Salicylic acid relieves salt stress damage on basil growth

Toshik Iarley da Silva[1]*, *Adriano Salviano Lopes*[2], *Marlon Gomes Dias*[1], *Anderson Carlos Melo Gonçalves*[3], *José Sebastião de Melo Filho*[2], *Thiago Jardelino Dias*[4]

10.1590/0034-737X202370040008

ABSTRACT

Salinity is one of the main challenges in agriculture, especially in arid and semi-arid regions. Salicylic acid application may be a strategy to mitigate the harmful effects of salt stress on plant growth. Basil (*Ocimum basilicum*) is a medicinal, spice, and ornamental plant grown around the world that has its growth reduced by salt stress. Therefore, the objective was to evaluate salicylic acid in mitigating the damage caused by salt stress in 'Cinnamon' basil. Growth was evaluated at 90 days after the start of irrigation with saline water. Salicylic acid application attenuates the harmful effects of salt stress on the number of leaves, number of inflorescences, leaf dry mass, inflorescence dry mass, root dry mass, seed mass, leaf area, leaf area ratio, specific leaf area, leaf mass ratio, root mass ratio, inflorescence mass ratio, Dickson quality index, sclerophilia index, robustness quotient and shoot root ratio. Salt stress decreased plant height, stem diameter, stem dry mass, and stem mass ratio of basil 'Cinnamon'. Salicylic acid can be used to lessen the harmful effects of salt stress on basil 'Cinnamon'.

Keywords: *Ocimum basilicum*; salinity of irrigation water; phytohormone

INTRODUCTION

Basil (*Ocimum basilicum* L. - Lamiaceae) is a species native to tropical Asia, introduced to Brazil by Italian immigrants (Oliveira *et al*., 2020). Basil is used in cosmetics and medicine industries, cooking, folk medicine, and essential oil extraction, mainly due to its high content of linalool (Vilanova *et al*., 2018; Chokami *et al*., 2019; Silva *et al*., 2019). Basil cultivation in Northeast Brazil is mainly done by small family farmers. However, this region is characterized by low rainfall, causing producers to use low-quality irrigation water, most of the time with high levels of salts (Silva *et al*., 2018).

The high salts content in irrigation water is a limiting factor for plant development, which can compromise the growth and physiology of plants (Nóbrega *et al*., 2021). The decrease in plant growth under salt stress is caused by the osmotic effect that reduces the water and essential elements absorption, causing nutritional imbalance, oxidative stress, and specific ions toxicity (Ahammed *et al*., 2018; Silva *et al*., 2019; Naveed *et al*., 2020).

The use of techniques to mitigate the harmful effects of salinity in plants is necessary. Salicylic acid can alleviate the harmful effects of salt stress by adjusting physiological and biochemical mechanisms (Kim *et al*., 2018). Foliar application of salicylic acid decreased lipid peroxidation caused by excess NaCl and improved plant growth. This behavior is related to a decrease in NaCl and an increase in Ca and Mg in the plant, in addition to the increase in the activity of the antioxidant system enzymes (SOD, CAT,

Submitted on June 14th, 2022 and accepted on January 13th, 2023.
[1] Universidade Federal de Viçosa, Departamento de Agronomia, Viçosa, Minas Gerais, Brasil. iarley.toshik@gmail.com; marlongomesdias@gmail.com;
[2] Universidade Federal da Paraíba, João Pessoa, Paraíba, Brazil. adrianolopes5656@gmail.com; sebastiaouepb@yahoo.com.br
[3] Universidade Federal de Roraima, Boa Vista, Roraima, Brazil. anderson.agroufpb@yahoo.com
[4] Universidade Federal da Paraíba, Areia, Paraíba, Brazil. thiagojardelinodias@gmail.com
*Corresponding author: iarley.toshik@gmail.com

GPX, etc.) (Joseph *et al*., 2010). Salicylic acid is used in the formulation of some biostimulants used in agriculture, as a growth promoter and plant resistance inducer. In addition, this phytohormone acts as an effective inducer of genes related to stress-linked proteins (Angooti & Nourafcan, 2015).

Several studies are performed with basil plants under salt stress and salicylic acid (Elhindi *et al*., 2017; Silva *et al*., 2019; Kahveci *et al*., 2021); however, few studies have been performed about such effects on the growth of 'Cinnamon' basil. Therefore, the objective was to evaluate salicylic acid in mitigating the damage caused by salt stress in 'Cinnamon' basil.

MATERIAL AND METHODS

The experiment was performed in a greenhouse at the Universidade Federal da Paraíba, Areia, Brazil. The experimental design was in randomized blocks, using an incomplete factorial scheme generated through the central composite design, with five electrical conductivities of irrigation water (ECw – 0.5, 1.3, 3.25, 5.2, and 6.0 dS m^{-1}) and five concentrations of salicylic acid (SA – 0, 0.29, 1.0, 1.71, and 2.0 mM – Silva *et al*., 2019). Totaling nine combinations (Table 1), with five repetitions and two plants per plot, with 90 plants analyzed at the end of the experiment.

Basil seeds were sowed in 162-cell polyethylene trays that were filled with soil and commercial organic compost (1:1, v:v). Basil seeds were obtained from the basil germplasm bank of the Universidade Federal de Sergipe. Seedlings were transplanted 25 days after sowing into 5 dm^3 pots with soil and 100 g of poultry manure. Saline waters were prepared by adding of NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ (7:2:1, v:v), respectively, to water (0.5 dS m^{-1}). Salicylic acid concentrations were prepared with 30% ethyl alcohol and Tween 80 (0.05%). Distilled water and Tween 80 (0.05%) were used as control. The plants were sprayed with 10 mL per plant of each treatment, every week for 21 days. Salt stress was applied 30 days after sowing along with salicylic acid applications.

Basil growth was evaluated 90 days after the start of saline water irrigation (DAI). A graduated ruler was used to measure plant height (PH); calipers were used to measure stem diameter (Ds); the number of leaves (NL) was measured manually. The plants were divided into root, stem, leaves and inflorescences and dried in an oven with forced air circulation at 65 ºC. Then, the plant parts were weighed on a precision scale (0.001 g). Seeds were separated from the inflorescences and weighed on a precision scale (0.001 g) to obtain the seed mass.

Leaf area (LA) was obtained by averaging the product of length and width of 20 leaves and the leaf area form factor (0.6775). Leaf area ratio (LAR) was obtained using the formula: leaf area (LA)/total dry mass (TDM). The specific leaf area (SLA) was obtained using the formula: LA/leaf dry mass (LDM). The leaf mass ratio (LMR) was obtained using the formula: leaf dry mass/TDM. The stem mass ratio was obtained using the formula: stem dry mass/TDM. The root mass ratio (RMR) was obtained using the formula: root dry mass/TDM. The inflorescence mass ratio (IMR) was obtained using the formula: inflorescence dry mass/TDM. The sclerophilia index was obtained using the formula: LDM/LA. The robustness quotient was obtained

Table 1: Combinations generated by the central composite design

Levels		Dose	
ECw	**SA**	**ECw**	**SA**
-1	-1	1.30	0.29
-1	1	1.30	1.71
1	-1	5.20	0.29
1	1	5.20	1.71
- α	0	0.50	1.00
α	0	6.00	1.00
0	α	3.25	2.00
0	- α	3.25	0.00
0	0	3.25	1.00

Electrical conductivity of irrigation water (ECw); salicylic acid (SA).

using the formula: plant height/stem diameter. Dickson quality index was obtained using the formula: TDM/((PH/Ds) + (shoot dry mass/root dry mass)). The root/shoot ratio was obtained using the formula: root dry mass/shoot dry mass.

Data were subjected to the normality test (Shapiro-Wilk) and homogeneity of variances (Bartlett) and to the regression analysis and, when the interaction between the factors was significant, response surface graphs were created, with the equations being generated by the rsm package (Lenth, 2009) and by the GA package (Scrucca, 2013). A canonical variables analysis with confidence ellipses ($p \leq 0.01$) were performed to study the interrelationship between variables and factors using the candisc package (Friendly & Fox, 2021). The statistical program R (R Core Team, 2021) was used to perform the statistical analysis.

RESULTS AND DISCUSSION

The summary of the analysis of variance (ANOVA) is shown in Table 2. The mean values per treatment for each variable are shown in Table 3.

The increase in salt stress reduced the plant height and stem diameter, with losses of 71.90 and 63.22%, respectively, when comparing the lowest and highest ECw (Figures 1A and 1C). Increasing the dose of salicylic acid increased plant height and stem diameter, with an increase of 109.02 and 89.87%, respectively, when comparing the lowest and highest doses (Figures 1B and 1D). Salicylic acid reduced the harmful effects of salt stress on the number of leaves and number of inflorescences, with the highest values (671 and 104) observed at ECws 0.52 and 0.91 dS m^{-1} and 1.98 and 1.99 mM of salicylic acid, respectively (Figures 1E and F).

The negative effect of salt stress on plant height and stem diameter is related to the decrease in CO_2 assimilation due to stomatal limitation and/or impairment in metabolic processes, which can lead to inhibition of cell division and expansion, as observed in pistachio (*Pistacia vera* L.) (Rahneshan *et al*., 2018). Furthermore, this behavior may be related to the negative effects of high salinity that can cause hyperionic and hyperosmotic stress, causing reduced plant growth and even death (Wang *et al*., 2018a). This action was also observed by Silva *et al*. (2022) in basil plants grown under salt stress. The beneficial effect of salicylic acid on plant height and stem diameter and attenuating salt stress on the number of leaves and number of inflorescences is related to the effect of this phytohormone in the regulation of several defense mechanisms, especially the maintenance of ionic balance and photosynthetic activity and detoxification of reactive oxygen species (ROS), as observed in maize (*Zea mays* L.) (Tahjib-Ul-Arif *et al*., 2018).

The increase in salinity of the irrigation water decreased the stem dry mass with losses of 33.05% when comparing the lowest and highest ECw (Figure 2A). Salicylic acid reduced this variable up to the dose of 1.71 mM, with an increase in the dose of 2.0 mM (Figure 2B). Salicylic acid mitigated the harmful effects of salt stress on leaf dry mass and inflorescence dry mass, with the highest values (17.40 and 40.40 g) observed in ECws 0.53 and 0.52 dS m^{-1} and at doses of 0.0015 and 1.99 mM salicylic acid, respectively (Figures 2C and 2D). In addition, salicylic acid application reduces the harmful effects of salt stress on root dry mass and seed mass, with the highest values (6.07 and 8.86 g) observed at ECws 0.51 and 0.50 dS m^{-1} and at doses of 0.013 and 0.774 mM of salicylic acid, in that order (Figures 2E and 2F). The attenuating effect of salicylic acid at low doses may be related to the signaling cascade effect that this phytohormone can cause in plants under stress.

Stem dry mass was reduced by increased salt stress due to membrane degradation, lipid peroxidation, and several other physiological and biochemical changes caused by stress, as observed in *Capsicum annuum* L. (Wang *et al*., 2018b). The beneficial effect of salicylic acid on stem dry mass and mitigating salt stress on leaf dry mass, inflorescence dry mass, root dry mass, and seed mass is related to the action of this phytohormone in accelerating plant growth under stress, improving physiological processes in leaves and reducing oxidative damage, as observed in *Cucumis sativus* L. (Miao *et al*., 2020). In addition to stimulating the production of antioxidants, osmotic substances, phytohormones, and secondary metabolites to protect photosynthetic organs and alleviate cellular damage (Miao *et al*., 2020).

Salicylic acid attenuated the harmful effects of salt stress on leaf area and leaf area ratio, with the highest values (2657.57 cm^2 and 34.87 cm^2 g^{-1}) observed at ECws 0.54 and 5.99 dS m^{-1} and 1.98 and 0.25 mM of salicylic acid, respectively (Figures 3A and 3B). Salicylic acid also mitigated the harmful effects of salt stress on specific leaf area and leaf mass ratio, with the highest values (328.98 cm^2 g^{-1} and 0.23 g g^{-1}) observed in ECws 5.99 and 0.51 dS m^{-1} and 0.86 and 0.0069 mM of salicylic acid, respectively (Figures 3C and D). The highest stem mass ratio (0.33 g g^{-1}) was observed with ECw of 2.64 dS m^{-1} (Figure 3E) and the lowest (0.29 g g^{-1}) was observed with 1.17 mM

Table 2: Summary of analysis of variance

SV	DF	Mean square				
		PH	Ds	NL	Ninf	SDM
Block	1	2.3000^{ns}	0.0120^{ns}	59.0000^{ns}	29.4700^{ns}	2.68^{ns}
ECw	1	3411.0000**	47.3860**	571920**	1826.91**	1251.85**
SA	1	191.4000**	0.2290**	3865**	347.84**	12.65**
ECw x SA	1	0.5000^{ns}	0.0060^{ns}	13468**	369.80**	2.24^{ns}
Residuals	35	8.80	0.0160	226.00	46.34	1.68
SV	**DF**	**LDM**	**IDM**	**RDM**	**SM**	**LA**
Block	1	0.000001^{ns}	2.26^{ns}	1.3460^{ns}	0.1900^{ns}	936^{ns}
ECw	1	521.36**	1245.49**	92.8270**	157.8240**	9043512**
SA	1	16.11**	19.65**	0.6170^{ns}	12.7970**	61121**
ECw x SA	1	6.35**	43.01**	6.0720**	2.4740**	212964**
Residuals	35	0.48	2.44	0.57	0.35	3577
SV	**DF**	**LAR**	**SLA**	**LMR**	**SMR**	**RMR**
Block	1	1.972^{ns}	262^{ns}	0.0002^{ns}	0.000013^{ns}	0.0002^{ns}
ECw	1	23.1720**	80866**	0.0224**	0.0118**	0.0059**
SA	1	13.4350*	9063**	0.0037**	0.0036**	0.0004*
ECw x SA	1	45.6060**	10514**	0.0013**	0.0003^{ns}	0.0014**
Residuals	35	2.3560	510.00	0.0001	0.0003	9.9E-5
SV	**DF**	**IMR**	**DQI**	**SI**	**RQ**	**RSR**
Block	1	0.000015^{ns}	0.1670^{ns}	5.10E-8^{ns}	0.0225^{ns}	0.0002^{ns}
ECw	1	0.1126**	27.9627**	3.09E-5**	14.1225**	0.0075**
SA	1	0.0047**	0.0569^{ns}	6.33E-6**	7.6866**	0.0004^{ns}
ECw x SA	1	0.0082**	1.1110**	4.23E-6**	0.4143^{ns}	0.0018**
Residuals	35	0.0003	0.0670	1.66E-7	0.2734	0.0001

Source of variation (SV); degree of freedom (DF); electrical conductivity of irrigation water (ECw); salicylic acid (SA); plant height (PH); stem diameter (Ds); number of leaves (NL); number of inflorescences (Ninf); stem dry mass (SDM); leaf dry mass (LDM); inflorescence dry mass (IDM); root dry mass (RDM); seed mass (SM); leaf area (LA); leaf area ratio (LAR); specific leaf area (SLA); leaf mass ratio (LMR); root mass ratio (RMR); inflorescence mass ratio (IMR); Dickson quality index (DQI); sclerophilia index (SI); robustness quotient (RQ); root/shoot ratio (RSR). The sources of

of salicylic acid (Figure 3F), above this dose, there was an increase for this variable. Salicylic acid reduced the harmful effects of salt stress on root mass ratio and inflorescence mass ratio, with the highest values (0.075 and 0.939 g g^{-1}) observed with ECws 0.53 and 5.99 dS m^{-1} and 0.025 and 1.99 mM of salicylic acid, respectively (Figures 3G and 3H).

Salicylic acid alleviated the deleterious effects of salt stress on leaf area, leaf area ratio, specific leaf area, leaf mass ratio, root mass ratio, and inflorescence mass ratio of basil plants, possibly because this phytohormone promotes the plant growth under salt stress, as observed in *C. sativus* (Miao *et al*., 2020). In addition, this phytohormone may increase the osmotic adjustment capacity of plants, improving their stress defense mechanisms, in addition to increasing the production of phytohormones to adjust physiological processes and reduce the harmful effects of stress (Khan *et al*., 2018; Malik *et al*., 2021). Thus, this phytohormone allows biomass accumulation in plants, even under stress. Salicylic acid increased the absorption of water, nutrients, root growth, and photosynthesis, contributing to the increase in the dry mass of plants under stress in a study performed with cucumber seedlings (Miao *et al*., 2020).

Table 3: Mean values per treatment of *Ocimum basilicum* 'Cinnamon' under salt stress (ECw) and treated with salicylic acid. Mean ± standard deviation

ECw ($dS\ m^{-1}$)	Salicylic acid (mM) 0.00	0.29	1.00	1.71	2.00
			Plant height (cm)		
0.50			102.26 ± 2.27		
1.30		89.08 ± 1.37		92.62 ± 2.62	
3.25	83.92 ± 0.92		84.48 ± 1.34		91.76 ± 0.79
5.20		74.82 ± 1.61		77.7 ± 4.06	
6.00			70.64 ± 5.08		
			Stem diameter (mm)		
0.50			8.42 ± 0.07		
1.30		8.79 ± 0.15		7.762 ± 0.14	
3.25	7.054 ± 0.11		7.112 ± 0.12		8.037 ± 0.19
5.20		6.686 ± 0.14		5.726 ± 0.07	
6.00			5.19 ± 0.11		
			Number of leaves		
0.50			576.8 ± 18.13		
1.30		545.4 ± 13.04		636.4 ± 7.23	
3.25	431.0 ± 10.95		445.2 ± 22.49		431.2 ± 12.93
5.20		307.8 ± 4.58		295.0 ± 12.93	
6.00			310.0 ± 14.25		
			Number of inflorescences		
0.50			81.4 ± 6.56		
1.30		90.2 ± 5.19		99.6 ± 3.72	
3.25	89.4 ± 6.18		85.4 ± 7.39		91.7 ± 3.57
5.20		87.6 ± 6.05		79.8 ± 8.84	
6.00			59.0 ± 5.09		
			Stem dry mass (g)		
0.50			23.42 ± 0.44		
1.30		24.13 ± 0.76		22.21 ± 2.24	
3.25	18.18 ± 1.48		20.35 ± 1.78		18.08 ± 0.53
5.20		12.19 ± 0.43		11.61 ± 0.61	
6.00			7.72 ± 0.59		
			Leaf dry mass (g)		
0.50			15.02 ± 0.84		
1.30		11.97 ± 0.81		9.69 ± 0.89	
3.25	10.88 ± 0.51		6.79 ± 0.52		8.91 ± 0.61
5.20		4.41 ± 0.40		4.39 ± 0.38	
6.00					
			Inflorescence dry mass (g)		
0.50					
1.30		31.39 ± 1.26		36.52 ± 2.01	
3.25	28.47 ± 1.81		28.48 ± 1.71		29.33 ± 1.29
5.20		23.36 ± 0.85		22.622 ± 1.32	
6.00			20.63 ± 1.09		

Continue...

Continuation...

ECw (dS m^{-1})	Salicylic acid (mM) 0.00	0.29	1.00	1.71	2.00
			Root dry mass (g)		
0.50			5.50 ± 0.28		
1.30		4.84 ± 0.25		3.53 ± 0.31	
3.25	3.12 ± 1.23		3.33 ± 0.41		4.38 ± 0.24
5.20		1.28 ± 0.14		1.57 ± 0.27	
6.00			1.21 ± 0.13		
			Seed mass (g)		
0.50			11.89 ± 0.32		
1.30		8.44 ± 0.85		8.25 ± 1.04	
3.25	7.79 ± 0.37		8.49 ± 0.28		6.42 ± 0.20
5.20		4.69 ± 0.25		5.90 ± 0.35	
6.00			4.96 ± 0.40		
			Leaf area (cm^2)		
0.50			2293.64 ± 72.08		
1.30		2168.78 ± 51.88		2530.64 ± 28.74	
3.25	1713.87 ± 43.56		1770.34 ± 89.43		1714.67 ± 20.65
5.20		1223.97 ± 18.21		1173.07 ± 51.42	
6.00			1232.72 ± 56.68		
			Leaf area ratio (cm^2 g^{-1})		
0.50			28.45 ± 0.89		
1.30		29.98 ± 1.48		35.29 ± 2.22	
3.25	28.35 ± 1.59		30.05 ± 1.58		28.28 ± 1.06
5.20		29.69 ± 0.62		29.20 ± 1.19	
6.00			37.12 ± 1.97		
			Specific leaf area (cm^2 g^{-1})		
0.50			153.01 ± 6.71		
1.30		182.27 ± 16.20		263.18 ± 23.58	
3.25	157.98 ± 10.13		262.88 ± 32.43		193.53 ± 15.75
5.20		279.65 ± 25.07		268.85 ± 22.86	
6.00			334.65±14.36		
			Leaf mass ratio (g g^{-1})		
0.50			0.186 ± 0.009		
1.30		0.165 ± 0.011		0.134 ± 0.009	
3.25	0.179 ± 0.011		0.116 ± 0.011		0.147 ± 0.006
5.20		0.107 ± 0.008		0.109 ± 0.011	
6.00			0.111 ± 0.002		
			Stem mass ratio (g g^{-1})		
0.50			0.29 ± 0.005		
1.30		0.333 ± 0.011		0.308 ± 0.022	
3.25	0.299 ± 0.009		0.345 ± 0.024		0.298 ± 0.015
5.20		0.295 ± 0.013		0.289 ± 0.017	
6.00			0.232 ± 0.015		

Continue...

Continuation...

ECw (dS m^{-1})	Salicylic acid (mM)				
	0.00	**0.29**	**1.00**	**1.71**	**2.00**
			Root mass ratio (g g^{-1})		
0.50			0.068 ± 0.003		
1.30		0.067 ± 0.004		0.049 ± 0.002	
3.25	0.051 ± 0.016		0.056 ± 0.006		0.072 ± 0.002
5.20		0.031 ± 0.003		0.039 ± 0.006	
6.00			0.036 ± 0.005		
			Inflorescence mass ratio (g g^{-1})		
0.50			0.455 ± 0.008		
1.30		0.434 ± 0.013		0.508 ± 0.015	
3.25	0.469 ± 0.023		0.483 ± 0.016		0.483 ± 0.008
5.20		0.566 ± 0.015		0.563 ± 0.022	
6.00			0.620 ± 0.014		
			Dickson quality index		
0.50			3.124 ± 0.112		
1.30		3.002 ± 0.109		2.295 ± 0.172	
3.25	1.955 ± 0.498		2.054 ± 0.170		2.498 ± 0.118
5.20		0.969 ± 0.083		1.047 ± 0.135	
6.00			0.825 ± 0.050		
			Sclerophilia index		
0.50			0.0065 ± 0.0003		
1.30		0.0055 ± 0.0004		0.0038 ± 0.0003	
3.25	0.0063 ± 0.0004		0.0038 ± 0.0005		0.00512 ± 0.0004
5.20		0.0036 ± 0.0003		0.0037 ± 0.0003	
6.00			0.0029 ± 0.0001		
			Robustness quotient		
0.50			12.14 ± 0.24		
1.30		10.14 ± 0.31		11.94 ± 0.52	
3.25	11.90 ± 0.31		11.88 ± 0.22		11.42 ± 0.19
5.20		11.19 ± 0.11		13.57 ± 0.66	
6.00			13.61 ± 0.93		
			Root/shoot ratio		
0.50			0.0732 ± 0.0039		
1.30		0.0723 ± 0.0043		0.0514 ± 0.0027	
3.25	0.0537 ± 0.0189		0.0598 ± 0.0071		0.0776 ± 0.0027
5.20		0.0319 ± 0.0032		0.0405 ± 0.0063	
6.00			0.0380 ± 0.0058		

Source of variation (SV); degree of freedom (DF); electrical conductivity of irrigation water (ECw); salicylic acid (SA); plant height (PH); stem diameter (Ds); number of leaves (NL); number of inflorescences (Ninf); stem dry mass (SDM); leaf dry mass (LDM); inflorescence dry mass (IDM); root dry mass (RDM); seed mass (SM); leaf area (LA); leaf area ratio (LAR); specific leaf area (SLA); leaf mass ratio (LMR); root mass ratio (RMR); inflorescence mass ratio (IMR); Dickson quality index (DQI); sclerophilia index (SI); robustness quotient (RQ); root/shoot ratio (RSR). The sources of variations intermediate that complete the ANOVA for the central composite design have been removed, keeping only the main ones.

Salicylic acid reduced the harmful effects of salt stress on the Dickson quality index and sclerophilia index, with the highest values (3.43 and 0.0082) observed in ECws 0.53 and 0.51 dS m^{-1} and with 0.0152 and 0.0013 mM of salicylic acid, respectively (Figures 4A and 4B). The lowest robustness quotient (11.34) was observed with the ECw of 2.44 dS m^{-1} (Figure 4C) and the highest (12.55) was observed with 1.28 mM of salicylic acid (Figure 3D). In

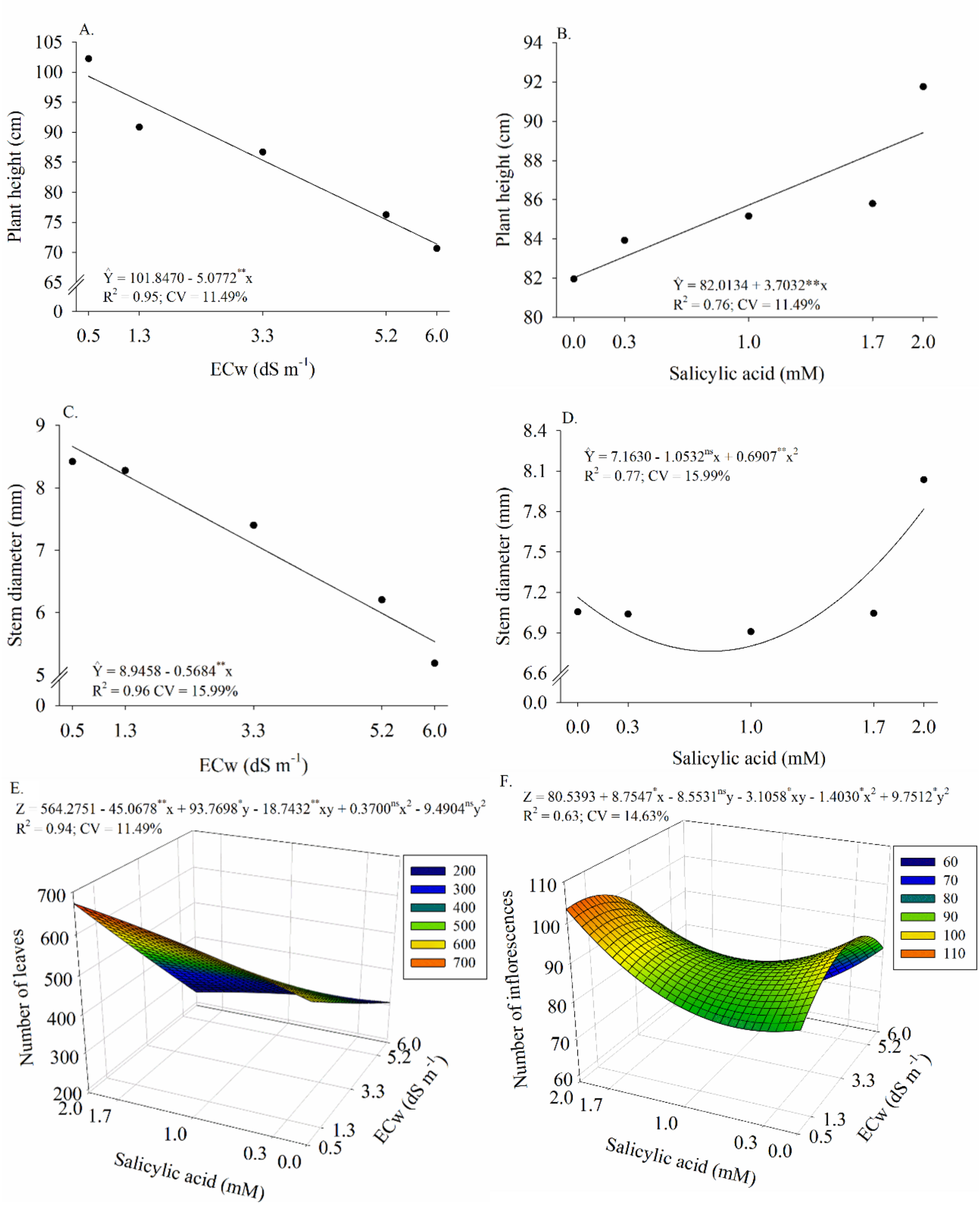

Figure 1: Plant height (A and B), stem diameter (C and D), number of leaves (E) and number of inflorescences (F) of *Ocimum basilicum* 'Cinnamon' under salt stress (ECw) and treated with salicylic acid. ns, *, ** - Not significant, significant at $p \leq 0.05$ and at $p \leq 0.01$ by F test, respectively.

addition, salicylic acid attenuated the harmful effects of salt stress on root/shoot ratio, with the highest value (0.082) observed with ECw 0.56 dS m^{-1} and 0.0059 mM of salicylic acid (Figure 4E).

The harmful effects of salt stress on the Dickson quality index, sclerophilia index, robustness quotient, and root/shoot ratio were mitigated by the salicylic acid. This behavior may be related to the action of salicylic acid as a regulator of the synthesis and osmolytes of the enzyme that is linked to growth and photosynthesis, acting mainly against the deleterious effects of salinity (Khanam & Mohammad, 2018). In addition, phytohormones act on gene signaling and expression, increasing plant tolerance to the effects of salt stress (Arif *et al.*, 2020).

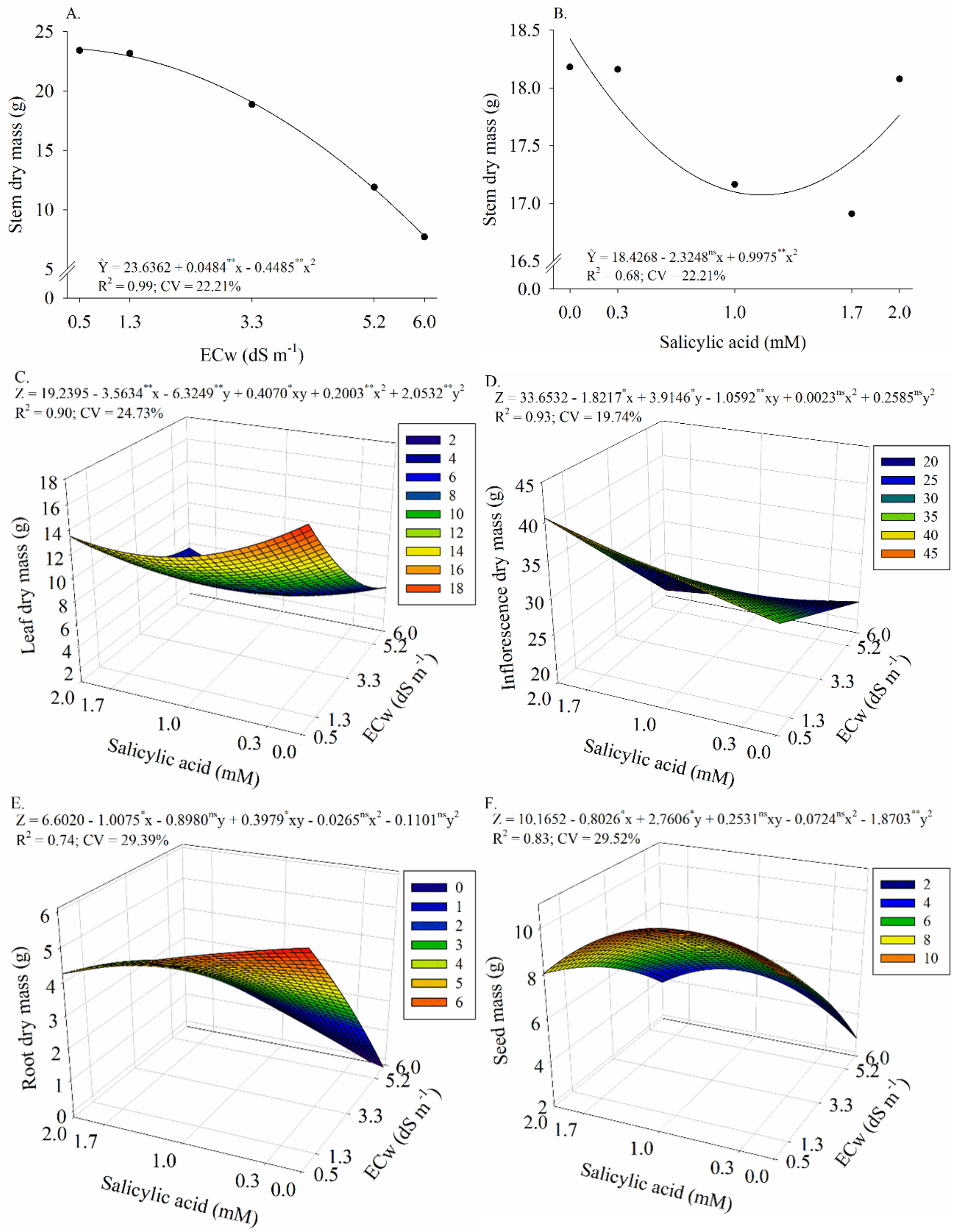

Figure 2: Stem dry mass (A and B), leaf dry mass (C), inflorescence dry mass (D), root dry mass (E) and seed mass (F) of *Ocimum basilicum* 'Cinnamon' under salt stress (ECw) and treated with salicylic acid. ns, *, ** - Not significant, significant at $p \leq 0.05$ and at $p \leq 0.01$ by F test, respectively.

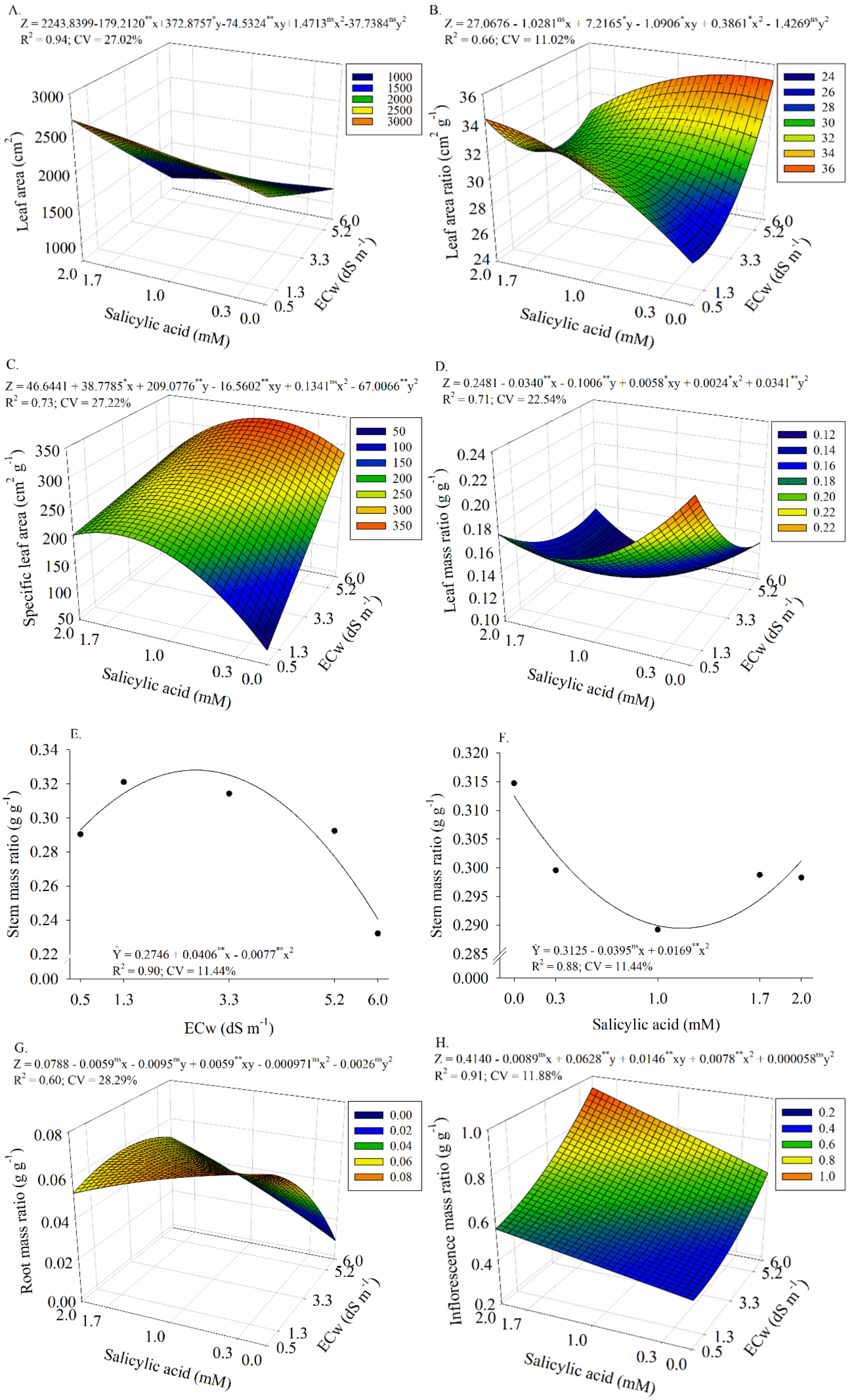

Figure 3: Leaf area (A), leaf area ratio (B), specific leaf area (C), leaf mass ratio (D), stem mass ratio (E and F), root mass ratio (G) and inflorescence mass ratio (H) of *Ocimum basilicum* ‘Cinnamon’ under salt stress (ECw) and treated with salicylic acid. ns, *, ** - Not significant, significant at $p \leq 0.05$ and at $p \leq 0.01$ by F test, respectively.

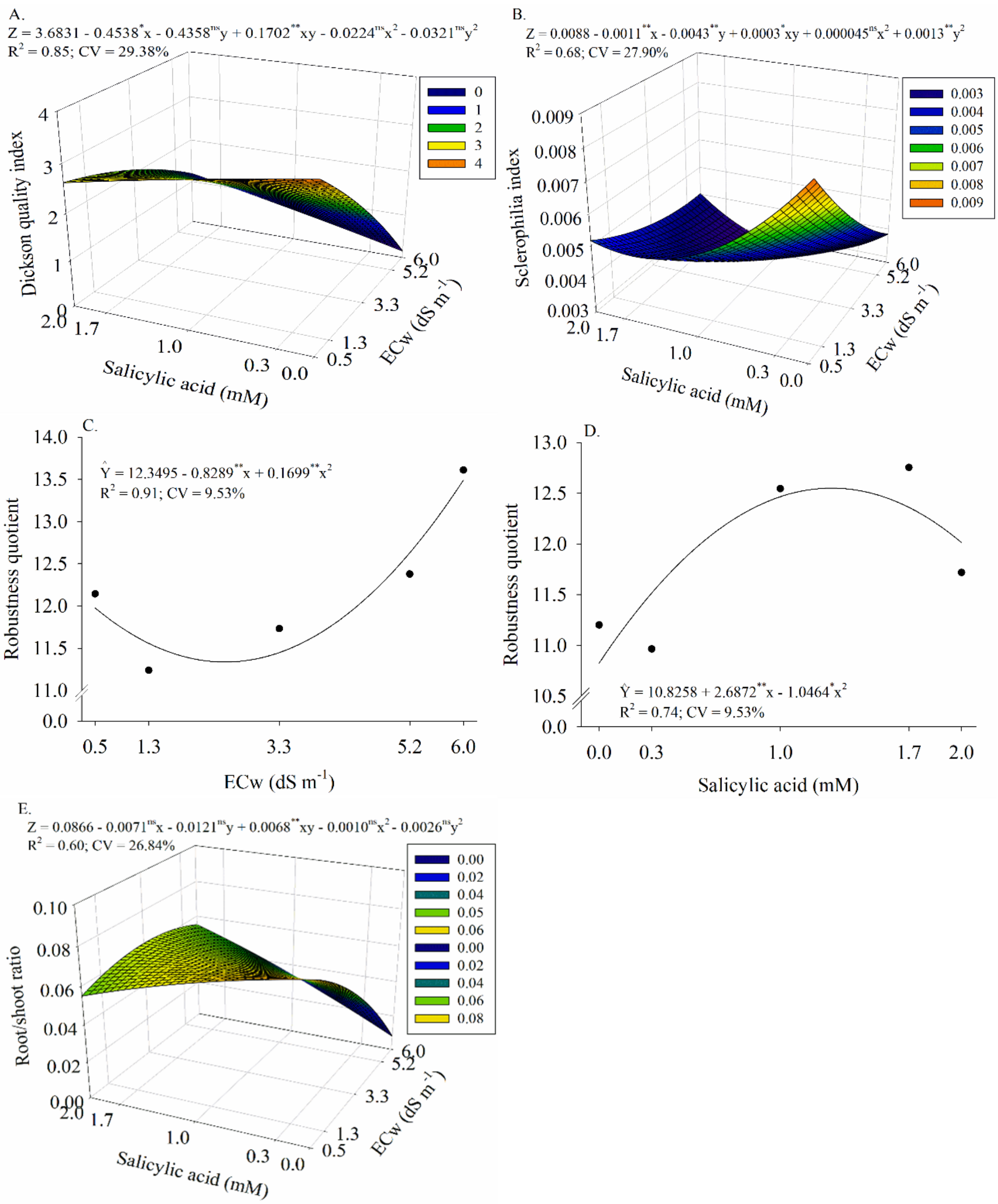

Figure 4: Dickson quality index (A), sclerophilia index (B), robustness quotient (C and D) and root/shoot ratio (E) of *Ocimum basilicum* ‘Cinnamon’ under salt stress (ECw) and treated with salicylic acid. ns, *, ** - Not significant, significant at $p \leq 0.05$ and at $p \leq 0.01$ by F test, respectively.

A canonical variables analysis with confidence ellipses were performed to assess the interrelationships between factors and variables. Stem diameter (Ds), root dry mass (RDM), stem dry mass (SDM), plant height (PH), leaf dry mass (LDM), seed mass (SM), inflorescence dry mass (IDM), and the number of leaves (NL) were more related to ECws 0.50 and 1.30 dS m^{-1} and 0.29 and 1.0 mM of salicylic acid (Figure 5A). Sclerophilia index (SI), leaf mass ratio (LMR), root mass ratio (RMR), root/shoot ratio (RSR), Dickson quality index (DQI), and leaf area (LA) had the highest relationship, with ECws 0.50 and 1.30 dS m^{-1} and 0.29, 1.0 and 1.71 mM salicylic acid (Figure 5B). Robustness quotient (RQ), inflorescence mass ratio (IMR), specific leaf area (SLA) were more closely related to ECw 6.0 dS m^{-1} and 1.0 mM of salicylic acid (Figure 5B).

The growth variables of basil plants were benefited from the salicylic acid application, indicating that the presence of this phytohormone mitigated the harmful effects of salt stress. This behavior may have occurred because this phytohormone increases plant tolerance under stress through changes in gene expression (Khan *et al.*, 2020). The reduction in growth due to increased salt stress may be

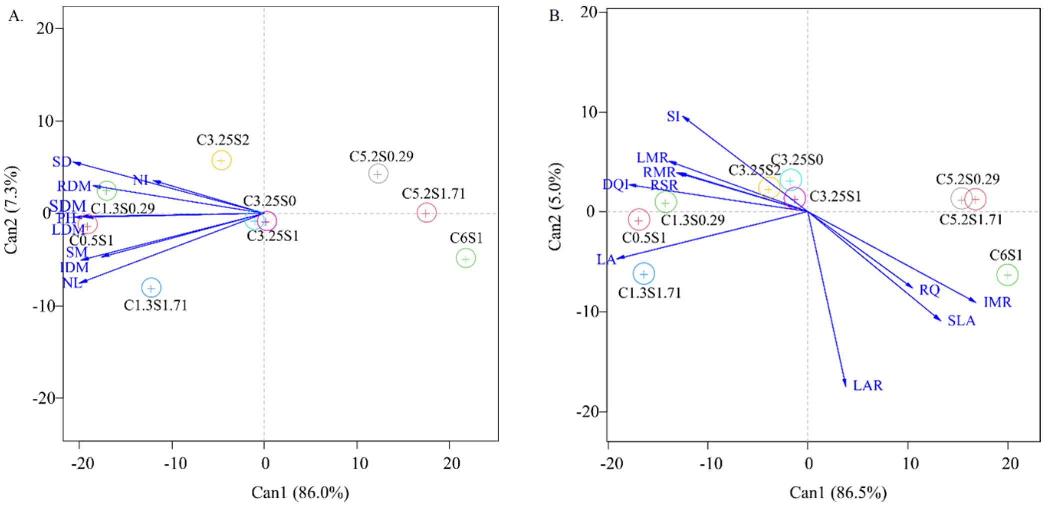

Figure 5: Canonical variables analysis with confidence ellipses between growth variables (A and B) of *Ocimum basilicum* 'Cinnamon' under salt stress (C) and salicylic acid (S). Stem diameter (SD); root dry mass (RDM); stem dry mass (SDM); plant height (PH); leaf dry mass (LDM); seed mass (SM); inflorescence dry mass (IMD),; number of leaves (NL); sclerophilia index (SI); leaf mass ratio (LMR); root mass ratio (RMR); root/shoot ratio (RSR); Dickson quality index (DQI); leaf area (LA); robustness quotient (RQ); inflorescence mass ratio (IMR); specific leaf area (SLA).

related to the harmful effects of salts on physiological and biochemical aspects, such as water absorption, photosynthesis, and oxidative stress (Tahjib-Ul-Arif *et al*., 2018).

CONCLUSIONS

Salicylic acid attenuates the harmful effects of salt stress in the basil growth. Salt stress decreased plant height, stem diameter, stem dry mass, and stem mass ratio of basil 'Cinnamon'. Salicylic acid can be used to lessen the harmful effects of salt stress on basil 'Cinnamon'.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

The authors thank to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for financial assistance to this study and to the Universidade Federal da Paraíba (UFPB) for all support.

REFERENCES

Ahammed GJ, Li Y, Li X, Han WY & Chen S (2018) Epigallocatechin-3-gallate alleviates salinity-retarded seed germination and oxidative stress in tomato. Journal of Plant Growth Regulation, 37:1349–1356.

Angooti F & Nourafcan H (2015) Efects of application method and level of salicylic acid on some morphological characteristics of *Ocimum basilicum* L. leaves under sodium chloride salinity stress. Biological Forum, 7:346–351.

Arif Y, Singh P, Siddiqui H, Bajguz A & Hayat Y (2020) Salinity induced physiological and biochemical changes in plants: An omic approach towards salt stress tolerance. Plant Physiology and Biochemistry, 156:64–77.

Chokami KM, Abdossi V, Samavat S, Moghadam AL & Moradi P (2019) Effect of different polyamines on some physiological traits, growth, and development of basil (*Ocimum basilicum* L.) in salt stress under hydroponic culture conditions. Journal of Applied Biology & Biotechnology, 7:7–13.

Elhindi KM, Al-Amri SM, Abdel-Salam EM & Al-Suhaibani NA (2017) Effectiveness of salicylic acid in mitigating salt-induced adverse effects on different physio-biochemical attributes in sweet basil (*Ocimum basilicum* L.). Journal of Plant Nutrition, 40:908–919.

Friendly M & Fox J (2021) candisc: visualizing generalized canonical discriminant and canonical correlation analysis. R package version 0.8-0.

Joseph B, Jini D & Sujatha S (2010) Insight into the role of exogenous salicylic acid on. Asian Journal of Crop Science, 2:226–235.

Kahveci H, Bilginer N, Diraz-Yildirim E, Kulak M, Yazar E, Kocacinar F & Karaman S (2021) Priming with salicylic acid, β-carotene and tryptophan modulates growth, phenolics and essential oil components of *Ocimum basilicum* L. grown under salinity. Scientia Horticulturae, 281:109964.

Khanam D & Mohammad F (2018) Plant growth regulators ameliorate the ill effect of salt stress through improved growth, photosynthesis, antioxidant system, yield and quality attributes in *Mentha piperita* L. Acta Physiologiae Plantarum, 40:188.

Khan N, Bano A, Ali S & Babar MDA (2020) Crosstalk amongst phytohormones from planta and PGPR under biotic and abiotic stresses. Plant Growth Regulation, 90:189–203.

Khan N, Bano A & Zandi P (2018) Effects of exogenously applied plant growth regulators in combination with PGPR on the physiology and root growth of chickpea (*Cicer arietinum*) and their role in drought tolerance. Journal of Plant Interactions, 15:239–247.

Kim Y, Mun BG, Khan AL, Waqas M, Kim HH, Shahzad R, Imram M, Byung-Wook Y & Lee IJ (2018) Regulation of reactive oxygen and nitrogen species by salicylic acid in rice plants under salinity stress conditions. Plos One, 13:e0192650.

Lenth RV (2009) Response-surface methods in R, using rsm. Journal of Statistical Software, 32:1–17.

Malik A, Mor VS, Tokas J, Punia H, Malik S, Malik K, Sangwan S, Tomar S, Singh P, Singh N, Himangini VN, Singh G, Kumar V & Karwasra A (2021) Biostimulant-treated seedlings under sustainable agriculture: a global perspective facing climate change. Agronomy, 11:14.

Miao Y, Luo X, Gao X, Wang W, Li B & Hou L (2020) Exogenous salicylic acid alleviates salt stress by improving leaf photosynthesis and root system architecture in cucumber seedlings. Scientia Horticulturae, 272:109577.

Naveed M, Sajid H, Mutafa A, Niamat B, Ahmad Z, Yaseen M, Kamran M, Rafique M, Ahmar E & Chen JT (2020) Alleviation of salinity-induced oxidative stress, improvement in growth, physiology and mineral nutrition of canola (*Brassica napus* L.) through calcium-fortified composted animal manure. Sustainability, 12:846.

Nóbrega JS, Bezerra AC, Ribeiro JES, Silva EC, Silva TI, Costa RNM, Silva AV, Lopes AS & Dias TJ (2021) Growth and gas exchange of purple basil submitted to salinity and foliar nitrogen fertilization. Journal of Plant Nutrition, 44:2729–2738.

Oliveira RSV, Salomão LC, Morgado HS, Sousa CM & Oliveira HFE (2020) Growth and production of basil under different luminosity and water replacement levels. Horticultura Brasileira, 38:324–328.

R Core Team (2021) R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Rahneshan Z, Nasibi F & Moghadam AA (2018) Effects of salinity stress on some growth, physiological, biochemical parameters and nutrients in two pistachio (*Pistacia vera* L.) rootstocks. Journal of Plant Interactions, 13:73–82.

Scrucca L (2013) GA: a package for genetic algorithms in R. Journal of Statistical Software, 53:1–37.

Silva TI, Silva JS, Dias MG, Martins JVS, Ribeiro WS & Dias TJ (2022) Salicylic acid attenuates the harmful effects of salt stress on basil. Revista Brasileira de Engenharia Agrícola e Ambiental, 26:399–406.

Silva EM, Lima GS, Gheyi HR, Nobre RG, Sá FVS & Souza LP (2018) Growth and gas exchanges in soursop under irrigation with saline water and nitrogen sources. Revista Brasileira de Engenharia Agrícola e Ambiental, 22:776–781.

Silva TI, Gonçalves ACM, Melo Filho JS, Alves WS, Basílio AGS, Figueiredo FRA, Dias TJ & Blank AF (2019) Echophysiological aspects of *Ocimum basilicum* under saline stress and salicylic acid. Revista Brasileira de Ciências Agrárias, 14:e5633.

Tahjib-Ul-Arif M, Siddiqui MN, Sohag AAM, Sakil MA, Rahman MM, Polash MAS, Mostofa MG & Tran LSP (2018) Salicylic acid-mediated enhancement of photosynthesis attributes and antioxidant capacity contributes to yield improvement of maize plants under salt stress. Journal of Plant Growth Regulation, 37:1318–1330.

Vilanova CM, Coelho KP, Luz TRSA, Silveira DPB, Coutinho DF & Moura EG (2018) Effect of different water application rates and nitrogen fertilization on growth and essential oil of clove basil (*Ocimum gratissimum* L.). Industrial Crops and Products, 125:186–197.

Wang Y, Wang M, Li Y, Wu A & Huang J (2018a) Effects of arbuscular mycorrhizal fungi on growth and nitrogen uptake of *Chrysanthemum morifolium* under salt stress. PLoS One, 13:e0196408.

Wang W, Wu Z, He Y, Huang, Y, Li X & Ye BC (2018b) Plant growth promotion and alleviation of salinity stress in *Capsicum annuum* L. by *Bacillus* isolated from saline soil in Xinjiang. Ecotoxicology and Environmental Safety, 164:520-529.