

Effects of the Arid Environment on the Reproductive Phenology of three Mangrove Tree Species in the Southern Baja California Peninsula, México

Reymundo Domínguez-Cadena^{1,2} · Rafael Riosmena-Rodríguez¹ · José Luis León-de la Luz²

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Abstract The flower and hypocotyl development of three mangrove tree species of the southern Baja California Peninsula were analyzed comparing four microtopographic flooding conditions and in relation to five environmental factors (relative humidity, rainfall ambient temperature, solar radiation and speed). The main objective was to evaluate the effects of an arid environment on the reproductive effort of the mangrove species present. Between 1 June to 5 November 2006 weekly measurements were made at three sites in La Paz Bay. During each visit we recorded the development of buds to flowers (anthesis) and eventually, if there was successful pollination, to propagule (viviparous embryo or hypocotyl) until they detached from the mother tree some time later. This was done for three selected stems of one tree per species for the four microtopographic conditions. Our results indicate that nearly 25 % of all flowering plants passed to hypocotyls and relative humidity and rainfall were the variables most associated with flower development. We found that humidity triggers the reproductive effort of mangroves species in this

arid region and that the microhabitat coast (BO) is the best condition for the development of flowers to hypocotyls for all three species on the eastern Baja California Peninsula. Because of exposure to the sea the trees are not water stressed at these sites.

Keywords *Rhizophora* · mangrove phenology · mangrove microtopography

Abbreviations

BO	Border condition
CH	Channel condition
PF	Permanent flood condition
IT	Temporary flood condition
RH	Relative humidity
Pp	Rainfall
S	Solar radiation
T	Ambient temperature
V	Wind velocity

✉ Rafael Riosmena-Rodríguez
riosmena@uabcs.mx

Reymundo Domínguez-Cadena
rdoming04@cibnor.mx

José Luis León-de la Luz
jlleon04@cibnor.mx

¹ Programa de Investigación en Botánica Marina, Departamento de Biología, Universidad Autónoma de Baja California Sur, Km. 5.5 carr. al sur, 23080 La Paz, BCS, Mexico

² Programa de Medioambiente y Conservación, Centro de Investigaciones Biológicas del Noroeste, S.C., Mar Bermejo No. 195, Col. Playa Palo de Santa Rita, 23090 La Paz, BCS, Mexico

Introduction

Mangrove forests are distributed in tropical coastal areas of the world (Macnae 1968; Chapman 1976; Lugo and Medina 2014) with some species having their geographical limits in the subtropical zone (Ramírez-García and Lot-Helgueras 1994; Dawes et al. 1999; Pacheco-Ruiz et al. 2006; Glenn et al. 2006; Zomlefer et al. 2006). Mangrove species in tropical areas are known to reproduce in the rainy season as shown by Jiménez (1988) for Costa Rica, Fernandes (1999) for the Brazilian coast and by Tyagi (2004) in northern Australia. Studies in southern Mexico by Tovilla (1998) and Tovilla and Orihuela (2002) have shown that heavy rainfall influences

flower and germination development in *Rhizophora mangle*, even though these species produce reproductive structures all year round they have a peak in the summer rainy season. In other species, such as *Avicennia marina*, reproduction is also restricted to the wet period (Duke 1990) and flower production varies on a latitudinal gradient (Clarke and Myerscough 1991).

On the arid Baja California Peninsula, where the limit of mangrove distribution ends on the Pacific coast of North America (Pacheco-Ruiz et al. 2006), the low and erratic freshwater availability has been proposed as the factor that determines the growth of all species of mangroves (López-Portillo and Ezcurra 2002; Rico-Gray and Palacios-Ríos 1996; Pacheco-Ruiz et al. 2006). Domínguez-Cadena et al. (2011) suggested that in southeastern Baja California Peninsula mangrove density and distribution are related to four microtopographic conditions.

This study investigates whether flower development and propagules (hypocotyls, living embryos) are significantly influenced by the four microtopographic conditions in the southeastern coastline of the Baja California Peninsula. We expected variations in response to water availability, salinity and seasonal changes related to the rainfall regime. We wanted to identify the environmental factor best correlated as a trigger of the phenological reproductive expression. Our null hypothesis is homogeneous flower and propagule production is produced at all microtopographic conditions with the alternative hypothesis that microtopographical conditions influence reproduction of reproduction.

Material and Methods

Study Site

The study area is located in La Paz Bay, on the southeastern coastline of the arid Baja California Peninsula (Fig. 1). García (1981) reported from the nearest meteorological station (La Paz) an arid and hot climate type BWh. The two main seasons are summer (June to October) and winter. Irregular rainfall occurs from August to September with at least 90 % of the total rainfall in the year occurring at this time. The winter occurs from December to February and is characterized by anticyclone northern cool winds. Three sites were selected, based on their accessibility and the presence of all the four microtopographic conditions (Fig. 1): Balandra Lagoon (Site 1, 24.3189°N; -110.3182°W), Pichilingue (Site 2, 24.2495°N, -110.3128°W) and Zacatecas Estuary (Site 3, 24.1741°N, -110.4348°W).

Sampling Design

Sampling started on June 1st, 2006 and ended October 27th, 2006 at the four mangrove microtopographic conditions as

described by Domínguez-Cadena et al. (2011). These are BO (border) condition, which is the most open site to the sea, influenced by tide levels and long waves. The CH (channel) condition occurs in a tract exposed to the daily tide regime, but the influence of the waves is barely significant. The permanent flood condition (PF) is located above the channel where the ground remains saturated, sea water flux is slow and it is a place of accumulation of organic matter and fine sediments. The temporary flood condition (TF) is the inland zone of the mangrove, only reached by the high water tides of winter. As a result salt accumulation and intermittent supply of marine water are common characteristics of the soil. In the eastern Peninsula, the mangroves are, as a rule, associated with an arroyo drainage, which after heavy rains supply fresh water and sediments from mountains, being the TF, which is firstly fed by such resources.

For each of the microtopographic conditions, we followed the methods proposed by Dawes et al. (1999), we selected three plots of 5 m × 5 m and in each plot one tree per species. For each selected tree, we followed the development of buds to flowers (anthesis) and eventually, if there was successful pollination, to propagule (viviparous embryo or hypocotyl) until they detached from the mother tree some time later. On each tree, we selected three permanent branch positions (low, medium, high) for weekly observations. Finally, for each species, we determined the successful rate of flower development to hypocotyls. The results were processed as follows: % of change = $\frac{\sum \text{numbers of total propagules}}{\sum \text{numbers of flowers}} \times 100$.

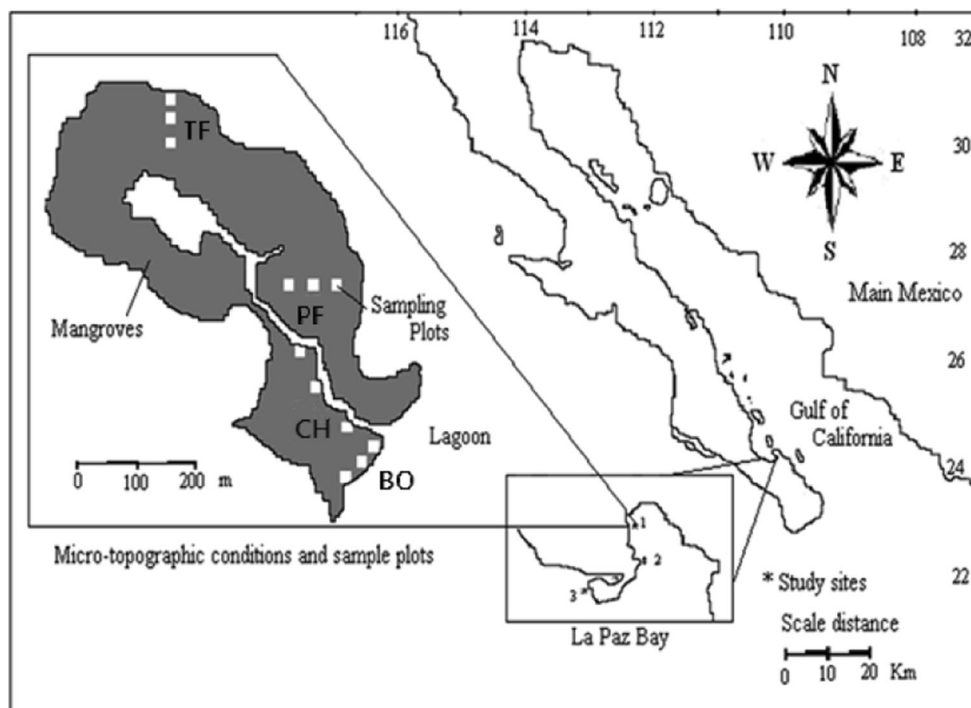
Environmental data were obtained from the automatized meteorological station located at the of Centro de Investigaciones Biológicas del Noroeste (CIBNOR) facility at the south of La Paz Bay. Data included relative humidity of the air (*RH*, mm), rainfall (*Pp*, mm), solar radiation (*S*, Watts/m²), ambient temperature (*T*, °C) and wind velocity (*V*, m/s).

Analysis

We used the Mann-Whitney (U-test) non-parametric test to compare the number of phenological events registered weekly per species for each microtopographical condition, since with this kind of data it is not acceptable to estimate the population from means and variance. In this test, phenological registrations of each species were ranked when compared between microtopographical conditions, null hypothesis (*H₀*) considered that paired registrations between topographical conditions have the same constant level (Zar 1984).

Additionally, multiple correlation tests (*r*) were performed (CSS 1991) to determine how the continuing appearance of flowers and hypocotyls were correlated with *RH*, *Pp*, *S*, *T*, and *V*. Each variable value corresponded to an average of the seven previous days at 15 h when compared with the weekly phenological register.

Fig. 1 Study site, La Paz Bay, Baja California Sur, Mexico where mangrove measurements were made at (1) Balandra, (2) Pichilingue, and (3) Zacatecas sites. The figure also illustrates for Site 1 the position of the three microtopographic conditions BO (border), CH (channel), PF (permanent flood condition) and IT (temporary flood condition)



Results

We have found the best rate of change from flower to propagule (Table 1) for *A. germinans* in BO condition (11.8 %). *Languncularia racemosa* had similar rates in CH (25.4 %) and BO (22.4 %) and *R. mangle* the best rate was in BO

Table 1 Percentage of successful development from flowers to hypocotyls for each species in the four microtopographic conditions at La Paz Bay mangroves during 2006

Species	Flowers No.	Hypocotyls No.	Pass %
<i>A. germinans</i>	3314	390	11.8
<i>L. racemosa</i>	5865	1315	22.4
<i>R. mangle</i>	688	194	28.2
∑ Border (BO)	9867	1899	19.2
<i>A. germinans</i>	NP	NP	NP
<i>L. racemosa</i>	5596	1425	25.4
<i>R. mangle</i>	527	59	11.2
∑ Channel (CH)	6123	1484	24.2
<i>A. germinans</i>	NP	NP	NP
<i>L. racemosa</i>	NP	NP	NP
<i>R. mangle</i>	506	70	13.8
∑ Permanent flood (PF)	506	70	13.8
<i>A. germinans</i>	5501	104	1.9
<i>L. racemosa</i>	NP	NP	NP
<i>R. mangle</i>	NP	NP	NP
∑ Temporary flood (IT)	5501	104	1.9

NP No reproductive trees

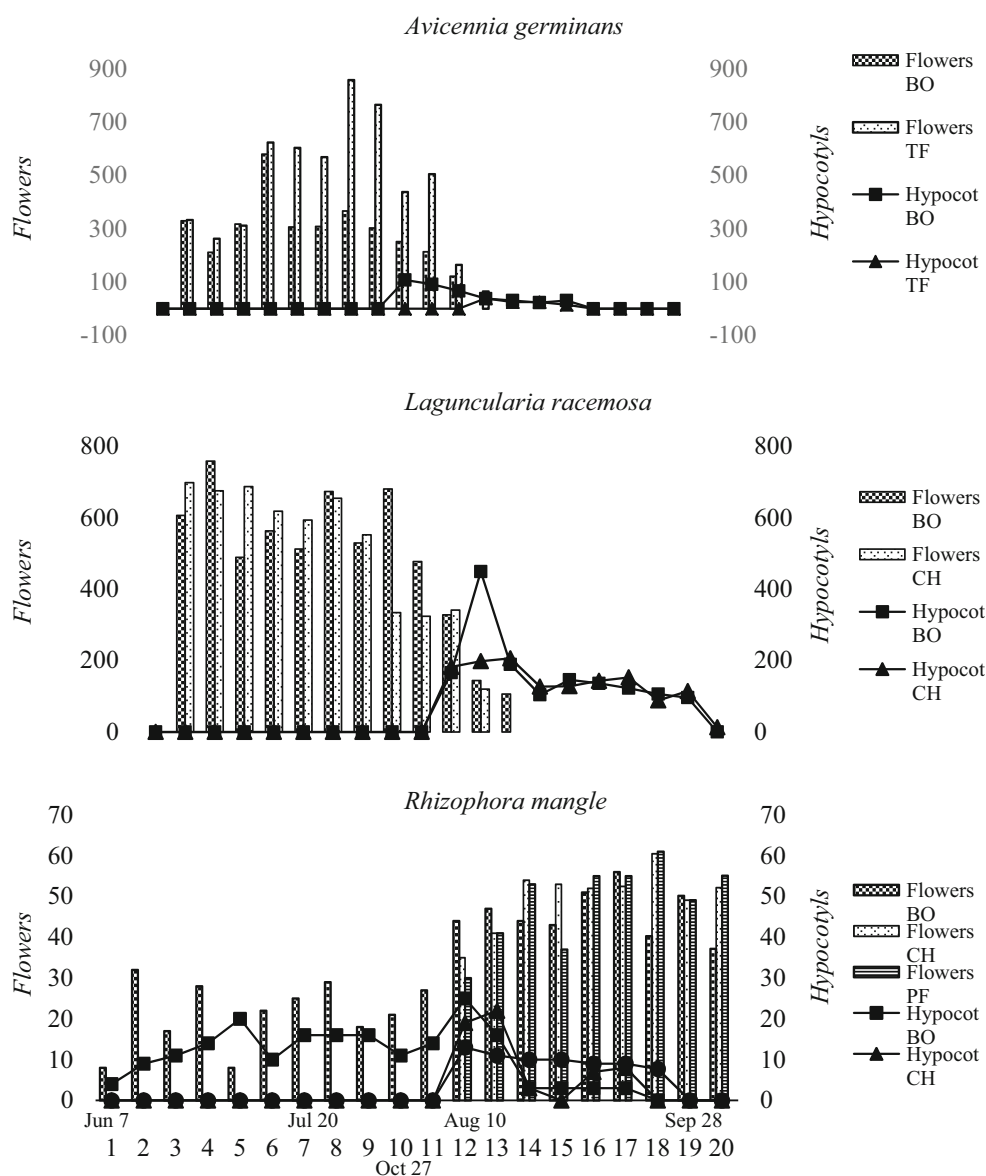
(28.2 %) compared with CH and PF conditions (11.2 %, 13.8 %).

We have found that phenology of flowers and propagules production progress simultaneously for all species (Fig. 2) in similar microtopographical conditions. However, *R. mangle* were present and reproductive in three microtopographic conditions. While, *A. germinans* and *L. racemosa* were present in two microconditions, no species occupied all four conditions. *Avicennia germinans* is present mainly in TF (the inland and driest mangrove sector) and incidentally in BO; *L. racemosa* is in CH (water flux continuous) and BO, and *R. mangle* is present mainly in BO, and in a lesser degree in CH and PF.

Our results suggest that *L. racemosa* and *A. germinans* had a similar flowering pattern (Fig. 2) since both already had flowers at the start of our observations, reach the same level of occurrences, and stop at the same time. *R. mangle* displayed an odd pattern since the flowering constantly increased in the BO condition producing at the same time a number of hypocotyls. However, in CH and PF flowering started in early August and trees set propagules quickly until early October. In all three conditions, the flowering period extended beyond the period of observations, we ceased our observations since the flowers produced during these last weeks (19–20) were systematically aborted.

Comparisons of flowers and propagules between the microtopographic conditions have shown the null hypothesis H_0 is that the number of registers (the phenological events) is of the same level at $\alpha = 0.05$ when comparing these between two given microtopographical conditions. In the case of *A. germinans* we compared the registers for two conditions

Fig. 2 Number of flowers and hypocotyls recorded for *A. germinans*, *L. racemosa*, and *R. mangle* species on 20 weekly sampling dates in BO, CH, PF and IT microtopographic conditions



where they appeared paired (BO-TF), for *L. racemosa* BO-CH, for *R. mangle* BO-CH, BO-PF, and CH-PF. Regarding flowering of *R. mangle*, between BO and CH the H_0 is rejected but in the propagules is accepted ($U_{10, 21} = 185$; $U_{15, 17} = 43$, respectively); between flowering of BO and PF the H_0 is rejected ($U_{10, 21} = 175.5$) but accepted between the hypocotyls output ($U_{7, 17} = 63$); and finally, between CH and PF the H_0 of flowering is accepted ($U_{10, 10} = 54$), and also between hypocotyls production ($U_{5, 7} = 20.5$). Our results showed not significant differences in the flowering of *A. germinans* between BO and TF conditions ($U_{11, 12} = 94$), and also in the propagules generation ($U_{4, 7} = 22$). *L. racemosa* flowering showed no differences between the BO and CH conditions ($U_{11, 12} = 70$), and also in the propagules output ($U_{9, 11} = 54$).

We have found a relationship between reproductive phenology and environmental variables. We calculated the multiple correlations (r) of flowers and hypocotyls for *A. germinans*, *L. racemosa* and *R. mangle* species as dependent variables and environmental data (RH , Pp , S , V , and T) as the independent variables (Table 2).

The model obtained for *A. germinans* (Table 2a) shows a significant level of correlation ($F = 24.06$; $p < 0.05$) for flowers in BO with RH and Pp ; for flowers in TF, the model also shows a good correlation ($F = 23.19$; $p < 0.05$) with also RH and Pp variables. For hypocotyl output, the model did not show a significant value ($F = 1.03$; 1.69 , $p > 0.05$) with any one of the five environmental variables in both conditions.

The models obtained for *L. racemosa* (Table 2b), show a significant level ($F = 31.75$; $p < 0.05$) for correlation of

Table 2 Estimating equations (r), variability explained, and significance level in the models between flowers and hypocotyls registers on environmental variables for *Avicennia germinans* (A), *Laguncularia racemosa* (B) and *Rhizophora mangle* (C)

Variables	Estimating equations	Variability	F	p
(A)				
Flowers BO	$Y = 737.48 - 15.49 * RH + 18.031 * Pp$	73 %	24.06	< 0.05
Flowers TF	$Y = 996.77 - 21.53 * RH + 36.44 * Pp$	70 %	23.19	< 0.05
Hypocot BO	NS	0.5 %	1.03	> 0.05
Hypocot TF	NS	13 %	1.69	> 0.05
(B)				
Flowers BO	$Y = 1286.64 - 26.79 * RH + 29.117 * Pp$	76 %	31.75	< 0.05
Flowers CH	$Y = -512.13 + 36.30 * T - 16.88 * RH + 155.05 * V + 19.32 * Pp$	87 %	34.47	< 0.05
Hypocot BO	NS	27 %	1.94	> 0.05
Hypocot CH	$Y = -1063.11 + 25.17 * T + 8.85 * RH - 6.56 * Pp$	42 %	5.51	< 0.05
(C)				
Flowers BO	$Y = -7.6952 + 1.1194 * RH - 116.525 * Pp$	65 %	16.33	< 0.05
Flowers CH	$Y = -58.6535 + 2.3517 * RH - 288.371 * Pp$	75 %	25.63	< 0.05
Flowers PF	$Y = -52.4499 + 2.1793 * RH - 297.067 * Pp$	67 %	18.62	< 0.05
Hypocot BO	$Y = -55.83 + 2.0607 * T$	27 %	8.31	< 0.05
Hypocot CH	NS	2.7 %	1.10	> 0.05
Hypocot PF	$Y = -74.70 + 1.7476 * T + 0.6093 * RH - 0.4103 * Pp$	46 %	6.40	< 0.05

BO Border, CH Channel, PF Permanent flood, IT Temporary flood., Hypocot Hypocotyls, RH Relative humidity, Pp Rainfall, T Ambient temperature, V Wind velocity, F F value, NS not significant

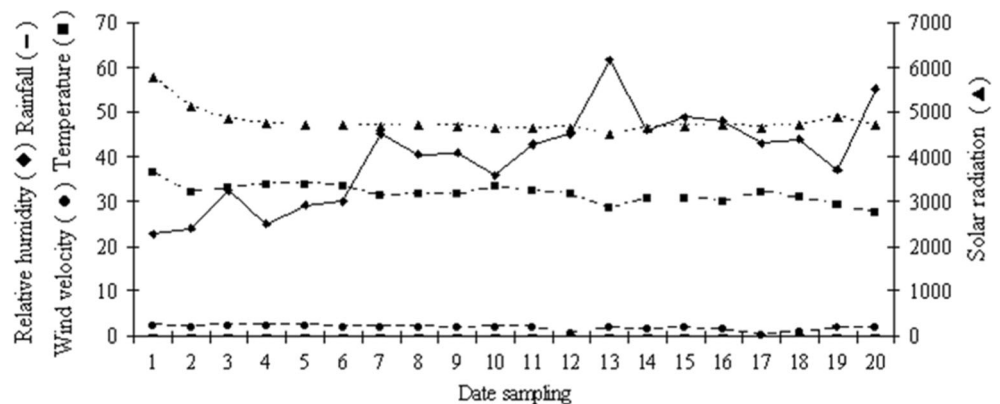
flowers in BO with RH and Pp , as well for CH also shows a high correlation ($F = 34.47$; $p < 0.05$) with T , RH , V , and Pp variables. For hypocotyls in both conditions we found a low correlation ($F = 1.94$, $p < 0.05$; $F = 5.51$, $p < 0.05$).

The models obtained for *R. mangle* flowering show (Table 2c) levels of correlation less reliable than in the former species ($F = 16.33$, $p < 0.05$ to $F = 25.63$, $p < 0.05$), and still lowest in the hypocotyl relationships ($F = 1.10$, $p < 0.05$ to $F = 8.31$, $p < 0.05$), but in the conditions, BO, CH and PF, the RH and Pp are the variables best related.

Discussion and Conclusions

Our results show that the flowering of *A. germinans*, *L. racemosa*, and *R. mangle* on the southeastern Baja California Peninsula, begins in June and July, although those months are the driest. However there was more flowering in August as this is the beginning of the rainy season and also the period when extreme tides occur (CICESE 2006). This allows the plants to recover from the water and salinity stress of spring and early summer. At this time *L. racemosa* and *A. germinans* reach their peak in flowering and *R. mangle* also

Fig. 3 Weekly climatic data from the automatic climatology station of Centro de Investigaciones Biológicas del Noroeste (CIBNOR, S.C.) near the south coast of La Paz Bay



shows an increase (Fig. 2). In Costa Rica, Jiménez (1988) found a close relationship between the recovery of the plant water balance and flowering and hypocotyl peaks for all mangroves. In our sites, *R. mangle* extended the flowering period beyond our study observations indicating that it probably flowers all year as in the Caribbean dry tropical areas. However all flower buds and flowers were aborted from September and thus *R. mangle* only had a relatively short period of setting hypocotyls (Fig. 3).

The best rate of development of flowers to hypocotyls for all three species occurred in the BO conditions where mangrove trees are exposed to the sea. The continuous availability of water ensured that the trees were not water stressed. The above observation is for *A. germinans* which is ecologically dominant in TF where there is ample tidal fluctuations.

Mangroves reach their distribution limits in the Baja California Peninsula, where the arid environmental conditions are a limitation for species and communities of tropical requirements. Thus, the phenological response is an important feature to document and to use to explain the present and future potential distribution of mangroves in the same peninsula in relation to future dynamics of global change and sea level rise. The difference between tropical and arid regions is the occurrence of strong abortion of the propagules due to salt stress in late fall resulting from increased tide level. The parental cost is high for *A. germinans* and *R. mangle* but not for *L. racemosa*, because this species responds faster to humidity and flood-saturated ground (López-Portillo and Ezcurra 2002).

In our study sites, we found that flowering of all three mangrove species had a positive correlation ($p < 0.05$) with relative humidity, an effect that is explained by the arrival of monsoonal environmental conditions in August and September. We note that permanent fresh water of riverine areas is not found in this region as is observed for mangroves in tropical America (Alvarez-Leon 1992; Tovilla and Orihuela 2002; López-Portillo and Ezcurra 2002; Sánchez-Nuñez and Mancera-Pineda 2011). The flower-hypocotyl development found in this study differs with other results from tropical regions. During long periods of rain and humidity in the tropical environment, the rate of hypocotyl development relative to the number of flowers produced is very low (Tovilla and Orihuela 2002) compared with our results.

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