Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252024v3712060rc

Scientific Article

Salicylic acid and soaking times on the emergence, gas exchange and early growth of umbu

Ácido salicílico e tempos de embebição na emergência, trocas gasosas e crescimento inicial de umbuzeiro

Máximo A. Correia[1], Luderlândio de A. Silva[1], Jackson S. Nóbrega[2]*, Lauter S. Souto[1], Larissa A. Brito[1], Romulo C. L. Moreira[3], Anielson dos S. Souza[1], Francisco V. da S. Sá[4]

[1]Agrifood Science and Technology Center, Universidade Federal de Campina Grande, Pombal, PB, Brazil. [2]Postgraduate Program in Agricultural Engineering, Universidade Federal de Campina Grande, Campina Grande, PB, Brazil. [3]Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil. [4]Department of Agrarian and Exact, Universidade Estadual da Paraíba, Catolé do Rocha, PB, Brazil.

ABSTRACT - Umbu is a fruit species to the Brazilian Caatinga, showing a significant potential for various purposes and serving as a source of job and income for small producers in northeastern Brazil. This species has seed coat dormancy, which limits the production of uniform planting areas. In this scenario, this study aimed to evaluate the overcoming of dormancy, gas exchange and initial growth of *S. tuberosa* subjected to different soaking times and concentrations of salicylic acid. The experiment was conducted in a randomized block design with a 5 × 5 factorial arrangement referring to five concentrations of salicylic acid (0, 40, 80, 120, and 160 mg L^{-1}) and five soaking times (0, 8, 16, 24, and 32 hours). Seed conditioning for 32 hours at the concentration of 120 mg L^{-1} promoted the highest germination percentage and germination speed index of *S. tuberosa* seedlings. Soaking at 40 and 80 mg L^{-1} of salicylic acid improves the gas exchange and growth of *S. tuberosa* seedlings. The concentration of 160 mg L^{-1} for 32 hours increased root, stem, and total dry matter. Leaf dry matter was higher in plants subjected to the concentration of 80 mg L^{-1} and the time of 14 hours. Conditioning the seeds for 32 hours at a concentration of 120 mg L^{-1} was effective in overcoming seed dormancy and could be a alternative for producing *S. tuberosa* seedlings.

Keywords: *Spondias tuberosa* Arruda. Caatinga. Seed conditioning. Seed dormancy. Phytohormone. Photosynthesis.

RESUMO - O umbuzeiro é uma fruteira da Caatinga com grande potencial de exploração, servindo como fonte de emprego e renda para os pequenos agricultores do Semiárido do Nordeste Brasileiro. É uma espécie que possui dormência tegumentar em suas sementes, o que limita à obtenção de um estande de plantas uniformes. Neste contexto, objetivou-se avaliar a superação da dormência de sementes, as trocas gasosas e o crescimento inicial de *S. tuberosa* submetidas a diferentes tempos de embebição e concentrações de ácido salicílico. O experimento foi realizado em delineamento de blocos casualizados com fatorial 5 × 5, sendo cinco concentrações de ácido salicílico (0, 40, 80, 120 e 160 mg L^{-1}) e cinco tempos de embebição (0, 8, 16, 24 e 32 horas). O condicionamento das sementes por 32 horas na concentração de 120 mg L^{-1}, proporcionou a maior porcentagem e índice de velocidade de emergência de plântulas de *S. tuberosa*. A embebição das sementes na concentração entre 40 e 80 mg L^{-1} de ácido salicílico, melhora as trocas gasosas e o crescimento das mudas de *S. tuberosa*. A concentração de 160 mg L^{-1} por 32 horas promoveu incremento na fitomassa seca da raiz, do caule e total. Enquanto a fitomassa seca das folhas foi maior nas mudas submetidas a concentração de 80 mg L^{-1} e no tempo de 14 horas. O condicionamento das sementes por 32 horas na concentração de 120 mg L^{-1} foi eficaz na superação de dormência das sementes, podendo ser uma alternativa para produção de mudas de *S. tuberosa*.

Palavras-chave: *Spondias tuberosa* Arruda. Caatinga. Condicionamento de sementes. Dormência de sementes. Fitohormônio. Fotossíntese.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: July 6, 2023.
Accepted in: March 14, 2024.

***Corresponding author:**
<jacksonnobrega@hotmail.com>

INTRODUCTION

Umbu (*Spondias tuberosa* Arruda) is a species found in the semi-arid region of Northeastern Brazil, representing an important source of income for farmers through the harvest and commercialization of fresh fruit or various by-products, e.g., sweets, pulp, syrups, liqueurs, concentrates, mousse, pickles, and others (CORDEIRO et al., 2020).

It is a plant that can tolerate aridity conditions equal to or lower than 0.50, according to the Thornthwaite index, and daily water deficit levels higher than 60% (BRASIL, 2018). The species can withstand and survive the harsh conditions of the semi-arid region of Brazil due to its ability to store water, nutrients, and organic solutes in its tuberous roots (PEREIRA et al., 2023).

The propagation of *S. tuberosa* occurs mainly sexually, being considered slow and uneven, with values below 30%, with germination beginning after 12 days, and can last up to 90 days (SOUZA et al., 2022). The seeds of this species are located within the endocarp, which is composed of three densely fibrous layers, and surrounded by a lignified layer that provides them with harshness and resistance, resulting in uneven germination due to the mechanical resistance of the endocarp, which prevents embryonic growth with the reduction in the inflow of water and oxygen (NÓBREGA et al., 2016).

The search for alternatives capable of overcoming dormancy in *S. tuberosa* seeds is extremely important as it can allow the future formation of orchards and favor income generation. Among the main methods of overcoming seed coat dormancy, chemical scarification using acids and bases, mechanical methods using sandpaper or rubbing the seeds on rough surfaces and soaking the seeds for different periods and temperatures stand out (GÓES et al., 2022).

Nóbrega et al. (2016) demonstrated that soaking *S. tuberosa* seeds for 24 hours in distilled water promoted improvements in emergence and initial establishment. Góes et al. (2022) observed that the adoption of the association of mechanical scarification followed by soaking of *Leucaena leucocephala* seeds for 24 hours in a solution containing 10 mg L^{-1} of salicylic acid improved emergence and initial growth.

Thus, seed conditioning through pre-soaking with phytohormones may be an alternative to reduce the juvenile period and improve germination (MATOS et al., 2020). Furthermore, salicylic acid is one of the phytohormones involved in seed germination, consisting of a phenolic compound that acts in the activation and signaling of genes involved in the regulation of several physiological processes, including germination (NÓBREGA et al., 2021). However, the main role of salicylic acid is related to its function in the plant defense system, promoting higher tolerance to biotic and abiotic stresses (SILVA et al., 2022; OLIVEIRA et al., 2023a).

From this perspective, this study aimed to evaluate the overcoming of seed dormancy, gas exchange, and seedling growth of *S. tuberosa* under different pretreatment times and concentrations of salicylic acid.

MATERIAL AND METHODS

The experiment was conducted under plant nursery conditions at the Universidade Federal de Campina Grande - UFCG, at the Center for Sciences and Agrifood Technology - CCTA, located in the municipality of Pombal, Paraíba, PB, Brazil, at the geographic coordinates 6º47'20" S and 37º48'01" W, at an elevation of 194 m.

The experimental design was in randomized blocks in a 5 x 5 factorial arrangement referring to five concentrations of salicylic acid (0, 40, 80, 120, and 160 mg L^{-1}) and five pre-soaking times (0, 8, 16, 24, and 32 hours), with 12 replications, totaling 300 experimental units.

The seeds used in this study came from plants located in floodplain areas in the municipality of Juazeirinho, in the Cariri region of Paraíba, located at the coordinates 7° 4' 1" S and 36° 34' 42" W, at an elevation of 558 m, collected in January and February 2021 during the species fruiting period. The fruits were harvested in the intermediate stage between unripe and ripe (NÓBREGA et al., 2016).

After fruit harvest, the pulp was removed at the Post-harvest Laboratory of CCTA. Seed drying was performed in the shade and under ambient conditions (temperature of 25 ºC and relative humidity of 60%) for seven days. After drying, the seeds were soaked in salicylic acid, which was performed by diluting the salicylic acid concentrations in 30% ethyl alcohol (99.5%), completing the volume with distilled water plus a control with distilled water, during different pre-soaking times.

The substrate used was prepared at a proportion of 2:1:1, with two parts of soil collected at a depth of 1 m, one part of cattle manure, and one part of washed sand. Subsequently, 200-mL containers were filled with the substrate and five seeds were sown per pot. Later on, the seedlings were thinned to one plant per container, maintaining the most vigorous plant.

Irrigation was performed daily and the volume was determined using drainage lysimeters. The volume applied to each container corresponded to the water balance, determined according to Equation 1:

$$VI = Va - Vd \qquad (1)$$

Where:
VI - water volume to be used in the irrigation event (mL);
Va - water volume applied in the previous irrigation event (mL);
Vd - water volume drained in the previous irrigation event (mL).

During the experiment, the percentage of seedling emergence was determined by counting the number of seedlings that emerged 45 days after sowing, considering the emergence of cotyledons above ground. The emergence speed index (ESI) was determined based on the daily counting of emerged seedlings using the methodology described by Maguire (1962), according to Equation 2.

$$ESI = \frac{E1}{N1} + \frac{E2}{N2} + \ldots + \frac{En}{Nn} \qquad (2)$$

Where:
ESI= emergence speed index;
E = number of seedlings emerged every day;
N = number of days from sowing at every count.

The gas exchange parameters were measured 60 days after sowing using a portable photosynthesis meter "LCPro+" manufactured by ADC BioScientific Ltda, operating at a temperature of 25 ºC, irradiation of 1200 μmol photons from the environment at a height of 3 m from the soil, through the following variables: CO_2 assimilation rate (A) (μmol CO_2 m^{-2} s^{-1}), transpiration (E) (mol H_2O m^{-2} s^{-1}), stomatal conductance (gs) (mol of H_2O m^{-2} s^{-1}), and internal CO_2 concentration (Ci) (μmol $m^{-2} s^{-1}$). The probe was placed on the third leaf from the apex. The water-use efficiency (WUE) was obtained by the ratio between A and E [(μmol CO_2 m^{-2} s^{-1}) (mol H_2O m^{-2} $s^{-1})^{-1}$], and the instantaneous carboxylation efficiency (iCE) [(μmol CO_2 m^{-2} s^{-1}) (μmol CO_2 m^{-1} $s^{-1})^{-1}$] was also calculated.

The morphological aspects of the crop were evaluated by performing the growth analysis of *S. tuberosa* seedlings based on plant height, measured with a ruler (cm) and considering the distance from the base of the plant to the insertion of the apical meristem, stem diameter, measured with a digital caliper (mm), and number of leaves, considering the leaves already formed.

The dry matter content of the seedlings was determined by separating the plants into leaves, stems, and roots immediately after they were cut. The collected material was stored in kraft paper bags and dried in a forced-air oven at 65 ºC for 72 hours. Then, the material was weighed on an analytical balance accurate to 0.001g, thus obtaining the dry phytomass of roots, leaves, stem, and the total dry matter, with values expressed in grams (g).

The data obtained were tested for normality (Shapiro-Wilk) and subjected to analysis of variance by the F-test ($P \leq 0.05$). In the significant cases, polynomial regression was applied for the concentrations of salicylic acid and soaking times using the statistical software Sisvar® (FERREIRA, 2019).

RESULTS AND DISCUSSION

According to the summary of the analysis of variance (Table 1), there was a significant effect of the interaction between the salicylic acid concentrations and the seed soaking times on seedling emergence (E%) and the emergence speed index (ESI) of *S. tuberosa* seedlings.

Table 1. Summary of the analysis of variance for the emergence percentage (E%) and emergence speed index (ESI) of *Spondias tuberosa* Arruda seedlings subjected to concentrations of salicylic acid and soaking times.

Source of variation	DF	Mean Square	
		E%	ESI
Soaking time (T)	4	676.47^{**}	0.0120^{**}
Linear regression	1	555.57^{**}	0.024^{**}
Quadratic regression	1	194.32^{ns}	0.0032^{ns}
Salicylic acid (SA)	4	1114.19^{**}	0.0096^{**}
Linear regression	1	4051.35^{**}	0.035^{**}
Quadratic regression	1	99.16^{ns}	0.000023^{ns}
Interaction (T x SA)	16	346.54^{**}	0.0048^{**}
Blocks	3	66.69^{ns}	0.0046^{ns}
Residual	72	84.04	0.0017
CV (%)	-	19.9	36.0
Shapiro Wilk		0.9993	0.9394

*significant at 0.05 probability level; ** significant at 0.01 probability level; ^{ns} not significant.

For the emergence percentage (E%), the salicylic acid concentrations of 40, 80, 120, and 160 mg L^{-1} led to values that are best described by the quadratic model, with the highest percentages (75.6 and 65.6%) occurring at the concentrations of 120 and 160 mg L^{-1}, respectively, both under a soaking time of 32 hours (Figure 1A). With regard to the control treatment (39.9%), these values represent increases of 36.2 and 25.7% compared to the values obtained at the concentrations of 120 and 160 mg L^{-1}, respectively. For the seedlings subjected to soaking and concentrations of 40 and 80 mg L^{-1}, the maximum values obtained were 42.6 and 49% at the times of 14 and 18 hours, respectively. Thus, it can be concluded that soaking in salicylic acid stimulates the germination of *S. tuberosa*. The seed osmopriming technique hydrates the internal tissues, increasing the respiratory activity and thus activating the germination metabolism. Furthermore, salicylic acid can act in the biosynthesis of gibberellic acid and enzymes that degrade reserves, inducing a reduction in the synthesis of abscisic acid and resulting in greater hormonal balance, thus favoring seed germination (LIU et al., 2019).

The emergence speed index was higher in seedlings subjected to soaking with SA, with the highest values of 0.126, 0.190, and 0.161 at the concentrations of 80, 120, and 160 mg L^{-1}, respectively at 32 hours of soaking (Figure 1B). In seeds subjected to the levels of 0 and 40 mg L^{-1}, the variable showed the highest value of 0.11 at the soaking time of 15 hours. Seed conditioning for 32 hours increased the seedling emergence speed of *S. tuberosa*, which can be explained by the longer exposure of seeds to the solution at a high concentration of salicylic acid (160 mg L^{-1}) since it is involved in enzymes that act in germination, possibly regulating the uniformity, speed, and final germination of seeds (NÓBREGA et al., 2021).

The summary of the analysis of variance (Table 2) revealed a significant effect of the interaction between the factors only on the CO_2 assimilation rate (A) of *S. tuberosa* plants, and significant effect of salicylic acid concentrations on stomatal conductance (gs), transpiration (E), CO_2 assimilation rate (A), internal CO_2 concentration (Ci), water use efficiency (WUE) and instantaneous carboxylation efficiency (iCE). The soaking times only affected WUE and iCE.

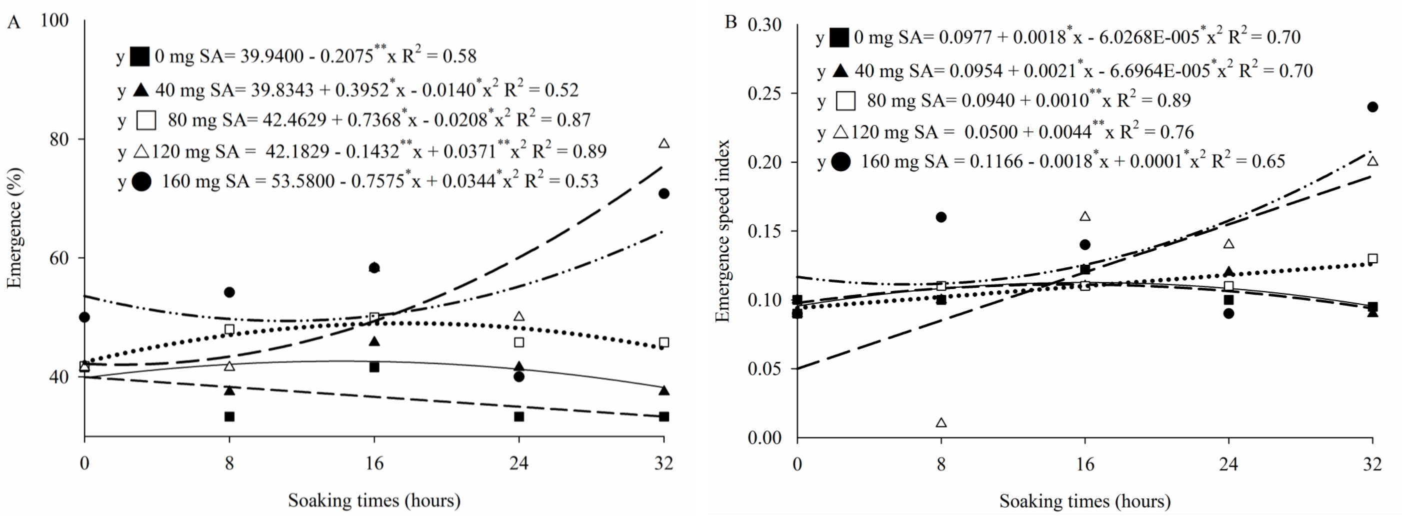

Figure 1. Emergence percentage – E% (A) and emergence speed index - ESI (B) of *Spondias tuberosa* Arruda seedlings subjected to concentrations of salicylic acid and soaking times.

Table 2. Summary of the analysis of variance for stomatal conductance (gs), transpiration (E), internal CO_2 concentration (Ci), CO_2 assimilation rate (A), water use efficiency (WUE), and instantaneous carboxylation efficiency (iCE) of *Spondias tuberosa* Arruda seedlings subjected to concentrations of salicylic acid and soaking times 60 days after sowing.

Source of variation	DF	Mean Square					
		gs	E	Ci	A	WUE	iCE
Soaking time (T)	4	0.00034^{ns}	0.083^{ns}	212.23^{ns}	4.53**	2.43**	0.00015**
Linear regression	1	0.000338^{ns}	0.133^{ns}	499.28^{ns}	12.68**	7.87*	0.00042**
Quadratic regression	1	0.00006^{ns}	0.044^{ns}	41.65^{ns}	0.031^{ns}	1.21^{ns}	0.00009^{ns}
Salicylic acid (SA)	4	0.00060**	0.219**	2515.2**	6.13**	1.90**	0.00017**
Linear regression	1	0.00011^{ns}	0.00045^{ns}	6006.0**	2.52*	3.10*	0.00042**
Quadratic regression	1	0.0021**	0.718**	2944.5**	21.81**	2.79*	0.00022**
Interaction (T x SA)	16	0.00020^{ns}	0.072^{ns}	513.06^{ns}	1.87**	0.372^{ns}	0.000030^{ns}
Blocks	3	0.00008^{ns}	0.095^{ns}	779.7^{ns}	1.30^{ns}	0.416^{ns}	0.000072^{ns}
Residual	72	0.00014	0.046	325.9	0.66	4.485	0.000026
CV (%)	-	27.0	23.6	7.71	20.5	15.82	31.1
Shapiro Wilk		0.9594	0.9318	0.9484	0.8249	0.9910	0.9283

*significant at 0.05 probability level; ** significant at 0.01 probability level; ^{ns} not significant.

Stomatal conductance (gs) showed values that are best described by the quadratic model, with the highest value (0.051 mol of H_2O m^{-2} s^{-1}) being achieved at the salicylic acid concentration of 89 mg L^{-1}, followed by *gs* reductions with the increase in concentration (Figure 2A). The occurrence of this effect indicates that salicylic acid is involved in the regulation of biochemical and physiological plant processes, acting in stomatal opening and closure (CHEN et al., 2022) and thus influencing the *gs* increase observed in plants of *S. tuberosa*.

The transpiration (E) and internal CO_2 concentration (Ci) behaved similar to *gs*, with the values being described by the quadratic model and the highest increments being achieved at the salicylic acid concentrations of 80 and 47 mg L^{-1}, with 1.015 and 243.01 mmol of H_2O m^{-2} s^{-1}, respectively (Figures 2B and 2C). This behavior reflects the increase of stomatal opening, implying higher transpiration and CO_2 absorption by the plant. Furthermore, this Ci increase could be associated with an increase in the enzymatic activity associated with CO_2 absorption at the chloroplast level, improving the carbon-use efficiency by plants (CHEN et al., 2022).

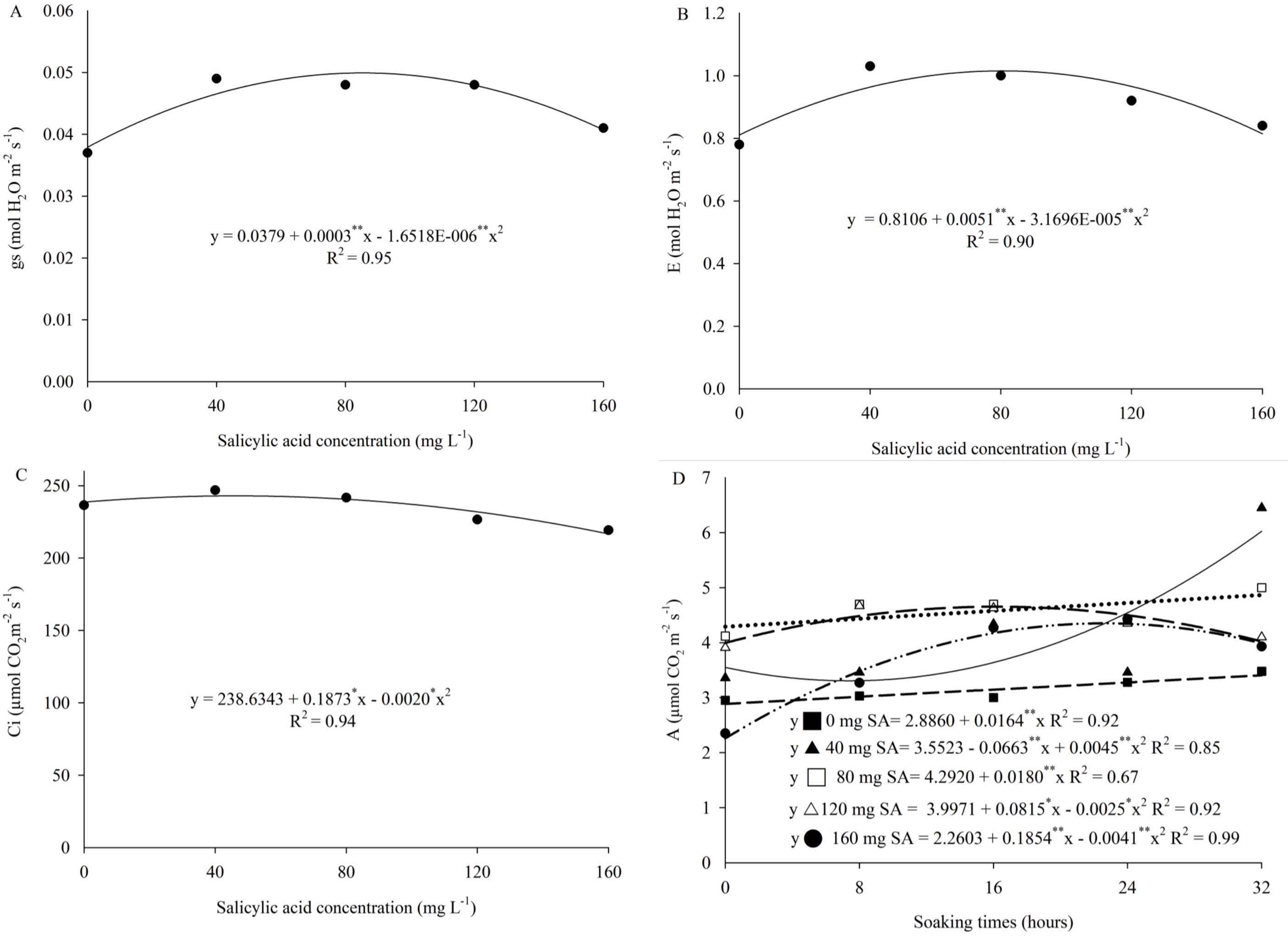

Figure 2. Stomatal conductance – gs (A), transpiration - E (B), internal CO_2 concentration – Ci (C), and CO_2 assimilation rate - A (D) of *Spondias tuberosa* Arruda seedlings subjected to salicylic acid concentrations and soaking times 60 days after sowing.

In the CO_2 assimilation rate (A), the highest values occurred in plants subjected to the salicylic acid concentrations of 40 and 80 mg L^{-1} and 32 hours of soaking, with increases of 5.83 and 4.86 µmol m^{-2} m^{-1}, respectively (Figure 2D). At the concentrations of 0, 120, and 160 mg L^{-1}, the maximum values obtained (3.41, 4.66, and 4.35 µmol CO_2 m^{-2} m^{-1}) occurred at 32, 16, and 23 hours of soaking. This behavior observed in *S. tuberosa* occurs due to the increase in stomatal opening and CO_2 absorption induced by salicylic acid. Furthermore, salicylic acid increases the antioxidant defense capacity of plants, activating the enzymes catalase, peroxidase, and superoxide dismutase, reducing lipid peroxidation and increasing membrane integrity, thus ensuring the production of photoassimilates and protecting the photosynthetic apparatus, finally increasing photosynthesis (AIRES et al., 2022).

With regard to the water use efficiency (WUE), the maximum value estimated for the effect of salicylic acid occurred at the concentration of 105 mg L^{-1}, equal to 4.638 [(µmol CO_2 m^{-2} s^{-1}) (mol H_2O m^{-2} s^{-1})$^{-1}$] (Figure 3A). With regard to the seed soaking time, the time of 32 hours promoted the highest WUE, 4.803 [(µmol CO_2 m^{-2} s^{-1}) (mol H_2O m^{-2} s^{-1})$^{-1}$] (Figure 3B). This effect indicates that salicylic acid improved water utilization by the plant, since the higher the WUE, the greater the plant's capacity to fix CO_2 per water molecule transpired, which was also observed by Barros et al. (2019) in cotton (*Gossypium hirsutum* L.) and by Silva et al. (2021) in soursop (*Annona muricata* L.).

With regard to the instantaneous carboxylation efficiency (iCE), the values were described by the quadratic model for the concentration of salicylic acid and the linear model for the seed soaking times, with the estimated values of 0.0455 and 0.0158 [(µmol CO_2 m^{-2} s^{-1}) (µmol CO_2 m^{-1} s^{-1}) $^{-1}$] at the concentration of 86 mg L^{-1} and after 32 hours of seed soaking, respectively (Figures 3C and 3D). The occurrence of this effect suggests a higher capacity to translocate assimilated carbon and membrane regulation, increasing the carboxylation efficiency (AIRES et al., 2022).

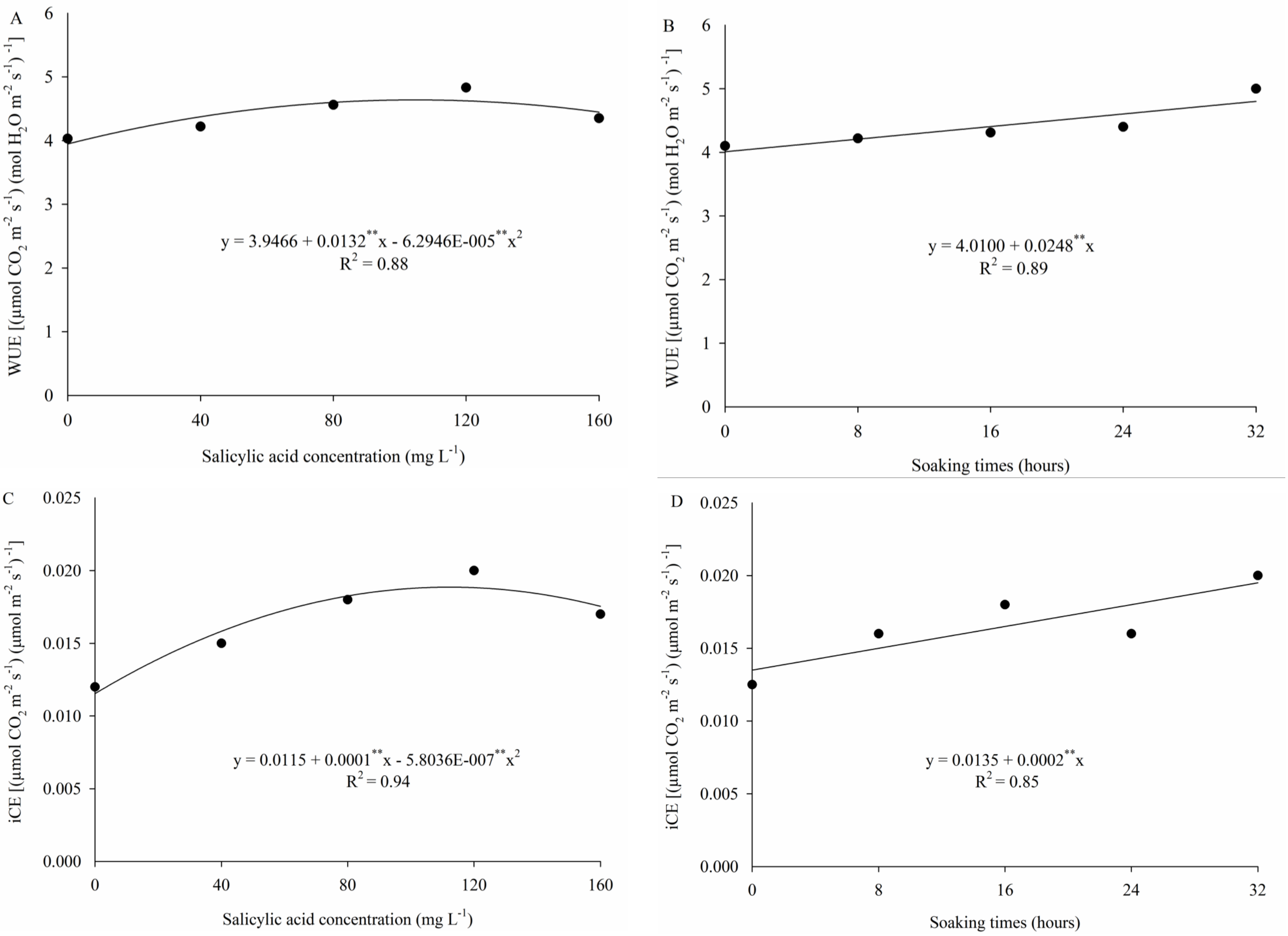

Figure 3. Water use efficiency – WUE (A and B) and instantaneous carboxylation efficiency – iCE (C and D) of *Spondias tuberosa* Arruda seedlings subjected to concentrations of salicylic acid and seed soaking times 60 days after sowing.

According to the summary of the analysis of variance (Table 3), it is observed that the interaction between the salicylic acid concentrations and soaking times significantly affected ($P \leq 0.01$) the variables of plant height (PH), number of leaves (NL), root dry matter (RDM), stem dry matter (SDM), leaf dry matter (LDM), and total dry matter (TDM) of *S. tuberosa* plants 60 days after sowing. Stem diameter was significantly affected only by the soaking times.

Plant height showed values that were described by the quadratic model, with the highest value (16.84 cm) occurring in plants subjected to the salicylic acid concentration of 40 mg L^{-1} and the soaking time of 32 hours, showing a superiority of 9.56% compared to the plants subjected to concentration of 0 mg L^{-1}, which showed the highest increase (15.23 cm) after 14 hours of seed soaking (Figure 4A). At concentrations of 80 and 160 mg L^{-1} of salicylic acid, the decreasing linear model fitted the values, with the highest increases (16.54 and 14.8 cm) occurring in plants formed from seeds not subjected to soaking (0 hours). On the other hand, the values of the concentration of 120 mg L^{-1} were not described by any regression model, with mean of 14.84 cm.

For the number of leaves, the highest value occurred in plants treated with 0 and 40 mg L^{-1} of salicylic acid, with the highest increases (9 leaves) occurring in plants subjected to seed soaking for 16 and 0 hours, respectively. On the other hand, the number of leaves at the concentrations of 120 and 160 mg L^{-1} was nine, obtained in plants originated from seeds soaked for 32 hours (Figure 4B). For stem diameter, there was an individual effect of the soaking periods, with the data being described by the quadratic model, the highest of which was 2.88 mm in plants produced from seeds soaked for 4 hours (Figure 4C).

This beneficial effect promoted by salicylic acid on the initial growth of *S. tuberosa* seedlings indicates that seed conditioning stimulates the emergence of radicles, as salicylic acid acts in the regulation of plant growth as part of cell division processes (NÓBREGA et al., 2018; SILVA et al., 2022). This demonstrates that seed conditioning with salicylic acid is a viable strategy to increase plant growth as this component is involved in physiological and biochemical processes (ZAID, MOHAMMAD; SIDDIQUE, 2022).

Table 3. Summary of the analysis of variance for plant height (PH), stem diameter (SD), number of leaves (NL), root dry matter (RDM), stem dry matter (SDM), leaf dry matter (LDM), and total dry matter (TDM) of *Spondias tuberosa* Arruda seedlings subjected to salicylic acid concentrations and soaking times 60 days after sowing.

Source of variation	DF	Mean Square						
		PH	SD	NL	RDM	SDM	LDM	TDM
Soaking time (T)	4	22.4^{**}	0.59^{**}	0.22^{ns}	0.14^{**}	0.010^{**}	0.011^{**}	0.29^{**}
Linear regression	1	17.9^{**}	0.29^{ns}	0.005^{ns}	0.01^{*}	0.004^{*}	0.014^{*}	0.005^{ns}
Quadratic regression	1	1.83^{ns}	0.001^{ns}	0.31^{ns}	0.05^{**}	0.007^{**}	0.0003^{ns}	0.11^{**}
Salicylic acid (SA)	4	17.9^{**}	0.34^{ns}	3.92^{**}	0.09^{**}	0.010^{**}	0.010^{*}	0.22^{**}
Linear regression	1	2.48^{ns}	12.5^{**}	0.08^{ns}	0.03^{**}	0.019^{**}	0.005^{ns}	0.15^{**}
Quadratic regression	1	63.2^{**}	2.77^{**}	12.9^{**}	0.02^{**}	0.011^{**}	0.032^{**}	0.73^{**}
Interaction (T x SA)	16	13.3^{**}	0.16^{ns}	5.21^{**}	0.06^{**}	0.009^{**}	0.010^{**}	0.19^{**}
Blocks	3	8.25^{ns}	0.40^{ns}	0.92^{ns}	0.005^{ns}	0.0008^{ns}	0.0003^{ns}	0.004^{ns}
Residual	72	2.35	0.14	0.76	0.003	0.0007	0.003	0.007
CV (%)		10.4	13.6	10.4	14.6	19.7	25.7	11.4
Shapiro Wilk		0.9218	0.9358	0.8810	0.9591	0.9563	0.9109	0.9152

*significant at 0.05 probability level; ** significant at 0.01 probability level; ^{ns} not significant.

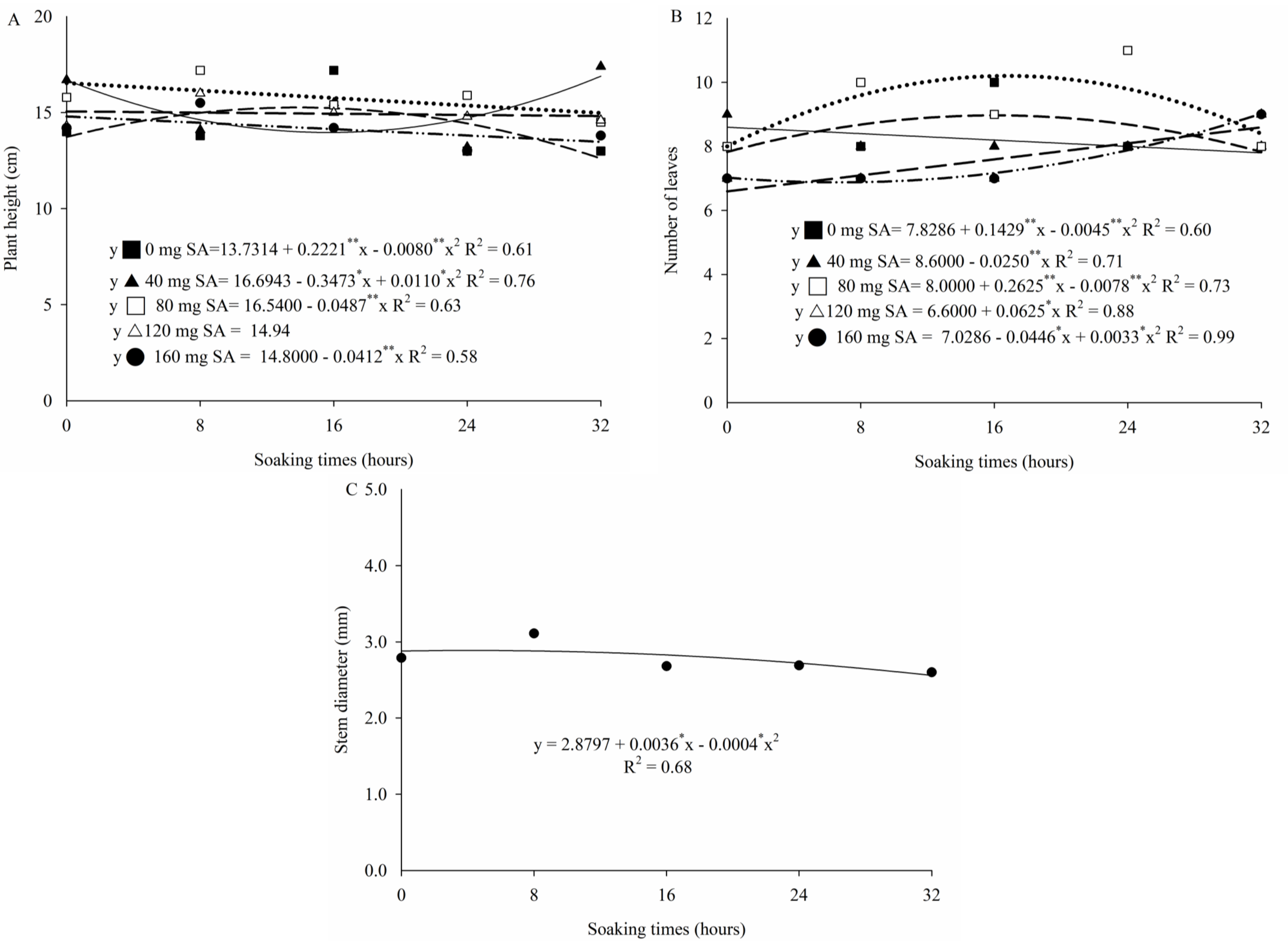

Figure 4. Plant height (A), number of leaves (B), and stem diameter (C) of *Spondias tuberosa* Arruda seedlings subjected to concentrations of salicylic acid and soaking times 60 days after sowing.

Root dry matter values were best described by the quadratic model for all concentrations, with the highest increases occurring at the salicylic acid concentrations of 120 and 160 mg L^{-1}, achieving 0.62 and 0.58 g in seeds soaked for 32 hours (Figure 5A). At the concentrations of 40 and 80 mg L^{-1}, the highest value (0.49 g) was obtained at 0 and 20 hours, respectively. On the other hand, the concentration of 0 mg L^{-1} led to the highest root dry matter value, which was 0.44 g after 6 hours of soaking. When comparing the maximum value obtained, there were increases of 10.2% at the concentrations of 40 and 80 mg L^{-1} and 29 and 24.1% at the concentrations of 120 and 160 mg L^{-1} compared to the control (0 mg L^{-1}), indicating that seed conditioning with salicylic acid stimulates root growth and favors the accumulation of root dry matter. Salicylic acid assists in the formation of adventitious roots due to its action in reducing the activity of the enzyme that regulates the homeostasis of indoleacetic acid (IAA), as observed by Dong et al. (2020) in cucumber.

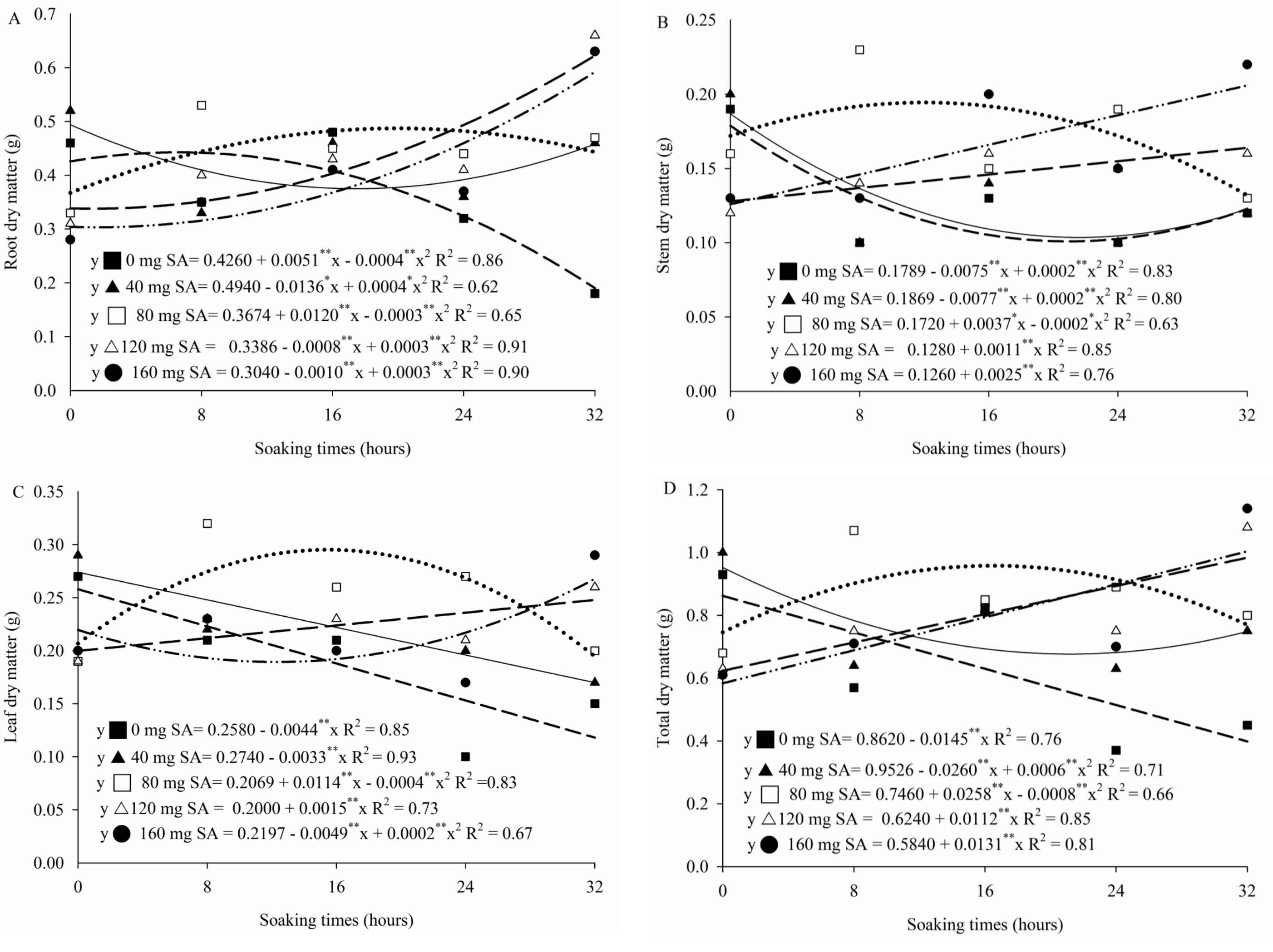

Figure 5. Dry phytomass of roots (A), stem (B), leaves (C), and total dry matter (D) of *Spondias tuberosa* Arruda seedlings subjected to concentrations of salicylic acid and soaking times 60 days after sowing.

With regard to the stem dry matter (Figure 5B), the application of the salicylic acid concentrations of 40, 80, and 160 mg L^{-1} promoted the highest values, with 0.18, 0.19, and 0.20 g at the soaking times of 0, 9, and 32 hours, respectively. At the concentrations of 0 and 120 mg L^{-1}, the highest increases (0.17 and 0.16 g) were obtained at 0 and 32 hours, respectively, which indicates the beneficial effect of salicylic acid on cell division and expansion, as observed by Oliveira et al. (2023) in guava seedlings (*Psidium guajava* L.) under saline conditions, with salicylic acid stimulating cell activity and increasing the stem biomass.

The leaf dry matter showed the highest increases in plants produced with seeds treated with 80 and 40 mg L^{-1} of salicylic acid, achieving the values of 0.29 and 0.27 g at the soaking times of 14 and 0 hours, respectively (Figure 5C). When the seeds were subjected to the salicylic acid concentrations of 120 and 160 mg L^{-1}, the highest increases (0.24 and 0.26 g) were obtained with the soaking period of 32 hours. On the other hand, the control (0 mg L^{-1}) led to the value of 0.25 g in plants formed from seeds with time 0 of soaking. This effect is associated with a higher leaf production and the development of a larger leaf area. Salicylic acid favors the photosynthetic activity, stimulating the production of photosynthetic pigments and photoassimilates, thus also favoring shoot growth (SILVA et al., 2023).

For the total dry matter, the highest increases occurred at the concentrations of 120 and 160 mg L^{-1}, with the values of 0.98 and 1.0 g, both obtained with 32 hours of soaking (Figure 5D). At the concentrations of 40 and 80 mg L^{-1}, the highest value obtained was 0.95 g, at 0 and 16 hours, respectively. In the control, the maximum value obtained was 0.86 g in plants whose seeds were not soaked (time 0). When comparing the values obtained with the control, there were increases of 9.5% at the concentrations of 40 and 80 mg L^{-1}, and of 12.2 and 14% at the concentrations of 120 and 160 mg L^{-1}, respectively. The beneficial effect of seed conditioning at the highest levels of salicylic acid indicates an improvement in plant growth through the stimulation of phytomass production. Allied to the fact that salicylic acid acts in physiological processes such as photosynthesis, increasing the production of photoassimilates, this component favors gains in phytomass production (SARACHO et al., 2021).

CONCLUSIONS

Conditioning the seeds for 32 hours at a concentration of 120 mg L^{-1} proved to be effective in promoting the overcoming of dormancy, being a viable alternative to standardize the germination and initial growth of *S. tuberosa* seedlings.

REFERENCES

AIRES, E. S. et al. Foliar application of salicylic acid intensifies antioxidant system and photosynthetic efficiency in tomato plants. **Bragantia**, 81: e1522, 2022.

BARROS, T. C. et al. Silicon and salicylic acid in the physiology and yield of cotton. **Journal of Plant Nutrition**, 42: 458-465, 2019.

BRASIL. Ministério da Integração Nacional. **Resolução nº 107/2017**. Disponível em:<https://www.gov.br/sudene/pt-br/centrais-de-conteudo/resolucao1072017-pdf>. Acesso em: 15 abr. 2018.

CHEN, G. et al. Effects of exogenous salicylic acid and abscisic acid on growth, photosynthesis and antioxidant system of rice. **Chilean Journal of Agricultural Research**, 82: 21-32, 2022.

CORDEIRO, B. M. P. C. et al. Anticryptococcal activity of hexane extract from 509 *Spondias tuberosa* Arruda and associated cellular events. **Journal de Mycologie Medicale**, 30: 100965, 2020.

DONG, C. J. et al. Salicylic acid regulates adventitious root formation via competitive inhibition of the auxin conjugation enzyme $CsGH_{3.5}$ in cucumber hypocotyls. **Planta**, 252: 1-15, 2020.

FERREIRA, D. F. Sisvar: a computer analysis system to fixed effects split plot type designs. **Revista Brasileira de Biometria**, 37: 529-535, 2019.

GÓES, N. H. et al. Ácido salicílico e o potencial de emergência de plântulas de leucena. **Revista do Instituto Florestal**, 34: 7-19, 2022.

LIU, J. et al. Exogenous salicylic acid improves the germination of *Limonium bicolor* seeds under salt stress. **Plant Signaling & Behavior**, 14: e1644595, 2019.

MAGUIRE, J. D. Speed of germination-aid in selection and evaluation for seedling emergence vigor. **Crop Science**, 2: 176-177, 1962.

MATOS, F. S. et al. Effect of gibberellin on growth and development of *Spondias tuberosa* seedlings. **Revista Caatinga**, 33: 1124-1130, 2020.

NÓBREGA, J. S. et al. Tratamentos pré-germinativos e desenvolvimento inicial de plântulas de umbuzeiro. In: SEABRA, G. (Ed.). **Educação Ambiental & Biogeografia**. Ituiutaba, MG: Barlavento, 2016. v.1, cap. 23 p. 253-265.

NÓBREGA, J. S. et al. Effect of salicylic acid on the physiological quality of salt-stressed *Cucumis melo* seeds**. Journal of Experimental Agriculture International**, 23: 1-10, 2018.

NÓBREGA, J. S. et al. Salicylic acid as a saline stress attenuator in the physiological quality of *Erythrina velutina* seeds. **Revista Árvore**, 45: e4521, 2021.

OLIVEIRA, C. J. A. et al. Saline stress and salicylic acid on growth and quality of guava 'Paluma' seedlings. **Revista Brasileira de Ciências Agrárias**, 18: e1991, 2023

PEREIRA, F. R. A. et al. Crescimento inicial de mudas de *Spondia tuberosa* irrigadas com água salina. **Revista JRG de Estudos Acadêmicos**, 6: 494-513, 2023.

SARACHO, L. C. S. et al. Salicylic acid increases growth of *Schinus terebinthifolia* seedlings subjected to varying irrigation intervals. **Floresta e Ambiente**, 28: e20200004, 2021.

SILVA, A. A. R. et al. Salicylic acid relieves the effect of saline stress on soursop morphysiology. **Ciência e Agrotecnologia**, 45: e007021, 2021.

SILVA, T. I. et al. Basil (*Ocimum basilicum*) growth under saline stress and salicylic acid. **Indian Journal of Traditional Knowledge**, 21: 443-449, 2022.

SILVA, T. I. et al. Ecophysiology and growth of basil (*Ocimum basilicum*) under saline stress and salicylic acid. **Acta Biológica Colombiana**, 28: 128-134, 2023.

SOUZA, A. D. V. et al. Superação de dormência de sementes de umbuzeiro em função da idade e diferentes concentrações de ácido giberélico. **Research, Society and Development**, 11: e1811931339, 2022.

ZAID, A.; MOHAMMAD, F.; SIDDIQUE, K. H. M. Salicylic acid priming regulates stomatal conductance, trichome density and improves cadmium stress tolerance in *Mentha arvensis* L. **Frontiers in Plant Science**, 13: 895427, 2022.