the daily average germination is significantly reduced ($p<0.05$) with increasing salinity for all peanut varieties (Table 3). There is no significant difference ($p=0.09$) for the daily germination averages of the controls of the three peanut varieties. Statistical analyzes on the daily average germination of each peanut variety show a significant statistical difference ($p<0.05$) for salinity. Variety V1 (peanut variety 55-33, Bambey) gave the lowest daily germination averages and variety V3 (peanut variety 73-33, Kaffrine) provided the highest values (Table 3).

Table 3 Daily average germination (DAG) of three peanut varieties (V1; V2; V3) depending on salinity

	NaCl concentration (mM)				
Varieties	**000**	**040**	**080**	**120**	**p-value**
V1	33.15_A a	16.98_B c	15.20_B b	9.99_B b	0.0021 **
V2	53.49_A a	32.47_B b	34.82_{AB} a	27.04_B a	0.016 *
V3	60.00_A a	46.11_{AB} a	38.30_{AB} a	30.56_B a	0.0136 *
p-value	0.09^{ns}	0.000854 ***	1.03e-05 ***	0.00172 **	

For each variety on the same line, the numbers followed by the same capital letters in subscript do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the different concentrations of NaCl. For each NaCl concentration on the same column, the numbers followed by the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties. Meaning code: ns = non-significant difference, $P \geqslant 0.05$; * = significant difference, $P < 0.05$; ** = significant difference, $P < 0.01$; *** = significant difference, $P < 0.001$; On the column, averages with identical letters are statistically equivalent to 5%.

The results of the statistical analyzes show significant differences ($p<0.01$) for millet, peanut, sorghum and cowpea only for 80 and 120 mM NaCl (Table 4). However, within the variety the analyzes revealed significant differences ($p<0.05$) only for peanut. The daily average germination of all seeds generally decreased with increasing salinity. The highest daily germination average (60.39) is obtained with cowpea (V4) in the absence of salinity. On the other hand, the lowest (9.99) is produced by the peanut variety V1 (55-33) under 120 mM NaCl (Table 4).

Table 4 Daily average germination (DAG) of three varieties of peanut (V1, V2, V3), a variety of cowpea (V4), two varieties of millet (V5; V6) and a variety of sorghum (V7) as a function of NaCl concentration

	NaCl concentration (mM)				
Varieties	**000**	**040**	**080**	**120**	**p-value**
V1	33.15_A a	16.98_B a	15.20_B b	9.99_B b	0.0021 **
V2	53.49_A a	32.47_B a	34.82_{AB} a	27.04_B a	0.016 *
V3	60.00_A a	46.11_{AB} a	38.30_{AB} a	30.56_B a	0.0136 *
V4	60.93_A a	49.63_A a	32.07_A a	25.18_A ab	0.25^{ns}
V5	39.17_A a	27.78_A a	31.11_A a	25.00_A ab	0.27^{ns}
V6	26.94_A a	39.17_A a	32.50_A a	19.44_A ab	0.16^{ns}
V7	35.83_A a	28.75_A a	27.78_A ab	30.00_A a	0.73^{ns}
p-value	0.15^{ns}	0.06^{ns}	0.00159 **	0.00979 **	

For each variety on the same line, the numbers followed by the same capital letters in subscript do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the different concentrations of NaCl. For each NaCl concentration on the same column, the numbers followed by the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties. Meaning code: ns = non-significant difference, $P \geqslant 0.05$; * = significant difference, $P < 0.05$; ** = significant difference, $P < 0.01$; *** = significant difference, $P < 0.001$; On the column, averages with identical letters are statistically equivalent to 5%.

3.5. Reduction of germination compared to the control by NaCl

The percentage reduction of germination generally increased with salinity (Table 5). On the other hand, the concentration of 40 mM NaCl seems to stimulate the germination of varieties V3 (peanut 73-33, Kaffrine) and V6 (millet souna 3, Kaffrine). Statistical analyzes show significant differences ($p=0.0144$) between the different varieties at the concentration of 120 mM NaCl only. Within the variety, there are statistically significant differences ($p<0.05$) between the concentrations for the varieties V1 (peanut 55-33 grown in Bambey), V3 (peanut 73-33 produced in Kaffrine) and V4 (peanut 73-33 grown in Bambey). undetermined early cowpea variety grown in Gassane) (Table 5).

Table 5 Effect of NaCl on the variation in the percentage reduction of germination (PRG) compared to the control three varieties of peanut (V1, V2, V3), one variety of cowpea (V4), two varieties of millet (V5; V6) and a variety of sorghum (V7)

	NaCl concentration (mM)				
Varieties	000	040	080	120	p-value
V1	0.00_{B} a	31.80_{AB} a	37.47_{AB} a	58.12_{B} a	0.0131 *
V2	0.00_{A} a	8.84_{A} a	8.00_{A} a	18.79_{A} ab	0.13 ns
V3	0.00_{B} a	-0.08_{B} a	8.23_{AB} a	13.97_{A} b	0.0173 *
V4	0.00_{B} a	2.84_{AB} a	5.18_{AB} a	12.28_{A} b	0.0312 *
V5	0.00_{A} a	18.89_{A} a	16.85_{A} a	37.22_{A} ab	0.11 ns
V6	0.00_{A} a	-22.03_{A} a	-0.24_{A} a	26.47_{A} ab	0.25 ns
V7	0.00_{A} a	16.67_{A} a	19.63_{A} a	13.33_{A} b	0.57 ns
p-value	NaN	0.15 ns	0.18 ns	0.0144 *	

For each variety on the same line, the numbers followed by the same capital letters in subscript do not present significant differences at the 5% threshold according to the Student-Newman-Keuls test for the different concentrations of NaCl. For each NaCl concentration on the same column, the numbers followed by the same lowercase letters are not significantly different at the 5% threshold according to the Student-Newman-Keuls test for the different varieties. Meaning code: ns = non-significant difference, $P \geqslant 0.05$; * = significant difference, $P < 0.05$; ** = significant difference, $P < 0.01$; *** = significant difference, $P < 0.001$; On the column, averages with identical letters are statistically equivalent to 5%.

4. Discussion

The final germination percentage decreased significantly (p<0.001) with the NaCl content for all peanut varieties (V1=55-33 from Bambey; V2=28-206 produced in Casamance; V3=73-33 from of Kaffrine) (Figure 1). Su *et al.* [21] observed the significant reduction (p<0.001) then inhibition of wheat germination by increasing salinity. Consistent results were obtained in three Bulgarian varieties of peanut (*Arachis hypogaea* L.) in the presence of 0, 50, 100, 150 and 200 mM NaCl [17]. The final germination percentage constitutes the best means of identifying the salt concentration which presents the physiological limit of seed germination ([6]; [16]). This parameter can still be influenced by salinity, seed longevity, sowing depth and osmotic pressure [21].

The greatest germination rates are obtained with V3 (73-33 from Kaffrine) (Figure 1). According to Akter *et al.* [9] this shows that this variety is more osmotolerant than other varieties.

Salt led to a reduction in the germination of peanuts and cowpeas (V4 = undetermined early cowpea variety grown in Gassane) (Figure 2). Similar results were also obtained on salinity in *Hedysarum flexuosum*, a spontaneous forage and pastoral legume of Mediterranean origin [22]. Regardless of the salinity level, the seed germination rates of different varieties of millet (*Pennisetum glaucum* (L.) R. Br.), cowpea (*Vigna unguiculata* L.), sorghum (*Sorghum bicolor* L.) and peanut (*Arachis hypogaea* L.) are statistically different (p<0.01) at the 5% threshold. The germination rate overall decreased with increasing NaCl concentration (Figures 1–3). These results confirm those of Moussa *et al.* [12] who showed in soft wheat that when salinity increases, the final germination percentage decreases. Our results corroborate those of Calone *et al.* [23] who showed that even the final germination rate of halophytes like *Salicornia europaea* is negatively affected by NaCl. The first consequence of salinity is the increase in external osmotic pressure creating physiological drought [24]. The reduction in the final germination percentage results from this water deficit which affects the speed of water absorption by seeds, imbibition and germination ([11]; [12]; [26]). Consistent results were obtained in rice (*Oryza sativa* L.) with a delay in germination for saline treatments [25]. According to Moussa *et al.* [12], the reduction in germination may also be linked to a strong absorption of Na^{+} and Cl^{-} ions during seed imbibition, inducing cellular toxicity which inhibits or slows germination. The results of Radhouane [14] contradict ours; he found an effect of salt stimulating the germination of six varieties of millet (*Pennisetum glaucum* (L.) R. Br.).

The quantities of salts that plants can tolerate without great damage to their culture vary depending on the families, genera and species, but also the varieties considered. This decrease can be caused by a disruption of the enzymatic systems involved in the different physiological functions of the germinating seed ([15]; [27]). This depressive effect of salinity on germination can also come from the increase in the osmotic potential of the culture substrate with the concentration of NaCl [28]. Indeed, the increase in the osmotic potential of the substrate lengthens the time necessary for imbibition and the establishment of mechanisms for adjusting the osmotic potential of the seeds, which delays and reduces germination ([11]; [26]; [28]). The seed adjusts its osmotic potential through the synthesis of numerous mineral and organic compounds such as proline and soluble sugars ([5]; [29]) in order to adapt to saline stress. This osmotic adjustment may be insufficient and lead to physiological dryness manifesting as a water deficit. This osmotic adjustment may be insufficient and lead to physiological dryness manifesting as a water deficit. The depressive effects of salt on germination are firstly osmotic in nature, then toxicity phenomena due to high concentrations can appear ([6]; [11]; [15]). However, despite sufficient osmotic adjustment, ionic toxicity can occur and cause irreversible damage. The mode of action of NaCl on germination can also be osmotic and/or toxic in nature linked to Na^+ and Cl^- ions ([5]; [30]). This toxic effect could occur in the imbibition phase or on the physiology of the seed without restriction of water supply.

The germination vigor index shows very significant statistical differences ($p<0.001$) at the 5% threshold between the different peanut varieties and within the same variety. Salinity led to a very significant reduction in the germination vigor index of peanut (*Arachis hypogaea* L.) (Table 1). These results confirm those of previous work carried out by Moussa et al. [12] in two varieties of soft wheat (*Triticum aestivum* L.). Consistent results were obtained with three Bulgarian varieties of peanut (*Arachis hypogaea* L.) [17]. Cowpea V4 and peanut varieties (V2 and V4) have the highest germination vigor index. However, the peanut variety V1 gave the lowest germination index regardless of the NaCl concentration (Table 2). The variety that has a higher germination vigor index is relatively more tolerant to salinity [12].

Whatever the concentration of NaCl, the indices of germination vigor of the seeds of the three varieties of peanut (*Arachis hypogaea* L.), of the variety of cowpea (*Vigna unguiculata* L.), of the two varieties of millet (*Pennisetum glaucum* L.) and the sorghum variety (*Sorghum bicolor* L.) show statistically significant differences ($p<0.005$) at the 5% threshold. For salinity, very significant statistical differences ($p<0.001$) are observed within the variety only for peanuts (V1, V2 and V3). For all seeds the germination vigor index is reduced by increasing the NaCl concentration (Tables 1 and 2). Our results agree with those of Desheva *et al.* [17] who observed in peanuts a reduction in the germination vigor index depending on the varieties and the increase in salinity. Calone *et al.* [23] showed that NaCl reduces the germination vigor index of *Salicornia europaea*, a halophytic *amaranthaceae*. Moussa *et al.* [12] found partly contradictory results in common wheat (*Triticum aestivum* L.).

Salinity led to a reduction in the coefficient for all varieties (Figure 4). Results in the same direction were obtained in soft wheat [12]. This decrease varied depending on the peanut varieties and the salt concentration (Figure 4). These results are in agreement with those of [17] who studied the influence of salinity on the germination and growth of peanut (*Arachis hypogaea* L.). This decrease corresponds to an increase in external osmotic pressure, which affects the speed of water absorption by the seeds ([5]; [31]).

The coefficient of velocity of germination presents statistically very significant differences ($p<0.05$) at the 5% threshold whatever the salinity level for the same concentration. These results agree with those of previous work carried out by Moussa *et al.* [12] in two varieties of soft wheat. On the other hand, for the four concentrations of NaCl, the coefficients of the germination speed of the peanut variety ((*Arachis hypogaea* L.) (V1=55-33 coming from Bambey; V2=28-206 produced in Casamance; V3= 73-33 from Kaffrine)) and that of millet V6 (*Pennisetum glaucum* L., millet Souna3 from Kaffrine) show significant statistical differences ($p<0.05$) within the variety. The reduction in the coefficient of velocity of germination increased with salinity and depending on the varieties (Figure 5). Similar results are obtained in two varieties of soft wheat [12]. NaCl reduces the velocity of germination and reduces the germination power of seeds; this reduction depends on the species, the variety, the intensity of saline stress and its duration of application [31]. The reduction in the coefficient of velocity of germination by salinity is noted in halophytic species such as *Salicornia europaea* [23]. Salinity negatively affects germination parameters by delaying or preventing the absorption of water necessary for the mobilization of reserves, or by the toxicity of the ions constituting the salt ([5]; [11]; [32]). This toxic effect can lead to the alteration of the metabolic processes of germination and in the extreme case to the death of the embryo by excess ions [15].

In the presence of NaCl, the daily average germination is significantly reduced ($p<0.05$) with increasing salinity for all peanut varieties (Table 3). However, Zhao *et al.* [20] observed beneficial effects of moderate salinity on seed germination of a leguminous plant from desert dunes in northern China (*Saphora alopecuroides*). As for high salinity, they observed depressive effects. Our results corroborate those of Camara *et al.* [16] who observed a drop in the daily average germination of three legumes (*Phaseolus vulgaris*, *Glycine max* and *Vigna unguiculata*) with increasing salinity. Similar results were observed in chickpea (*Cicer arietinum* L.). This reduction in the daily average germination results from a drop in germination speed [15]. There is no significant difference ($p=0.09$) for the daily germination averages of the controls of the three peanut varieties. Statistical analyzes on the daily average germination of each peanut variety show a significant statistical difference ($p<0.05$) for salinity (Table 3). Moussa *et al.* [12] did not observe any significant difference between wheat varieties and, on the other hand, they obtained a very highly significant difference between the four salinity levels and a significant interaction between salinity levels and varieties. The daily average germination is an indicator of seed vigor [33].

The results of the statistical analyzes show significant differences ($p<0.01$) for millet, peanut, sorghum and cowpea only for 80 and 120 mM NaCl. However, within the variety the analyzes revealed significant differences ($p<0.05$) only for peanut. The increase in salinity generally led to a decrease in the average daily germination of all seeds of all varieties (Table 4). NaCl reduces the speed and rate of seed germination [16]. Corroborating results were obtained in varieties of soft wheat (*Triticum aestivum* L.) and durum wheat (*Triticum durum* Desf.) ([6]; [10]). On the one hand, the decrease in the average daily germination of all the varieties with the increase in the concentration of NaCl is explained by the time necessary for the seed to put in place mechanisms allowing it to adjust its internal osmotic pressure ([5]; [6]; [11]). On the other hand, it is linked to an increase in external osmotic pressure, which slows down the speed of water absorption by seeds and induces physiological drought ([12]; [24]).

The percentage reduction of germination generally increased with salinity (Table 5). Consistent results were observed in a leguminous fabaceae, *Hedysarum flexuosum* [22]. Salinity reduces the speed of germination, the germination capacity of seeds and the final germination rate of seeds ([6]; [16]), which results in an increase in the final germination percentage by report to the witness. However, the concentration of 40 mM NaCl seems to stimulate the germination of varieties V3 (peanut 73-33) and V6 (Souna3 millet from Kaffrine) (Table 5). The reduction in germination percentage by salinity depends on the variety [34]. On the other hand, moderate salinity is beneficial for the germination of *Saphora alopecuroides* seeds [20] and leads to a decrease in the percentage reduction with the moderate increase in salt contents.

Statistical analyzes show significant differences ($p=0.0144$) between the different varieties at the concentration of 120 mM NaCl only. Within the variety, there are statistically significant differences ($p<0.05$) between the concentrations for the varieties V1 (peanut 55-33, Bambey), V3 (peanut 73-33, Kaffrine) and V4 (peanut variety undetermined early cowpea grown in Gassane) (Table 5). On the other hand, Moussa *et al.* [12] observed a very highly significant difference in the percentage reduction in germination of two varieties of common wheat (*Triticum aestivum* L.) by salinity. The reduction in germination compared to the control can be attributed to physiological drought resulting from an increase in external osmotic pressure by salinity [24]. The depressive effect of salinity is linked to concentration and variety [35]. This reduction depends on the ability of the seed to maintain its metabolism under conditions of high salt stress and to sufficiently adjust its internal osmotic pressure through the synthesis of compounds including proline and soluble sugars [5].

5. Conclusion

Laboratory studies have shown a significant reduction in germination depending on NaCl concentration and variety.

Cowpea (V4 = undetermined early cowpea variety grown in Gassane) is more tolerant of salinity than peanuts, the latter tolerates salt better than millet and sorghum. Among the peanut varieties, V3 (peanut 73-33, Kaffrine) is less sensitive to salinity. The variety of millet V5 (undetermined variety of millet grown in Gassane) and that of sorghum (V7= undetermined variety of sorghum grown in Gassane) are more resistant to NaCl as far as cereals are concerned.

Cowpea is said to be more osmotolerant than peanuts and especially cereals such as millet and sorghum. These varieties would be the most recommended for successful cultivation in a saline environment.

Compliance with ethical standards

Disclosure of conflict of interest

Authors declare that no conflict of interest exist.

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