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Short communication

Germination of *Avicennia schaueriana* and *Laguncularia racemosa* from two physiographic types of mangrove forest

Viviane F. Cavalcanti [a,*], Antônio Carlos S. de Andrade [a], Mário Luiz G. Soares [b]

[a] *Laboratório de Sementes, Instituto de Pesquisas Jardim Botânico do Rio de Janeiro (JBRJ), Pacheco Leão, 915, CEP 22460-030 Rio de Janeiro, RJ, Brazil*

[b] *Universidade do Estado do Rio de Janeiro (UERJ), São Francisco Xavier, 524, 4° andar, CEP 20550-013 Rio de Janeiro, RJ, Brazil*

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Abstract

In order to evaluate intra-specific differences related to the source of propagules this study conducted biometric and germination analyses considering two physiograpic types of mangrove forests: fringe and shrub-basin. These forests represent the extremities of a marked gradient of tidal flooding frequency, going from river to salt flat. Germination tests were performed in control conditions (distilled water and without addition of water) and in solutions of NaCl or polyethylene glycol 6000 which are equivalent to water potentials (Ψ) of −0.4, −0.8, −1.6 and −2.4 MPa. The parameters analyzed were germinability (G; %) and mean germination time index (t, days), which report viability and vigour of propagules, respectively. Results revealed significant intra-specific differences: smaller propagules (differences were about 1.7 and 1.2 mm in length for *Avicennia schaueriana* and *Laguncularia racemosa*, respectively) with lower viability (differences were from 16.2 to 43.2% in G for both species) from shrub-basin in relation to fringe forest and stronger vigour (reductions in t were from 1 to 3 days) of the *L. racemosa* propagules from the shrubs. We also noted that water potentials promoted by NaCl were more severe for *A. schaueriana* than for *L. racemosa* and that the opposite effect occurred with PEG.

Keywords: Mangrove; Salt flat; NaCl; Polyethylene glycol

1. Introduction

Mangroves are characteristic intertidal plant formations found on sheltered tropical and subtropical coastlines and exhibit a tremendous range of form (Saenger, 2003). A convenient system of mangrove communities' classification was proposed by Lugo and Snedaker (1974). They recognized six physiographic types of forests based on the relationship between the structure and complexity of the forest and a characteristic set of environmental variables, such as soil type and depth, soil salinity range and tidal flooding rates. Such variables regulate and maintain the primary productivity levels, respiration, nutrient cycles and organic matter exchange with adjacent ecosystems (Schaeffer-Novelli et al., 1990). Later, Schaeffer-Novelli et al. (2000) recognized two main physiographic types of mangrove forests: (1) fringe forests, which are located at the edges of water bodies (estuaries, bays and rivers) and are frequently flooded by tides, thus, yielding greater substratum overwash, organic matter exportation and structural development; (2) basin forests, which occur in inland areas that are less frequently flooded by tides and where an accumulation of organic matter and anoxia can be found in the sediment. In regions where precipitation is lower than evapotranspiration rates, or rainfall is strongly seasonal, the formation of uncolonized salt flats behind basin forests is common. Under such stressful conditions trees abutting salt flats have stunted growth and basin forests assume a shrub physiognomy (Saenger, 2003).

Taking into consideration that the environmental factors that affect the fixation of carbon and the acquisition of nutrients by the plants also affect reproduction (Chiarello and Gulmon, 1991) and considering the structural development as an integrate variable of the physiological mangrove plant response to these environmental factors (Lin and Sternberg, 1992a; Jimenez, 1999; Lovelock and Feller, 2003; Lovelock et al., 2006), this study aims to answer the question: are propagules from fringe and shrub-basin forest similar in biometrics, viability and vigour? For this purpose the intra-specific

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[*] Corresponding author. Tel.: +55 2132042089.
E-mail address: vi.oliveira@gmail.com (V.F. Cavalcanti).

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differences in biometrics and germination of propagules were evaluated for *Avicennia schaueriana* and *Laguncularia racemosa* species.

2. Materials and methods

2.1. Study site

The study site is located in Sepetiba Bay (23°00′S–23°05′S and 43°30′W–43°35′W), southeast Brazil. It comprises a system made up of mangrove forests and associated salt flats, where evaporation exceeds precipitation during several months of the year (Köppen's climate is Aw—tropical, dry, and humid, with dry winters). In this system, a decreasing frequency of tidal floodings from water bodies (bay, river or creeks) to salt flats and an associated increasing levels of physico-chemical stress results in a markedly structural zonation pattern of mangrove vegetation (Pellegrini et al., 2000).

For the collection of propagules we considered a transect perpendicular to Piracão river, where the fringe mangrove stand is more structurally developed (mean height of 7.6 m and diameter at breast height of 9.3 cm) than the basin one, that has a shrub physiognomy at the interface with a salt flat. The shrubs do not exceed 1.5 m in height and show numerous trunks with ramifications from the base (Pellegrini et al., 2000). Significant differences in tidal flooding frequency (718 and 649 inundations year^{-1}, at fringe and shrub-basin forest, respectively), intersticial water salinity (26 and 38 ppt, at fringe and shrub-basin forest, respectively) and total nitrogen concentration (1.3 and 0.4 g kg^{-1}, at fringe and shrub-basin forest, respectively) have been presented as explanations for physiognomies observed (Pellegrini et al., 2000; Corrêa, 2003).

2.2. Collection of propagules

From January to March 2004, mature propagules of each species (*A. schaueriana* and *L. racemosa*) were collected from fringe (20 trees) and shrub-basin (20 trees) forests. The criterion for propagule maturity was the fall after a collector's slight touch.

After collection, propagules were immediately transported in impermeable polyethylene packing to the lab. The ill-formed and damaged propagules were discarded from the sample. After selection, they were stored at 20 °C for approximately 15 h.

2.3. Biometrics and germination of propagules

The propagules were evaluated according to variables such as dry mass (g), water content (% fresh weight), length and width (mm). To compute the water content and dry mass, propagules ($n = 10 \times 10$) were oven-dried at 70 °C for 48 h. A digital caliper was used to measure the length and width of 100 propagules.

Germinative behavior of the propagules was analyzed according to the following control conditions: (1) 30 mL of distilled water ($\Psi = 0$ MPa) and (2) without any addition of water or solution, that means only with the ''intrinsic water content'' (IWC) of propagules. The experiments performed in controlled temperature (30 ± 2 °C) with a photoperiod of 8 h. Before being sowed in ''gerbox'' containers, the propagules had been washed in tap water, then in 1% sodium hypochlorite for 1 min and finally in distilled water to prevent the proliferation of fungi. *A. schaueriana* propagules were sowed without the pericarp, which detached itself from the fruit after some minutes in contact with water during the process of asepsis. In each control condition, for each physiographic type we used four repetitions of 40 propagules of *L. racemosa*, and seven repetitions of 20 propagules of *A. schaueriana*.

The germination was evaluated daily, for 15 days, using the protusion of the hypocotyls-radicle axes ($\geq$3 mm) with positive geotropism as germination criteria for *L. racemosa* and the protusion of primary roots and positive geotropism of hypocotyl for *A. schaueriana*.

The variables used to estimate the viability and vigour of the propagules were, respectively: (1) germinability (G; %), given by the proportion between the number of germinated propagules and the total number of propagules set for germination, and (2) mean germination time index (t; days), computed as weighed mean of the germination times, using as the weighs the number of propagules which were germinated in the daily intervals, as it has been suggested by Santana and Ranal (2004).

To compare the physiographic types by means of biometric measurements, dry mass, water content and germination (G and t) in the control conditions (0 MPa and IWC), we ran a t-test, according to the number and variance of samples (Zar, 1996).

2.4. Influence of different water availability in the germination of propagules

Fringe and shrub-basin propagules were directly set to absorb and germinate in water potentials (Ψ) of −0.4, −0.8, −1.6 and −2.4 MPa, generated by polyethylene glycol 6000 (PEG) or NaCl solutions. PEG and NaCl solutions were prepared based on the Michel and Kaufmann (1973) and the Van't Hoff equations (Salisbury and Ross, 1992), respectively. NaCl and PEG have been used extensively as osmotica, but the former is absorbed by seeds and may result in toxic effects in some cases (Bradford, 1995). The relationship between the water potential of NaCl solutions and salinity was measured by a refractometer: −0.4, −0.8, −1.6 and −2.4 MPa corresponded to 5.0, 10.0, 20.0 and 29.0 ppt.

To guarantee the water potential, we changed the volume (30 mL) of the solution in each repetition every 5 days. Also, to avoid evaporation, recipients were protected by polyethylene plastic bags. We did not use any kind of substratum.

The experiments were outlined randomly, according to the factorial system and to the number of repetitions previously described (0 MPa and IWC), for each water potential and physiographic type. The same is true for the research conditions and procedures, as well as for the variables that were analyzed.

Statistical analyses of results were conducted by software Statistica 6.0. The Tukey-test ($p < 0.05$) was run for a comparison between means, whenever there was significance according to F ($p < 0.05$). Likewise, the individual effects of the water potentials and of the two physiographic types (fringe and shrub-basin), as well as the effects among the factors were evaluated. Treatments that did not show germination in the experimental unity were not included in the statistical analysis.

3. Results

3.1. Biometrics and germination of propagules

Results show a significant difference in the biometric characteristics, dry mass, and water content of the propagules collected from fringe and shrub-basin forests (Table 1). In general the propagules from fringe were larger for both species; however, they differed with respect to dry mass and water content. The *L. racemosa* propagules from fringe forest showed higher dry mass and lower water content. The *A. schaueriana* propagules showed no significant difference in dry mass; however, the water content of those from shrub-basin forest was lower.

With regard to germination of both species under 0 MPa and IWC conditions, propagules from fringe forest showed a significant higher G than those from shrub-basin forest. The IWC results are probably not related to the propagules' water content, because although the *A. schaueriana* propagules from the fringe have showed higher water content, the opposite occurred for *L. racemosa*. Likewise, the dry mass would not explain the differences observed. Only length agreed with the higher G of the fringe propagules (Table 1).

Table 1
Biometrics, dry mass (10 propagules), water content and germination, in 0 MPa and intrinsic water content (IWC), of *Avicennia schaueriana* and *Laguncularia racemosa* propagules from two forest types (fringe and shrub-basin)

A. schaueriana	Shrub-basin	Fringe	d.f.	*t*	*p*
Length (mm)	29.6 ± 2.4	31.3 ± 2.8	198	4.513	**
Width (mm)	18.8 ± 1.5	19.6 ± 1.9	188	3.472	**
Dry mass (g)	13.1 ± 1.0	13.0 ± 1.5	18	0.3052	ns
Water content (% f.w.)	59.5 ± 0.9	75.4 ± 2.1	11	28.939	**
Germination in 0 MPa					
G (%)	17.1 ± 19.1	48.6 ± 11.1	12	3.764	**
t (days)	5.4 ± 1.4	5.3 ± 0.3	4	0.122	ns
Germination in IWC					
G (%)	3.6 ± 3.8	35.7 ± 7.3	12	10.324	**
t (days)	7.9 ± 1.8	6.5 ± 0.7	3	0.219	ns

L. racemosa	Shrub-basin	Fringe	d.f.	*t*	*p*
Length (mm)	15.3 ± 1.1	16.5 ± 1.1	198	8.114	**
Width (mm)	9.0 ± 1.2	8.7 ± 0.7	161	1.985	*
Dry mass (g)	1.1 ± 0.1	1.5 ± 0.1	18	12.561	**
Water content (% f.w.)	66.0 ± 0.9	60.0 ± 0.6	18	18.756	**
Germination in 0 MPa					
G (%)	53.1 ± 8.3	93.1 ± 3.8	6	8.819	**
t (days)	5.9 ± 0.6	6.3 ± 0.5	6	1.033	ns
Germination in IWC					
G (%)	9.4 ± 5.2	46.9 ± 10.5	6	6.420	**
t (days)	9.5 ± 1.7	12.3 ± 0.4	3	3.249	*

G: germinabilility; t: mean germination time index. d.f.: degrees of freedom; t: t-test values; p: statistical significance level. $^{*}p < 0.05$; $^{**}p < 0.01$.

The t index indicated an intra-specific difference only for the *L. racemosa* propagules that had been submitted to IWC treatment. Results show greater speed (lower t values) in the germination process of propagules from the shrub-basin forest (Table 1).

3.2. Influence of different levels of water availability in the germination of propagules

The *A. schaueriana* propagules from distinct forests showed differences in G (Table 2). Under PEG water potentials, propagules from the fringe forest showed higher G when compared to those from shrub-basin forest (Table 3). The same result holds true for the −0.4 MPa NaCl (Table 3).

Variations in t for *A. schaueriana* propagules were promoted by water potentials (PEG or NaCl) only (Table 2). There was a significant delay in the germination process according to the increase in NaCl concentration, until the point (−1.6 MPa) where the process could not be concluded (G equal to zero) (Table 3). The deterioration of the propagules by the end of the experiment with NaCl indicated a toxic effect of the saline solution on them, as opposed to germination in PEG solutions of up to −2.4 MPa (Table 3).

Table 2
Analysis of variance results of the water potentials (Ψ) (simulated with PEG and NaCl) and forest types (fringe and shrub-basin) effects on germination of *A. schaueriana* and *L. racemosa* propagules

	d.f.	MS	
		G (%)	*t* (days)
A. schaueriana			
PEG			
Forest type	1	26144.64*	2.773$^{\mathrm{ns}}$
Ψ (PEG)	3	63.10$^{\mathrm{ns}}$	4.293*
Forest type × Ψ	3	238.69$^{\mathrm{ns}}$	3.511$^{\mathrm{ns}}$
Residuals	48/37	87.95	1.375
NaCl			
Forest type	1	14858.04*	6.738$^{\mathrm{ns}}$
Ψ (NaCl)	1	1808.04*	39.003*
Forest type × Ψ	1	2322.32*	0.006$^{\mathrm{ns}}$
Residuals	24/23	233.04	1.701

	d.f.	MS	
		G (%)	*t* (days)
L. racemosa			
PEG			
Forest type	1	544.49*	8.87*
Ψ (PEG)	3	1689.26*	0.17$^{\mathrm{ns}}$
Forest type × Ψ	3	507.49*	2.97*
Residuals	24	72.33	0.84
NaCl			
Forest type	1	395.50*	1.978*
Ψ (NaCl)	3	47.60$^{\mathrm{ns}}$	4.755*
Forest type × Ψ	3	224.70*	1.547*
Residuals	24	24.90	0.348

Differences are presented by "*" when they were significant ($p < 0.05$) and by ns when they were not. G: germinabilility; t: mean germination time index.

Table 3
Effects of PEG and NaCl water potentials (*Ψ*) and forest types (fringe and shrub-basin) on germination of *A. schaueriana* propagules

Ψ (MPa)	*G* (%)		*Ψ* (MPa)	*t* (days)		
	Shrub-basin	Fringe		Shrub-basin	Fringe	$\bar{X}$
PEG						
−0.4	2.9 ± 3.9	47.1 ± 16.8	−0.4	5.7 ± 1.5	6.5 ± 1.0	6.3 ± 1.2 ab
−0.8	2.1 ± 2.7	54.3 ± 12.4	−0.8	7.0 ± 0.0	5.5 ± 0.4	5.9 ± 0.8 b
−1.6	7.1 ± 6.4	39.3 ± 8.9	−1.6	7.1 ± 1.6	7.2 ± 1.2	7.2 ± 1.3 ab
−2.4	4.3 ± 3.5	48.6 ± 10.7	−2.4	8.2 ± 2.1	6.6 ± 0.6	7.3 ± 1.6 a
$\bar{X}^*$	4.1 ± 4.5	47.3 ± 13.0				

Ψ (MPa)	*G* (%)		*Ψ* (MPa)	*t* (days)		
	Shrub-basin	Fringe		Shrub-basin	Fringe	$\bar{X}$
NaCl						
-0.4^*	42.1 ± 22.9 a	76.4 ± 14.6 a	−0.4	6.0 ± 1.1	5.0 ± 0.5	5.5 ± 1.0 b
-0.8^{ns}	14.3 ± 10.2 b	12.1 ± 9.5 b	−0.8	8.4 ± 2.1	7.4 ± 1.0	8.0 ± 1.6 a
−1.6	0.0	0.7 ± 1.9	−1.6			
−2.4	0.0	0.0	−2.4			

Values are means ± S.D. Differences between propagules from different forest type (rows) are presented by "*" when they were significant ($p < 0.05$) and by ns when they were not. Significant differences ($p < 0.05$) among water potentials (lines in NaCl or PEG table division) are presented by different letters. *G*: germinabilility; *t*: mean germination time index.

For the *L. racemosa* propagules, both G and t responded to the interaction of factors such as origin of the propagules (physiographic type) and water potentials in PEG or NaCl solutions (Table 2).

In treatments that yielded significant differences between forests (−0.4 MPa PEG or NaCl and −0.8 MPa PEG) (Table 4), *L. racemosa* propagules from the shrub-basin forest showed lower *G* when compared to those from fringe forest. However, the germination process of propagules from fringe forests was slower (higher *t* values) for −0.4 MPa PEG, −0.8 MPa PEG and NaCl and −2.4 MPa NaCl (Table 4). Also, only the *L. racemosa* propagules from fringe forests showed a reduction in *G* following the reduction in the water availability simulated by PEG solutions. It is worth highlighting that *G* values in all NaCl water potentials were higher than in PEG water potentials, whatever the source of propagules (Table 4).

Table 4
Effects of PEG and NaCl water potentials (*Ψ*) and forest types (fringe and shrub-basin) on germination of *L. racemosa* propagules

Ψ (MPa)	*G* (%)		*Ψ* (MPa)	*t* (days)	
	Shrub-basin	Fringe		Shrub-basin	Fringe
PEG					
-0.4^*	45.0 ± 15.1 a	79.4 ± 6.9 a	-0.4^*	6.7 ± 0.8	8.9 ± 0.6
-0.8^*	49.4 ± 7.5 a	65.6 ± 6.3 ab	-0.8^*	6.9 ± 0.8	8.8 ± 0.7
-1.6^{ns}	48.1 ± 11.3 a	60.0 ± 7.4 b	-1.6^{ns}	7.3 ± 0.8	7.8 ± 0.5
-2.4^{ns}	45.0 ± 4.1 a	40.6 ± 3.2 c	-2.4^{ns}	8.0 ± 1.7	7.6 ± 0.9

Ψ (MPa)	*G* (%)		*Ψ* (MPa)	*t* (days)	
	Shrub-basin	Fringe		Shrub-basin	Fringe
NaCl					
-0.4^*	76.3 ± 4.8	97.5 ± 2.0	-0.4^{ns}	7.3 ± 0.6 ab	6.8 ± 0.4 b
-0.8^{ns}	86.9 ± 2.4	95.6 ± 4.3	-0.8^*	6.1 ± 0.6 b	7.2 ± 0.7 b
-1.6^{ns}	90.6 ± 4.3	91.3 ± 6.3	-1.6^{ns}	7.7 ± 1.0 a	7.8 ± 0.2 b
-2.4^{ns}	88.1 ± 3.2	85.6 ± 9.0	-2.4^*	7.7 ± 0.6 a	9.1 ± 0.3 a

Values are means ± S.D. Differences between propagules from different forest type (rows) are presented by "*" when were significative ($p < 0.05$) and by ns when were not. Significant differences ($p < 0.05$) among water potentials (lines in NaCl or PEG table division) are presented by different letters. *G*: germinability; *t*: mean germination time index.

4. Discussion

Differences between propagules produced by mangrove trees growing under distinct environmental conditions were addressed by Jimenez (1985), Lin and Sternberg (1992b), Smith and Snedaker (1995) and Elster (1997).

Reductions in size like we observed in *A. schaueriana* and *L. racemosa* propagules from shrub-basin forest was found in *Rhizophora mangle* propagules from hypersaline areas of Florida (Jimenez, 1985; Lin and Sternberg, 1992b). Even though the influence of size on germination has not been evaluated in the present study, it is possible that biometric differences have interfered with higher germinability of propagules from the fringe forest. This relation was observed by Khan et al. (2000), which revealed that the tolerance of halophytic seeds of *Atriplex triangularis* increases during germination, according to the size of the seeds. Under water stress, *Glycine max* (Meckel et al., 1984) and *Erodium brachycarpum* (Stamp, 1990) are examples of non-mangrove plants that produced seeds with reduced dry mass, like propagules from shrubs of *L. racemosa*.

Propagules of *A. schaueriana* and *L. racemosa* possess enough water content to promote germination, without addition of water (IWC). This characteristic may be relevant for low tides, mainly in areas where the frequency of tidal flooding is low. Also, the *L. racemosa* propagules from shrub-basin forest showed higher water content in comparison to those from fringe forest. This fact may be due to the mechanism that increases succulence for maintenance of osmotic balance in the member. Such a mechanism was described for leaves of this species and is common in hypersaline areas (Biebl and Kinzel, 1965; Medina, 1999). On the other hand, *A. schaueriana* has a mechanism for salt excretion, by means of specific leaf glands. Consequently, this species does not show a noticeable increase in succulence (Medina, 1999).

For both species we verified lower *G* values for propagules from the shrub-basin forest either in the controls (0 MPa and IWC) and in less severe conditions of water potentials (*A. schaueriana*: all PEG water potentials and −0.4 MPa NaCl; *L. racemosa*: −0.4 and −0.8 MPa PEG). This indicates their lower viability when they were compared to those from fringe forest. According to Smith and Snedaker (1995), differences in physiologic quality are more noticeably under low levels of stress. On the other hand, high levels of stress may be more effective than any other compensatory process that is associated with internal factors of the propagules, which makes them more similar among themselves and in their capacity to compete and survive. Thus, under more severe conditions of water potentials (*A. schaueriana*: −0.8, −1.6 and −2.4 MPa NaCl; *L. racemosa*: −1.6 and −2.4 MPa PEG) results showed no significant intra-specific differences. These results agree with Elster (1997) that verified high rates of mortality among propagules from *A. germinans* and *L. racemosa* trees growing under severe saline stress in Colombia.

As noted for *A. schaueriana* propagules, increases in salinity lead to a reduction and/or delay in germination of both halophyte and glycophyte seeds (Ungar, 1995) and the toxic effects of NaCl solutions are frequently found (Bradford, 1995). However, an experiment with artificial seawater reveals the *Avicennia* sp. propagules germinated without damage under salinities up to 35 ppt (Ye et al., 2005). According to Karzel (1926) NaCl solutions are extremely toxic to cellular plasma, while the toxic effect is alleviated by different salts in solution.

With regard to *L. racemosa* germination, our study reveals an unexpected more severe effect of PEG than NaCl solutions and an important aspect considering the mean germination time index. Despite the reduction in viability, the results indicate greater vigour (lower *t*) for the propagules from the shrub-basin forest. In the same way, Smith and Snedaker (1995) found that *R. mangle* seedlings from a high salinity site (36 ppt) exhibited faster growth than those from a low salinity site (5 ppt) when both had been treated with low salinity water (5 ppt). The authors concluded that probably there is a strengthening of the propagules from high salinity site, which may be related to the enzymatic activation and metabolic reactions common in halophytes under salt conditions (Cowan and Rose, 1991).

The results allowed us to conclude that there are intra-specific differences in biometrics, viability and vigour of the propagules from fringe and shrub-basin forests. As stated by Chiarello and Gulmon (1991), these differences are probably related to environmental conditions to which the mother tree was submitted to during maturation of propagules. Thus, severe conditions such as low frequency of tidal inundation, high salinity and low nitrogen concentration that together were presented as explanations for the stunted growth of the shrubs at Sepetiba bay (Pellegrini, 2000; Corrêa, 2003) may have indirectly promoted the reduction in size and viability of propagules from both species studied. However, the greater vigour of the *L. racemosa* propagules from shrub-basin forest indicates a positively aspect of those environmental conditions.

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