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Germination and vigor of soybean genotypes seeds under saline stress[1]

Germinação e vigor de genótipos de soja sob estresse salino

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HIGHLIGHTS:
Conventional genotypes have greater salt stress tolerance than transgenic types.
Salt stress has greater deleterious effect on soybean vigor than on germination.
The germination speed index is directly related to the tolerance level of the variety.

ABSTRACT: Soybean stands out among the crops with the greatest application of transgenics, mainly for tolerance to herbicides, pests, and diseases; however, studies on salt stress in genetically modified plants are scarce. This study aimed to evaluate the tolerance of both traditional and genetically modified soybean genotypes to saline stress during the germination and seedling phases. Seeds of 13 soybean genotypes were selected (five traditional (BRS Carnaúba, BRS Pérola, BRS Tracajá, BRS Sambaíba, and FTR-4389) and eight transgenic (BRS Sambaíba RR, BRS-333-RR, BRS-9820- RR, PAS-13565-74-RR, PAS-11711-007-RR, BRS-918-IPRO, AS-3810-IPRO, and M-8210-IPRO)), subjected to four osmotic potentials (0.0, 0.1, -0.2, and -0.3 MPa). The seed quality was evaluated using the following variables: the germination percentage, germination speed index, shoot length, root length, dry mass accumulation, and salinity tolerance index. All variables were found to be affected by salt stress. However, the conventional genotypes, BRS Carnaúba, BRS Pérola, BRS Tracajá, and BRS Sambaíba, and the RR group PAS-13565-74-RR, and PAS-11711-007-RR were tolerant to salinity, whereas the genotypes FTR-4389 (conventional) and BRS Sambaíba RR (RR) were less tolerant to salt stress, and all genotypes in the IPRO group were moderately tolerant to salt stress.

Key words: *Glycine max* L., seed quality, salinity

RESUMO: A soja destaca-se entre as culturas com maior aplicação da transgenia, principalmente para tolerância a herbicidas, pragas e doenças, mas são escassos estudos sobre estresse salino em plantas geneticamente modificadas. O objetivo desta pesquisa foi avaliar a tolerância ao estresse salino de genótipos de soja, tradicionais e geneticamente modificadas, nas fases de germinação e plântulas. Para tanto, foram utilizadas sementes de 13 genótipos de soja, sendo cinco tradicionais (BRS Carnaúba, BRS Pérola, BRS Tracajá, BRS Sambaíba e FTR-4389) e oito transgênicas (BRS Sambaíba RR, BRS-333-RR, BRS-9820-RR, PAS-13565-74-RR, PAS-11711-007-RR, BRS-918-IPRO, AS-3810-IPRO e M-8210-IPRO), submetidas a quatro potenciais osmóticos (0.0; -0.1; -0.2 e -0.3 MPa). A qualidade das sementes foi avaliada a partir das seguintes variáveis: porcentagem de germinação, índice de velocidade de germinação, comprimento da parte aérea, comprimento de raiz, acúmulo de massa seca e índice de tolerância à salinidade. Todas as variáveis foram afetadas pelo estresse salino. Os genótipos convencionais BRS Carnaúba, BRS Pérola, BRS Tracajá, BRS Sambaíba, bem como do grupo RR PAS-13565-74-RR e PAS-11711-007-RR são tolerantes à salinidade. Os genótipos FTR-4389 (convencional) BRS Sambaíba RR (RR) são menos tolerantes ao estresse salino. Todos os genótipos do grupo IPRO são moderadamente tolerantes ao estresse salino.

Palavras-chave: *Glycine max* L., qualidade de sementes, salinidade

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Introduction

Brazil is the world's second largest producer of soybean (*Glycine max* L.), and 135.912,3 million tons were produced in the 2020/21 harvest (CONAB, 2019). Despite being mainly produced in the midwest region of Brazil, where the major producers are the states of Mato Grosso, Goiás and Mato Grosso do Sul, soybean production is expanding in other regions, such as in northeastern Brazil.

When saline water is used for irrigation, changes can occur to the physiological nature and initial development of most crops, which poses risks to agricultural production. Soybean is classified as being moderately salinity tolerant, with a threshold salinity of 5.0 dS m^{-1} in the saturation extract of soil, or of 3.3 dS m^{-1} in irrigation water, and a relative loss of 20% in yield occurs per unit increase in salinity from these levels (Ayres & Westcot, 1999). The effects can be noted during germination due to both the interference of salts in cell metabolism and a reduction in the osmotic potential of the seed, which causes water stress and hinders the absorption of water (Barbieri et al., 2019).

Several studies conducted on soybean seeds have shown that the osmotic stress caused by NaCl reduces germination and seed vigor (Zhang et al., 2020; Agha et al., 2021; Fu et al., 2022). However, the effect of salt stress on seed germination and vigor depends (among other factors) on the genetic material used (Chichanoski et al., 2019).

In this context, it is of great importance to investigate which genotypes have the greatest salinity tolerance in the early stages of plant development. Among the main factors determining soybean yield, high and uniform germination and emergence in the field are of utmost importance, especially under conditions of salt stress (Shu et al., 2017). Therefore, this study aimed to evaluate the tolerance of soybean genotypes, both traditional and genetically modified, to saline stress in the germination and seedling phases.

Material and Methods

The experiment was conducted at the Seed Analysis Laboratory of the Universidade Federal Rural do Semi-Árido, Mossoró-RN, Brazil (5° 11' S, 37° 20' W; altitude 18 m).

Seeds from 13 soybean cultivars, five traditional and eight transgenic (Table 1), were subjected to four osmotic potentials induced by sodium chloride (0.0, -0.1, -0.2, and -0.3 MPa), in a 13 x 4 factorial scheme. The study design was completely randomized, and four replicates of 50 seeds per plot were established. Distilled water was used as the control (0.0 MPa).

Table 1. Soybean genotypes used in the experiment

Cultivars	Origin
Conventional	
BRS Carnaúba	Embrapa Meio-Norte
BRS Pérola	Embrapa Meio-Norte
BRS Tracajá	Embrapa Meio-Norte
BRS Sambaiba	Embrapa Meio-Norte
FTR 4389	Fazenda Tavares Melo
Transgenic	
BRS Sambaíba	Embrapa Meio-Norte
BRS 333 RR	Embrapa Meio-Norte
BRS 9820 RR	Embrapa Meio-Norte
PAS 13565-74 RR	Embrapa Meio-Norte
PAS 11711 007 RR	Embrapa Meio-Norte
BRS 918 IPRO	Embrapa Meio-Norte
AS 3810 IPRO	Embrapa Tabuleiros Costeiros)
M-8210-IPRO	Embrapa Tabuleiros Costeiros)

The seeds were first subjected to asepsis using 1% sodium hypochlorite. They were then sown in a paper towel roll (Germitest®), moistened with a volume equivalent of 2.5 times its dry weight, and placed to germinate in a Biological Organism Development (BOD) chamber at 25 °C to germinate, under the conditions of 8 h light and 16 h dark (Brasil, 2009). A germinated seed count was conducted on the 8th day after sowing, and the results were expressed as a percentage of normal seedlings (Brasil, 2009).

A seedling germination speed index was constructed simultaneously with the germination test, where daily counts were made from the 2nd day of sowing and continued until the 8th day. The index was calculated by adding the ratios of the number of seedlings germinated in the period to the number of days from sowing to germination, using the formula proposed by Maguire (1962), Eq. 1.

$$GSI = \frac{G_1}{N_1} + \frac{G_2}{N_2} + \ldots + \frac{G_n}{N_n} \quad (1)$$

where:

GSI - germination speed index;

G_1, G_2 and G_n - number of normal seedlings germinated each day; and,

N_1, N_2, ... N_n - number of days after sowing the first, second and last count.

The shoot and primary root lengths of normal seedlings in each treatment were measured after the germination test was completed, 8 days after sowing. The length of the root (RL) (base of the neck to the end of the root) and that of the shoot (SL) (base of the neck to the insertion of the cotyledons) of normal seedlings in the experimental unit were measured using a ruler graduated in millimeters, and results were expressed in centimeters per seedling (cm).

The seedlings were packed in paper bags and dried in a forced-air circulation oven at 60 °C for 72 hours to determine the dry mass of the seedlings. They were then weighed on a precision scale, and the results were expressed in milligrams (mg).

From the production of total dry mass, the genotypes were classified according to their tolerance to salt stress by observing the percentage increase or decrease in their relative performances when the absolute value of the non-salinized treatment was 100% (Soares Filho et al., 2016), Eq. 2.

$$RP = \left[\frac{(PSTS - PCTS)}{PSTS}\right]100 \quad (2)$$

where:

RP - reduction of dry mass production, %;

POST - dry mass production without salinity treatment, g; and,

PWST - dry mass production with salinity treatment, g.

The genotypes were then classified as follows in relation to their tolerance to salinity using their relative reduction in total dry mass: tolerant (T), from 0 -20%; moderately tolerant (MT), from 21-40%; moderately susceptible (MS), 41-60%; and susceptible (S), above 60% (Soares Filho et al., 2016).

The data obtained were subjected to an analysis of variance (F test), and the variables that showed significant responses to treatments were analyzed using a means comparison test for cultivars (Scott-Knott, $p \leq 0.05$) and a regression analysis to assess the effect of the osmotic potentials. Statistical analyses were performed using SISVAR® version 5.6 statistical software (Ferreira, 2014).

Results and Discussion

All variables analyzed were affected by the interaction between genotype and salinity (Table 2). However, the germination percentages of the genotypes in all osmotic potentials differed markedly. The M-8210-IPRO genotype showed the lowest values for all osmotic potentials, despite showing no differences from the BRS Pérola and BRS-333-RR genotypes in the absence of NaCl, and its average germination percentage was lower than that of the other genotypes by approximately 6.74%, 19.07%, 20.28%, and 16.36% at potentials of 0.0, -0.1, -0.2, and 0.3 MPa, respectively (Table 3).

The results differed considerably between the genotypes with respect to the effects of the osmotic potential on germination. For example, no significant responses were observed for the genotypes BRS Carnaúba, BRS Pérola, BRS Tracajá, BRS Sambaíba, FTR-4389, BRS Sambaíba RR, PAS-13565-74-RR, PAS-11711-007-RR, or BRS-918-IPRO. For the BRS-333-RR genotype, there was a positive and linear response to a reduction in the osmotic potential during germination, and it increased by 9.6% at a potential of -0.3 MPa compared to germination observed at a potential of 0.0 MPa (Table 3). In contrast, the AS-3810-IPRO genotype showed a linear and negative response; therefore, at the highest osmotic potential (-0.3 MPa), there was an 8.7% reduction in seed germination. For the BRS-9820-RR and M-8210-IPRO genotypes, quadratic responses occurred, so that the reduction of the osmotic potential to -0.21 and -0.18 MPa, reduced the germination, obtaining 85.35 and 85.75%, respectively, remaining practically constant from these values (Table 3).

Several authors have confirmed that the germination potential of soybean seeds reduces in response to salinity, and variations have been seen between genotype responses. Similar to the study conducted by Putri et al. (2017) on 16 soybean genotypes (Detam 2, Detam 3, Detam 4, Pangrango, Ijen, Mahameru, Baluran, Petek, G100H, Kaba, Ichiyou, IAC100, Argopuro, Gumitir, Seulawah, and Merbabu), and that of Begum et al. (2022) with four genotypes (PI408105A (PI5A), PI567731 (PI31), PI567690 (PI90), and PI416937 (PI37)) under saline stress ranging from 0 mM NaCl to 150 mM NaCl. The reduction in germination in response to osmotic stress occurs because of a deficit in water and the effects of an accumulation of toxic ions that interfere with the absorption of nutrients and cause cytotoxicity and reductions in cell division and embryo development (Taiz et al., 2017; Silva et al., 2019).

The germination speed index (GSI) differed considerably between the genotypes at all osmotic potentials; M-8210-IPRO and AS-3810-IPRO had the lowest values, with average GSIs of 21.58, 19.59, 17.41, and 16.23, respectively (Table 4).

The analysis of the effect of potential on the GSI revealed no significant response for the genotypes BRS Tracajá, BRS Sambaíba RR, PAS-13565-74-RR, and BRS-918-IPRO, but responses were seen for the other genotypes. The genotypes

Table 2. Summary of analysis of variance for germination (GER), germination speed index (GSI), shoot length (SL), root length (RL) and dry mass (MS) in soybean genotypes subjected to salt stress

Variation sources	DF	Mean squares				
		GER	GSI	SL	RL	MS
Genotypes (G)	12	288.08**	194.19**	17.19**	30.59**	88.71**
Salinity (S)	3	44.61*	131.65**	68.67**	71.92**	284.77**
G x S	36	27.46*	13.89**	5.65**	7.07**	40.97**
Residue	104	13.13	3.06	0.77	2.59	4.02
CV (%)		3.80	6.83	15.34	20.35	

DF - Degrees of freedom; CV - Coefficient of variation; * - Significant at $p \leq 0.05$; ** - Significant at $p \leq 0.01$ by the F test

Table 3. Germination percentage of soybean genotypes at each osmotic potential and in function of osmotic potential

Genotypes	Osmotic potential (MPa)				Regression equations	R^2
	0	-0.1	-0.2	-0.3		
BRS Carnaúba	97.33 a	94.67 a	96.67 a	96.67 a	Not significant	---
BRS Pérola	93.33 b	94.67 a	95.33 a	97.33 a	Not significant	---
BRS Tracajá	98.67 a	99.33 a	98.00 a	99.33 a	Not significant	---
BRS Sambaíba	97.33 a	94.67 a	98.00 a	98.00 a	Not significant	---
FTR-4389	100.00 a	98.00 a	96.00 a	95.33 a	Not significant	---
BRS Sambaíba RR	99.33 a	99.33 a	100.00 a	100.00 a	Not significant	---
BRS-333-RR	90.00 b	93.33 a	96.00 a	98.67 a	$Y = 28.7^{**}x + 90.20$	0.99
BRS-9820-RR	100.00 a	87.33 b	87.50 a	86.67 b	$Y = 296.0^{*}x^2 + 128.62^{**}x + 99.31$	0.92
PAS-13565-74-RR	98.00 a	97.33 a	96.00 a	98.00 a	Not significant	---
PAS-11711-007-RR	96.67 a	95.33 a	99.33 a	100.00 a	Not significant	---
BRS-918-IPRO	100.00 a	98.67 a	99.33 a	100.00 a	Not significant	---
AS-3810-IPRO	96.00 a	94.00 a	92.00 a	87.33 b	$Y = -28^{**}x + 96.53$	0.95
M-8210-IPRO	90.67b	77.33 c	76.67 b	80.67 c	$Y = 433.33^{**}x^2 + 160.67^{*}x + 90.27$	0.97

Averages followed by the letter in the columns do not differ by the Scott-Knott test ($p \leq 0.05$); **, * - Significant at $p \leq 0.01$ and ≤ 0.05 probability, respectively, by the F test

Table 4. Germination speed index of soybean genotypes as a function of osmotic potential

Genotypes	Osmotic potential (MPa)				Regression equations	R^2
	0	-0.1	-0.2	-0.3		
BRS Carnaúba	39.08 a	31.44 a	28.67 a	22.53 b	$Y = -52.44^{**}x + 38.30$	0.97
BRS Pérola	28.06 c	30.21 a	28.72 a	27.22 a	$Y = -92.25^{**}x^2 - 23.36^{*}x + 28.24$	0.86
BRS Tracajá	27.89 c	28.72 a	30.22 a	28.17 a	Not significant	---
BRS Sambaíba	31.58 b	30.31 a	30.14 a	26.56 a	$Y = -15.25^{**}x + 31.93$	0.83
FTR-4389	25.27 c	25.56 b	23.56 c	20.92 b	$Y = -14.75^{**}x + 26.01$	0.82
BRS Sambaíba RR	25.11 c	26.33 b	24.94 b	24.44 b	Not significant	---
BRS-333-RR	33. 94 b	29.39 a	28.67 a	26.94 a	$Y = -21.72^{**}x + 32.99$	0.88
8 BRS-9820-RR	26.28 c	21.11 c	20.28 d	18.47 b	$Y = -24.25^{**}x + 25.17$	0.87
PAS-13565-74-RR 9	27.53 c	25.11 b	26.33 b	24.72 b	Not significant	---
PAS-11711-007-RR	25.39 c	27.94 a	26.55 b	24.61 b	$Y = -112.28^{*}x^2 - 29.94^{*}x + 25.55$	0.91
BRS-918-IPRO	25.61 c	27.78 b	27.50 b	24.28 b	Not significant	---
AS-3810-IPRO	21.53 d	20.94 c	18.39 e	17.00 c	$Y = -16.14^{**}x + 21.89$	0.95
M-8210-IPRO	21.64 d	18.25 c	16.44 e	15.47 c	$Y = -20.31^{**}x + 21.00$	0.93

Averages followed by the letter in the columns do not differ by the Scott-Knott test ($p \leq 0.05$); **, * - Significant at $p \leq 0.01$ and ≤ 0.05 probability, respectively, by the F test

BRS Carnaúba, BRS Sambaíba, FTR-4389, BRS-333-RR, BRS-9820-RR, AS-3810-IPRO, and M-8210-IPRO showed linear reductions in their GSIs in response to a reduction in osmotic potential; the potential of -0.3 MPa provided the lowest values, with the greatest reductions observed in the genotypes BRS Carnaúba, BRS-9820-RR, and M-8210-IPRO, in which reductions of 41.1%, 28.9%, and 29.0% occurred, respectively. In contrast, the BRS Sambaíba, FTR-4389, and PAS-13565-74-RR 9 genotypes showed lower losses of 14.3%, 17.0%, and 19.5%, respectively. The BRS Pérola and PAS-11711-007-RR genotypes showed quadratic responses to the increase in osmotic potential, with increases in their GSIs reaching potentials of -0.13 MPa, showing a reduction from this saline level (Table 4).

These results show that there was great variability between the responses of the genotypes in relation to salinity stress, as reflected in the GSI, which indicates that there were significant differences between the salinity tolerance levels of the genotypes. According to Cavalcante et al. (2019), cultivars that are more tolerant have less vigor but a higher germination speed. This is due to the ability of some genotypes to maintain osmotic homeostasis, which favors tissue hydration at unfavorable osmotic potentials for the species (Sá et al., 2017).

A reduction in the GSI under saline stress in association with an osmotic potential ranging from 0.0 MPa to 1.2 MPa has been reported by other authors working with several species of agronomic interest, such as soybean (Chichanosk et al., 2019), sunflower (Rossetto et al., 2021), and oat (Timm et al., 2015). According to Leal et al. (2020), this is because low osmotic potentials reduce the absorption of water by seeds and can prevent the sequence of events in the germination process from occurring, thereby reducing the germination speed and percentage.

In general, it appears that the effect of saline stress had a greater effect on the GSI than on total germination, which shows that GSI is one of the main parameters that should be evaluated in germination tests. According to Nunes et al. (2021), a seed that germinates faster has greater vigor. Lennon et al. (2021) reinforced these genotypes with rapid germination, using this potential as a strategy to establish themselves in the environment as quickly as possible or when appropriate, taking advantage of environmental conditions favorable to the development of the new individual.

The SL analysis revealed significant differences between the genotypes at all osmotic potentials (Table 4). In the absence of NaCl (0.0 MPa), the highest values were observed in the genotypes FTR-4389, BRS Sambaíba RR, BRS-9820-RR, PAS-11711-007-RR, BRS-918-IPRO, and AS-3810-IPRO, whereas the genotypes BRS Carnaúba and BRS Pérola had lower SLs. At a potential of -0.1 MPa, the highest values were obtained for the genotypes BRS Tracajá, FTR-4389, 9 PAS-13565-74-RR, PAS-11711-007-RR, and BRS-918-IPRO. The results also showed similar behavior between the genotypes at potentials of -0.2 MPa and -0.3 MPa, with the best performances seen in the genotypes BRS Tracajá, BRS Sambaíba, BRS Sambaíba RR, BRS-333-RR, PAS-13565-74-RR, PAS-11711-007-RR, and BRS-918-IPRO (Table 5).

Table 5. Shoot length (cm) in seedlings of soybean genotypes as a function of osmotic potential

Genotypes	Osmotic potential (MPa)				Regression equations	R^2
	0	-0.1	-0.2	-0.3		
BRS Carnaúba	3.33 e	5.25 c	4.25 b	1.75 b	$Y = -110.50^{**}x^2 - 27.41^{*}x + 3.40$	0.98
BRS Pérola	1.91 e	4.67 c	4.75 b	3.17 b	$Y = -108.50^{**}x^2 - 36.41^{*}x + 1.96$	0.99
BRS Tracajá	4.08 d	8.42 a	7.55 a	5.75 a	$Y = -135.51^{**}x^2 - 50.19^{*}x + 4.29$	0.92
BRS Sambaíba	6.25 b	6.15 b	6.42 a	4.08 a	$Y = -56.02^{*}x^2 - 10.56^{*}x + 6.10$	0.88
FTR-4389	7.58 a	9.08 a	5.25 b	2.83 b	$Y = -98.01^{*}x^2 - 11.32^{**}x + 7.92$	0.90
BRS Sambaíba RR	7.73 a	6.12 b	7.02 a	4.72 a	$Y = -8.83^{**}x + 7.45$	0.85
BRS-333-RR	7.21 b	6.97 b	7.95 a	4.77 a	$Y = -73.51^{**}x^2 - 15.71^{*}x + 6.94$	0.74
BRS-9820-RR	7.98 a	5.05 c	4.75 b	2.09 b	$Y = -17.99^{**}x + 7.67$	0.93
PAS-13565-74-RR	5.53 c	8.38 a	7.65 a	3.90 a	$Y = -165.25^{**}x^2 - 43.68^{*}x + 5.55$	0.99
PAS-11711-007-RR	8.45 a	8.71 a	8.37 a	5.56 a	$Y = -76.75^{**}x^2 - 14.02^{*}x + 8.36$	0.97
BRS-918-IPRO	9.30 a	7.73 a	6.10 a	4.30 a	$Y = -16.64^{**}x + 9.35$	0.99
AS-3810-IPRO	7.92 a	6.51 b	4.30 b	3.42 b	$Y = -15.70^{**}x + 7.89$	0.98
M-8210-IPRO	6.75 b	6.59 b	3.78 b	3.15 b	$Y = -13.61^{**}x + 7.11$	0.88

Averages followed by the letter in the columns do not differ by the Scott-Knott test ($p \leq 0.05$); **, * - Significant at $p \leq 0.01$ and ≤ 0.05 probability, respectively, by the F test

With respect to the osmotic potential, different responses were observed in the analyzed genotypes. The BRS Sambaíba, BRS Sambaíba RR, BRS-9820-RR, BRS-918-IPRO, AS-3810-IPRO, and M-8210-IPRO genotypes showed a linear and negative SL response to the osmotic potential, with the lowest SL values occurring at a potential of -0.3 MPa. Among these, the greatest losses occurred with the genotypes BRS-9820-RR, BRS-918-IPRO, AS-3810-IPRO, and M-8210-IPRO, with reductions of 70.4%, 53.4%, 59.7%, and 57.4%, respectively. The other genotypes showed quadratic responses, and the CPA of the genotypes BRS Carnaúba, BRS Pérola, BRS Tracajá, BRS Sambaíba, FTR-4389, BRS-333-RR, PAS-13565-74-RR, and PAS-11711-007-RR, initially increased in response to a decrease in osmotic potential up to -0.12, -0.17, -0.18, -0.09, -0.06, -0.11, -0.13, and -0.09 MPa, respectively, and then decreased from these levels (Table 5).

These results are in agreement with those of Chichanosk et al. (2019) who used soybean cultivar seeds (TMG 7062 IPRO, 63i64 RSF IPRO, and 7166 RSF IPRO) and solutions of potassium chloride (KCl) (0.0, -0.4, -0.8, and -1.2 MPa). According to Taiz et al. (2017), the exposure of seedlings to increasing salinity contributes to lower growth rates because the toxicity caused by Na^+ and Cl^- ions reduces turgor pressure and interferes with the processes of cell elongation and division.

The RLs of the genotypes differed at all osmotic potentials. At a potential of 0.0 MPa, the highest values were obtained for the genotypes FTR-4389, PAS-11711-007-RR, and BRS-918-IPRO. When the seeds were subjected to an osmotic potential of -0.1 MPA, the RLs of the BRS Tracajá and FTR 4389 genotypes were longer. In the potential -0.2 MPa, there was less differentiation between the materials studied, with emphasis on the genotypes BRS Pérola, BRS Tracajá, BRS Sambaíba, FTR-4389, BRS Sambaíba RR, BRS-333-RR, PAS-13565-74-RR, PAS-11711-007-RR, BRS-918-IPRO, and AS-3810-IPRO. However, at a potential of -0.3 MPa, only the genotype PAS-11711-007-RR showed a higher CR, whereas the genotypes BRS Carnaúba, BRS Pérola, BRS-333-RR, BRS-9820-RR, PAS- 13565-74-RR, and M-8210-IPRO showed lower root system growth (Table 6).

With respect to the effect of osmotic potential on RL, responses varied according to the analyzed genotype. For the genotypes BRS Carnaúba, BRS Pérola, BRS Tracajá, and M-8210-IPRO, quadratic responses were seen in relation to a reduction in the osmotic potential, and an increase in RL was observed up to -0.11, -0.16, -0.15, and -0.07 MPa, respectively, decreasing from these potentials.

For the genotypes FTR 4389, BRS Sambaíba RR, BRS-333-RR, BRS-9820-RR, PAS-13565-74-RR, and BRS-918-IPRO, linear and negative responses were seen in relation to a reduction in the osmotic potential, and a potential of -0.3 MPa provided a lower RL, with considerable losses occurring in the genotypes FTR-4389, BRS-9820-RR, and BRS-918-IPRO of 46.7%, 52.1%, and 43.4%, respectively. In contrast, the applied osmotic potentials did not affect the RL of BRS Sambaíba, PAS-11711-007-RR, and AS-3810-IPRO genotypes (Table 6).

According to Barichello et al. (2021), a decreased root length is related to damage caused by the toxic effect of excess salts, because the concentration of ions in the cytosol becomes cytotoxic in relation to the ions, which causes protein denaturation and membrane destabilization and may ultimately result in cell death.

In general, the SL was more affected by the saline levels than the RL, which implies that seedlings started to invest seed reserves in root production with the objective of increasing water uptake; this effect was also observed by Almeida et al. (2020) with respect to corn.

The analysis of the accumulation of dry mass (DM) showed significant differences between the genotypes at all saline levels. In the absence of NaCl (0.0 MPa), the DM of the genotypes BRS Sambaíba, FTR-4389, BRS Sambaíba RR, BRS-333-RR, BRS-9820-RR, BRS-918-IPRO, AS-3810-IPRO, and M-8210- IPRO was the highest, whereas the lowest values occurred in the BRS Carnaúba, BRS Pérola, and PAS-11711-007-RR genotypes. For the -0.1 MPa potential, the genotypes BRS Tracajá, FTR-4389, BRS-333-RR, PAS-11711-007-RR, BRS-918-IPRO, AS-3810-IPRO, and M-8210-IPRO were superior to too much and the results of these genotypes were similar. For the -0.2 MPa potential, the highest DM values were observed for the BRS Tracajá, PAS-11711-007-RR and BRS-918-IPRO genotypes. At the highest osmotic potential (-0.3 MPa), the highest DM values were obtained for the genotypes BRS Tracajá, BRS Sambaíba, BRS Sambaíba RR, BRS-333-RR, PAS-11711-007-RR, BRS- 918-IPRO, and AS-3810-IPRO, whereas the lowest MS occurred in the BRS Carnaúba genotype (Table 7).

The analysis of the effect of salt stress on the accumulation of DM showed that the genotypes BRS Carnaúba, BRS Pérola,

Table 6. Root length (cm) in seedlings of soybean genotypes as a function of osmotic potential

Genotypes	Osmotic potential (MPa)				Regression equations	R^2
	0	-0.1	-0.2	-0.3		
BRS Carnaúba	6.00 c	9.58 c	5.75 b	3.92 c	$Y = -135.25^{**}x^2 - 30.50^{*}x + 6.47$	0.74
BRS Pérola	4.42 c	7.83 c	7.33 a	5.33 c	$Y = -135.25^{**}x^2 - 42.80^{*}x + 4.54$	0.96
BRS Tracajá	5.08 c	13.67 a	9.33 a	7.17 b	$Y = -268.75^{**}x^2 - 82.55^{*}x + 5.84$	0.72
BRS Sambaíba	8.50 b	9.33 c	7.25 a	7.42 b	Not significant	---
FTR 4389	12.08 a	12.25 a	8.25 a	6.75 b	$Y = -20.00^{**}x + 12.83$	0.87
BRS Sambaíba RR	9.98 b	8.80 c	7.90 a	7.33 b	$Y = -8.85^{*}x + 9.83$	0.98
BRS-333-RR	9.33 b	6.89 c	7.60 a	6.12 c	$Y = -8.92^{*}x + 8.82$	0.71
BRS-9820-RR	9.72 b	7.61 c	5.77 b	4.86 c	$Y = -16.42^{**}x + 9.45$	0.98
PAS-13565-74-RR	8.37 b	7.97 c	7.25 a	4.95 c	$Y = -10.97^{**}x + 8.78$	0.86
PAS-11711-007-RR	11.55 a	10.91 b	10.72 a	10.43 a	Not significant	---
BRS-918-IPRO	12.00 a	10.23 b	7.30 a	7.29 b	$Y = -17.02^{**}x + 11.76$	0.90
AS-3810-IPRO	8.73 b	10.03 b	6.63 a	7.68 b	Not significant	---
M-8210-IPRO	6.37 c	7.24 c	5.50 b	3.80 c	$Y = -64.25^{**}x^2 - 9.82^{*}x + 6.50$	0.94

[#] Averages followed by the letter in the columns do not differ by the Scott-Knott test ($p < 0.05$); **, * - Significant at 0.01 and 0.05 probability, respectively

Table 7. Total dry mass (mg) in seedlings of soybean genotypes as a function of osmotic potential

Genotypes	Osmotic potential (MPa)				Regression equations	R^2
	0	-0.1	-0.2	-0.3		
BRS Carnaúba	14.44 d	27.39 b	25.67 b	13.13 c	$Y = -637.25^{**}x^2 - 185.53^{*}x + 14.63$	0.99
BRS Pérola	17.93 d	25.80 b	25.40 b	21.26 b	$Y = -300.25^{**}x^2 - 99.66^{*}x + 18.16$	0.97
BRS Tracajá	20.93 c	36.06 a	32.47 a	26.97 a	$Y = -515.75^{**}x^2 - 169.25^{*}x + 21.77$	0.89
BRS Sambaíba	27.87 a	30.60 b	27.24 b	24.66 a	$Y = -132.75^{*}x^2 - 26.83^{*}x + 28.21$	0.87
FTR-4389	38.00 a	37.90 a	29.87 b	19.00 b	$Y = -269.25^{*}x^2 - 15.74^{*}x + 38.25$	0.99
BRS Sambaíba RR	32.67 a	31.75 b	26.45 b	24.35 a	$Y = -30.26^{**}x + 33.34$	0.94
BRS-333-RR	34.63 a	33.65 a	25.67 b	24.25 a	$Y = -39.12^{*}x + 35.42$	0.89
BRS-9820-RR	38.23 a	26.13 b	22.90 b	18.73 b	$Y = -61.73^{**}x + 35.76$	0.90
PAS-13565-74-RR	15.30 d	29.90 b	26.60 b	18.50 b	$Y = -576.50^{**}x^2 - 175.55^{*}x + 15.95$	0.94
PAS-11711-007-RR	26.27 b	33.53 a	37.60 a	25.87 a	$Y = -474.75^{**}x^2 - 145.30^{*}x + 25.64$	0.90
BRS-918-IPRO	39.50 a	38.65 a	33.66 a	26.54 a	$Y = -43.87^{**}x + 41.17$	0.99
AS-3810-IPRO	36.17 a	33.54 a	26.00 b	22.63 a	$Y = -48.16^{**}x + 36.81$	0.96
M-8210-IPRO	31.13 a	38.33 a	28.25 b	19.53 b	$Y = -398.01^{**}x^2 - 74.52^{*}x + 32.06$	0.90

[#] Averages followed by the letter in the columns do not differ by the Scott-Knott test ($p < 0.05$); **, * - Significant at 0.01 and 0.05 probability, respectively

BRS Tracajá, BRS Sambaíba, FTR-4389, PAS-13565-74-RR, PAS-11711-007-RR, and M-8210-IPRO had quadratic responses; the amount of DM increased with a reduction in the osmotic potential up to -0.15 levels; -0.17; -0.16; -0.10; -0.03; -0.15; -0.15; and 0.09 MPa, respectively, showing, however, reduction from these values (Table 7).

Pereira et al. (2016) reported similar results and found that a high salt stress tolerance, especially in the early stages of development, is an adaptive characteristic that enables seedlings to be established in areas affected by salt. Genetic divergence occurs in this respect because only certain genotypes have efficient salt stress tolerance mechanisms.

In contrast, the genotypes BRS Sambaíba RR, BRS-333-RR, BRS-9820-RR, BRS-918-IPRO, and AS-3810-IPRO showed linear and negative responses, and a decrease in the osmotic potential caused reductions in the amount of DM for these genotypes. The lowest values were obtained at a potential of -0.3 MPa, with greater losses occurring in the genotypes BRS-9820-RR and AS-3810-IPRO, with reductions of 49.0% and 39.2%, respectively (Table 7).

These results demonstrate the possibility that these genotypes have a greater sensitivity to salt stress, and this effect has been attributed to the embryonic axis having a lower capacity to transform the supply of storage tissue reserves (or a reduced capacity to incorporate them) (Azevedo Neto et al., 2020).

The reduction in plant growth under salt stress occurs due to a reduction in turgor pressure, which indirectly causes water stress and suppresses cell growth and expansion, thereby affecting metabolism and resulting in impaired growth and the establishment of seedlings (Seleiman et al., 2021).

Table 7 shows the relative reductions in dry mass production and a comparison between the values obtained for each genotype in relation to the osmotic control potential (0.0 MPa). The values show that there was no reduction in biomass accumulation for some of the cultivars at all osmotic potentials, for example the genotypes BRS Pérola, BRS Tracajá, and PAS-13565-74-RR. The genotypes BRS Carnaúba and PAS-11711-007-RR showed no relative reduction in the production of dry mass at potentials of -0.1 MPa and -0.2 MPa, while the genotypes BRS Sambaíba and M-8210-IPRO showed no relative loss in the production of dry mass at a potential of -0.1 MPa (Table 8).

Table 8. Relative loss in dry matter (%) production and classification of genotypes to salinity

Genotypes	Osmotic potential (MPa)		
	-0.1	-0.2	-0.3
BRS Carnaúba	0.0 T*	0.0 T	9.1 T
BRS Pérola	0.0 T	0.0 T	0.0 T
BRS Tracajá	0.0 T	0.0 T	0.0 T
BRS Sambaíba	0.0 T	2.3 T	11.5 T
FTR-4389	0.3 T	21.4 MT	50.0 MS
BRS Sambaíba RR	2.8 T	19.0 T	25.5 MT
BRS-333-RR	2.8 T	25.9 MT	30.0 MT
BRS-9820-RR	31.7 MT	40.1 MS	51.0 MS
PAS-13565-74-RR	0.0 T	0.0 T	0.0 T
PAS-11711-007-RR	0.0 T	0.0 T	1.5 T
BRS-918-IPRO	2.2 T	14.8 T	32.8 MT
AS-3810-IPRO	7.3 T	28.1 MT	37.4 MT
M-8210-IPRO	0.0 T	9.3 T	37.3 MT

*There was no reduction in dry weight compared to the control treatment (0.0 MPa); T - Tolerant; MT - Moderately Tolerant; MS - Moderately susceptible

With respect to the lowest osmotic potential used and consequently the highest level of saline stress, the genotypes BRS Carnaúba, BRS Pérola, BRS Tracajá, BRS Sambaíba, PAS-13565-74-RR, and PAS-11711-007- RR were classified as being tolerant to salinity. However, the genotypes FTR-4389 and BRS Sambaíba RR showed lower tolerance and were classified as moderately susceptible to salinity (Table 8).

Conclusions

1. The conventional genotypes, BRS Carnaúba, BRS Pérola, BRS Tracajá, and BRS Sambaíba, and the transgenics PAS-13565-74-RR and PAS-11711-007-RR were tolerant to salinity up to an osmotic potential of -0.3 MPa.
2. The genotypes FTR-4389 (conventional) BRS Sambaíba RR (transgenic) were found to be moderately susceptible to salt stress at an osmotic potential of -0.3 MPa.
3. All of the genotypes in the IPRO group were found to be moderately tolerant to salt stress up to an osmotic potential of -0.3 MPa.

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Literature Cited

Agha, M. S.; Abbas, M. A.; Sofy, M. R.; Haroun, S. A.; Mowafy, A. M. Dual inoculation of Bradyrhizobium and Enterobacter alleviates the adverse effect of salinity on *Glycine max* seedling. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, v.49, p.1-18, 2021. https://doi.org/10.15835/nbha49312461

Almeida, C. de S.; Guariz, H. R.; Pinto, M. A. B.; Almeida, M. F. de. Germination of creole maize and fava bean seeds under salt stress. Revista Caatinga, v.33, p.853-859, 2020. http://dx.doi.org/10.1590/1983-21252020v33n329rc

Ayres, R. S.; Westcot, D. W. A qualidade da água na agricultura. 2.ed. Campina Grande: UFPB, 1999. 153p.

Azevedo Neto, A. D. de; Mota, K. N. A. B.; Silva, P. C. C.; Cova, A. M. W.; Ribas, R. F.; Gheyi, H. R. Selection of sunflower genotypes for salt stress and mechanisms of salt tolerance in contrasting genotypes. Ciência e Agrotecnologia, v.44, p.1-14, 2020. https://doi.org/10.1590/1413-7054202044020120

Barbieri, G. F.; Stefanello, R.; Menegaes, J. F.; Munareto, J. D.; Nunes, U. R. Seed Germination and Initial Growth of Quinoa Seedlings Under Water and Salt Stress. Journal of Agricultural Science, v.11, p.1-9, 2019. https://doi.org/10.5539/jas.v11n15p153

Barichello, H. A.; Stefanello, R.; Bastiani, G. G. de; Neves, L. A. S. das. Effect of salt stress on germination and initial development of *Ruta graveolens* L. Hoehnea, v.48, p.1-6, 2021. https://doi.org/10.1590/2236-8906-120/2020

Begum, N.; Hasanuzzaman, M.; Li, Y.; Akhtar, K.; Zhang, C.; Zhao, T. Seed germination behavior, growth, physiology and antioxidant metabolism of four contrasting cultivars under combined drought and salinity in soybean. Antioxidants, v.3, p.1-23, 2022. https://doi.org/10.3390/antiox11030498

Brasil. Ministério da Agricultura, Pecuária e Abastecimento. Secretaria de Defesa Agropecuária. Regras para análise de sementes. Brasília: MAPA/ACS, 2009. 339p.

Cavalcante, J. A.; Reolon. F.; Moraes, C. L. de; Ternus, R. M.; Silva, R. N. O. da; Martins, A. B. N.; Moraes, D. M. de. Potencial fisiológico de sementes de duas cultivares de arroz em resposta ao stresse salino. Revista de Ciências Agrárias, v.42, p.184-193, 2019. https://doi.org/10.19084/RCA17279

Chichanoski, C.; Ferreira, B. R.; Moterle, L. M.; Santos, R. F. dos. Physiological potential of soybean seeds under hypoxia and salinity stress. Científica, v.47, p.210-220, 2019. http://dx.doi.org/10.15361/1984-5529.2019v47n2p210-220

CONAB -Companhia Nacional de Abastecimento. Acompanhamento da safra brasileira de grãos - Safra 2018/19 - Décimo segundo levantamento. 2019. Available on: <https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-degraos>. Accessed on: Mar. 2020.

Ferreira, D. F. Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. Ciência e Agrotecnologia, v.38, p.109-112, 2014. https://doi.org/10.1590/S1413-70542014000200001

Fu, X.; Wang, J.; Shangguan, T.; Wu, R.; Li, S.; Chen, G.; Xu, S. SMXLs regulate seed germination under salinity and drought stress in soybean. Plant Growth Regulation, v.96, p.397-408, 2022. https://doi.org/10.1007/s10725-021-00786-6

Leal, C. C. P.; Torres, S. B.; Dantas, N. B. de L.; Aquino, G. S. M.; Alves, T. R. C. Water stress on germination and vigor of 'mofumbo' (*Combretum leprosum* Mart.) seeds at different temperatures. Revista Ciência Agronômica, v.51, p.1-7, 2020. https://doi.org/10.5935/1806-6690.20200013

Lennon, J. T.; den Hollander, F.; Wilke-Berenguer, M.; Blath, O. Principles of seed banks and the emergence of complexity from dormancy. Nature Communications, v.12, p.1-16, 2021. https://doi.org/10.1038/s41467-021-24733-1

Maguire, J. D. Speed of germination aid in selection and evaluation for seedling emergence and vigor. Crop Science, v.2, p.176-77, 1962. http://dx.doi.org/10.2135/cropsci1962.0011183X000200020033x

Nunes, V. V.; Silva-Mann, R.; Vasconcelos, M. C.; Rodrigues, A. M. B.; Souza, J. L. Physical and physiological quality of mangaba seeds obtained by different processing methods. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.429-435, 2021. http://dx.doi.org/10.1590/1807-1929/agriambi.v25n6p429-435

Pereira, F. E. C. B.; Medeiros Filho, S.; Torres, S. B.; Martins, C. C.; Brito, S. F. de. Saline stress and temperatures on germination and vigor of *Piptadenia moniliformis* Benth. seeds. Revista Brasileira de Engenharia Agrícola Ambiental, v.20, p.649-653, 2016. https://doi.org/10.1590/1807-1929/agriambi.v20n7p649-653

Putri, P. H.; Susanto, G. W. A.; Artari, R. Response of soybean genotypes to salinity in germination stage. Nusantara Bioscience, v.9, p.133-137, 2017. https://doi.org/10.13057/nusbiosci/n090204

Rossetto, C. A. V.; Medici, L. O.; Morais, C. S. B. de; Martins, R. da C. F.; Carvalho, D. F. de. Seed germination and performance of sunflower seedlings submitted to produced water. Ciência e Agrotecnologia, v.45, p.1-11, 2021. https://doi.org/10.1590/1413-7054202145010521

Sá, F. V. da S.; Nascimento, R. do; Pereira, M. de O.; Borges, V. E.; Guimaraes, R. F. B.; Ramos, J. G.; Mendes, J. da S.; Penha, J. L da. Vigor and tolerance of cowpea (*Vigna unguiculata*) genotypes under salt stress. Bioscience Journal, v.33, p.1488-1494, 2017. https://doi.org/10.14393/BJ-v33n6a2017-37053

Seleiman, M. F.; Al-Suhaibani, N.; Ali, N.; Akmal, M.; Alotaibi, M.; Refay, Y.; Dindaroglu, T.; Abdul-Wajid, H. H.; Battaglia, M. L. Drought Stress Impacts on Plants and Different Approaches to Alleviate Its Adverse Effects. Plants, v.10, p.1-25, 2021. https://doi.org/10.3390/plants10020259

Shu, K.; Qi, Y.; Chen, F.; Meng, Y.; Luo, X.; Shuai, H.; Zhou, W.; Ding, J.; Du, J.; Liu, J.; Yang, F.; Wang, Q.; Liu, W.; Yong, T.; Wang, X.; Feng, Y.; Yang, W. Salt stress represses soybeanbean seed germination by negatively regulating GA biosynthesis while positively mediating ABA biosynthesis. Frontier in Plant Science, v.8, p.1-12, 2017. http://dx.doi.org/10.3389/fpls.2017.01372

Silva, M. F. da; Araújo, E. F.; Silva, L. J. da; Amaro, H. T. R.; Dias, L. A. dos S.; Dias, D. C. F. dos S. Tolerance of crambe (*Crambe abyssinica* Hochst) to salinity and water stress during seed germination and initial seedling growth. Ciência e Agrotecnologia, v.43, p.1-13, 2019. https://doi.org/10.1590/1413-7054201943025418

Soares Filho, W. S.; Gheyi, H. R.; Brito, M. E. B.; Nobre, R. G.; Fernandes, P. D.; Miranda, R. S. Melhoramento genético e seleção de cultivares tolerantes à salinidade. In: Gheyi, H. R.; Dias, N. S.; Lacerda, C. F.; Gomes Filho, E. (ed.) Manejo da salinidade na agricultura: Estudos básicos e aplicados. Fortaleza, CE: INCTSal, 2016 p.259-274.

Taiz, L.; Zeiger, E.; Møller, I. M.; Murphy, A. Fisiologia e desenvolvimento vegetal. 6th. Porto Alegre, RS: Artmed. 2017. 888p.

Timm, F. C.; Bandeira, J. M.; Bicca, M. L.; Dode, J. de S.; Moraes, D. M. de. Germinação e crescimento de plântulas de genótipos de aveia branca submetidas ao estresse salino. Semina: Ciências Agrárias, v.36, p.2987-2999, 2015. http://dx.doi.org/10.5433/1679-0359.2013v34n6Supl1p3455

Zhang, M.; He, S.; Qin, B.; Jin, X.; Wang, M.; Ren, C.; Cao, l.; Zhang, Y. Exogenous melatonin reduces the inhibitory effect of osmotic stress on antioxidant properties and cell ultrastructure at germination stage of soybean. PLoS ONE, v.15, p.1-22, 2020. https://doi.org/10.1371/journal.pone.0243537