Germination response of palm seeds on a two-way thermogradient plate[1]

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ABSTRACT

Palm trees are propagated almost exclusively by seeds and each species germinates under a certain temperature range. In this sense, the two-way thermogradient plate may be used to determine temperature limits for germination and seed response to temperature. The objective was to define the alternating temperature regime promoting higher and faster seed germination of *Carpentaria acuminata* and *Phoenix canariensis* palms using a two-way thermogradient plate. This equipment allowed 64 combinations of alternating and constant temperatures, ranging from 6.97 to 36.42 ºC for *C. acuminata*, and 7.96 to 35.94 ºC for *P. canariensis*. Seeds were sown in Petri dishes (25 x 9 cm) containing 1% water agar. Linear regressions were estimated to determine cardinal temperatures. After 50 days, non-germinated seeds were transferred from the two-way thermogradient plate to a germination chamber at 30 °C. The temperature regime promoting highest seed germination percentage of *C. acuminata* was 30.45/33.00 °C (day/night), with minimum, optimum, and maximum temperatures of 9.13, 28.53, and 36.33 °C, respectively. For seed germination of *P. canariensis*, the most appropriate temperature regime was 29.77/17.93 °C (day/night), with minimum, optimum, and maximum temperatures of 9.53, 28.03, and 35.43 °C, respectively.

Keywords: Arecaceae; cardinal temperatures; *Carpentaria acuminata*; palm propagation; *Phoenix canariensis*; temperature sensitivity.

INTRODUCTION

Palms belong to the Family Arecaceae that comprises more than 3,500 species from more than 240 genera, spread throughout the world, mainly in the tropical regions of Asia, Indonesia, the Pacific Islands, and the Americas (Lorenzi *et al.*, 2004). According to Uhl & Dransfield (1987), palms are distributed in virtually all tropical and subtropical regions, not occurring in desert or semi-desert areas, except when there is water near the surface, forming oases, with only few species occurring in temperate zones.

The carpentaria palm [*Carpentaria acuminata* (H. Wendl. & Drude) Becc.] originates from banks of rivers and streams in flooded forests of Northern Australia, while the Canary Island date palm (*Phoenix canariensis* Hort. ex Chabaud) comes from coastal areas of open vegetation on stony and dry terrains of the Canary Islands (Lorenzi *et al.*, 2010). Although exotic, both species are widely used in Brazilian landscaping (Batista *et al.*, 2016).

The propagation of palm trees is done, almost exclusive-

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ly, by seeds. However, germination is generally considered slow, uneven, and often low, with great variation along that process which is influenced by several factors, such as seed maturation degree, pericarp presence or absence, period between harvest and sowing, environmental temperature, and substrate (Broschat, 1994; Pivetta *et al.*, 2007; Viana *et al.*, 2016).

Among all, temperature is a critical environmental factor that regulates seed dormancy overcome and induces germination (Baskin & Baskin, 2014; El-Keblawy, 2017). Its effect at germination time affects the rate of water uptake by seeds and may alter, among others, germination percentage, speed, and uniformity (Bewley & Black, 1996; Carvalho & Nakagawa, 2000; Castro & Hilhorst, 2004). Therefore, there is a characteristic thermal range for each species, so values below or above minimum and maximum cardinal temperatures may turn seed germination impossible (Carvalho & Nakagawa, 2000). Moreover, within such range, the temperature also acts on the necessary time to reach maximum germination (Bewley & Black, 1985).

Seeds of certain species show better germinative behavior when submitted to temperature alternation corresponding to natural fluctuations found in the environment, with lower night and higher day temperatures; however, there are also species which seed germination is favored when submitted to constant temperatures (Copeland & McDonald, 1995; Salomão *et al.*, 1995; Lima *et al.*, 1997). Palm seeds usually germinate under a certain temperature range that may be defined by their place of origin, so the ultimate establishment of this amplitude is fundamental to define the possible geographic distribution of each species. Luz *et al.* (2008), for instance, indicate the temperature range of 25 to 30 °C for seed germination of *Dypsis decaryi*, while Wen (2019) recommends 20 to 30 °C for *Archontophoenix alexandrae* germination. Furthermore, Lorenzi *et al.* (2004) and Broschat (1994) suggest the ideal temperatures of 24 to 28 °C and 30 to 35 °C, respectively, for seed germination of several palm species.

In this sense, the two-way thermogradient plate, which is a bi-directional incubator, may generate data to determine the temperature limits for seed germination of many species; furthermore, it may be used for the development of germination temperature threshold models to assess the sensitivity of germination response to temperature (Manger, 1999).

The objective of this work was to define the alternating temperature regime promoting higher and faster seed germination of *Carpentaria acuminata* and *Phoenix canariensis* palms using a two-way thermogradient plate.

MATERIAL AND METHODS

The work was carried out at the Seed Conservation Department of the Millennium Seed Bank, Wakehurst, belonging to the Royal Botanic Gardens, Kew, and located in Ardingly, Sussex, UK. Seeds were taken from pulped fruits of carpentaria palm and Canary Island date palm obtained from a commercial company located in London, UK. Water content of the seed lots and embryos were 18.13 ± 1.7% and 19.12 ± 2.1%, respectively, for carpentaria palm, and 10.32 ± 1.3% and 18.24 ± 2.9%, respectively, for Canary Island date palm, determined by the oven method at 103 °C for 17 hours (ISTA, 2017).

The germination test was conducted according to the Millennium Seed Bank methodology. Therefore, seeds were washed in a 2% sodium hypochlorite solution for 10 minutes in gentle manual shaking, then washed three times in distilled water, and sown in Petri dishes (25 x 9 cm) containing 1% water agar. There were 20 seeds per Petri dish for each temperature on the two-way thermogradient plate, and 64 temperature combinations for each species.

The Petri dishes were placed on the two-way thermogradient plate in an 8 x 8 factorial scheme. The two-way thermogradient plate was set with two temperature gradients that could vary from 4 to 40 °C. The equipment then ranged from 6.97 to 36.42 ºC for Carpentaria palm, and from 7.96 to 35.94 ºC for Canary Island date palm, with a 12-hour photoperiod (50-100 W m^{-2} light photon flow) in one direction during the day and over the same temperature range in the perpendicular direction at night. Alternating temperatures (day/night) promoted a constant temperature line from the lower left (always cold) to the upper right corner (always hot) (Figure 1).

The equipment then allowed for seed germination testing under a wide range of constant and alternating temperature regimes over time, resulting in 64 temperature combinations (regimes), with eight constant temperatures and 76 alternating temperatures; each combination represented a temperature regime (alternating and/or constant) with no replication. However, for statistical analysis, the germination results of both palm species were grouped into some temperature combinations to obtain the replicates. Eight groups of eight replicates were used for the analysis, considering temperature extreme and central conditions, with up to 5 °C difference among replications.

(a)

cold/night \ hot/day	7.63	11.45	15.26	19.08	22.88	26.70	30.51	34.33
36.33	36.20/8.55	36.24/12.33	36.27/16.11	36.31/19.89	36.35/23.66	36.39/27.44	36.42/31.22	**35.73**
32.44	32.29/8.29	32.34/12.08	32.38/15.87	32.42/19.66	32.47/23.44	32.51/27.23	**31.78**	32.59/34.81
28.56	28.39/8.02	28.44/11.82	28.48/15.62	28.53/19.42	28.58/23.21	**27.82**	28.67/30.81	28.73/34.61
24.67	24.48/7.76	24.54/11.57	24.59/15.38	24.64/19.19	**23.84**	24.75/26.80	24.80/30.61	24.86/34.42
20.79	20.58/7.50	20.64/11.32	20.69/15.14	**19.86**	20.81/22.77	20.88/26.59	20.93/30.41	20.99/34.23
16.90	16.67/7.24	16.74/11.07	**15.85**	16.87/18.73	16.93/22.55	17.00/26.38	17.06/30.21	17.12/34.04
13.01	12.77/6.97	**11.82**	12.90/14.65	12.98/18.49	13.04/22.32	13.12/26.16	13.18/30.00	13.26/33.84
9.13	**7.78**	8.94/10.56	9.01/14.41	9.09/18.26	9.16/22.10	9.24/25.95	9.31/29.80	9.39/33.65

hot/night

cold/day

(b)

cold/night \ hot/day	8.21	12.09	15.98	19.86	23.74	27.63	31.51	35.40
35.43	34.71/7.96	34.92/11.95	35.12/15.94	35.33/19.93	35.53/23.92	35.74/27.91	35.94/31.90	**36.02**
31.73	31.24/8.03	31.38/11.99	31.52/15.95	31.66/19.91	31.80/23.87	31.94/27.83	**31.93**	32.22/35.75
28.03	27.76/8.10	27.84/12.03	27.91/15.96	27.99/19.89	28.07/23.82	**27.95**	28.22/31.68	28.30/35.61
24.33	24.29/8.17	24.30/12.07	24.31/15.97	24.32/19.87	**24.05**	24.35/27.67	24.36/31.57	24.37/35.47
20.63	20.82/8.24	20.77/12.11	20.71/15.98	**20.23**	20.60/23.71	20.55/27.58	20.49/31.45	20.44/35.32
16.93	17.35/8.31	17.23/12.15	**16.55**	16.99/19.83	16.87/23.66	16.75/27.50	16.63/31.34	16.51/35.18
13.23	13.87/8.38	**12.94**	13.50/16.00	13.32/19.81	13.14/23.61	12.96/27.42	12.77/31.23	12.59/35.04
9.53	**9.42**	10.15/12.22	9.90/16.01	9.65/19.79	9.41/23.56	9.16/27.34	8.91/31.12	8.66/34.90

hot/night

cold/day

Figure 1: Temperature distribution on the two-way thermogradient plate used to evaluate seed germination response of Carpentaria palm (*Carpentaria acuminata*) (a) and Canary Island date palm (*Phoenix canariensis*) (b) along 50 days.

Seed germination was evaluated based on the emission of the germinative bud, every two days, for 50 days. Germination proportion was then plotted to produce a contour map of the 'landscape' germination to highlight optimal conditions for germination. Mean germination percentage was also calculated for the constant temperatures, i.e., from the lower left corner of the plate (always cold) to the upper right corner of the plate (always hot). Germination rate was also evaluated, expressed as 1/T50, which is the time, in days, to reach 50% of the final germination percentage. Linear regressions were estimated using the germination rate values to determine base and maximum temperatures (Tb and Tm, respectively) (Covell *et al.*, 1986). The optimal temperature (To) was estimated by the intersection between these two regression lines (Hardegree, 2006).

In addition, at the end of the experiment, seeds that did not germinate on the two-way thermogradient plate were transferred to a germination chamber type BOD, at 30 °C with a 12-hour photoperiod, to verify whether the extreme temperatures (either low or high) caused any harm in the seeds.

Germination percentage data were transformed into arcsine and submitted to the variance analysis, and means were compared by the Tukey test ($P \leq 0.05$). The Sigma Plot 9.0 (Sigma Plot, 2004) software was used to plot the combination of the germination data with temperature regimes.

RESULTS

Both species germinated under a great temperature range on the two-way thermogradient plate. However, seeds under low temperature regimes did not germinate, i.e., those placed near the lower left corner (always cold), with temperatures close to 7.78 °C for Carpentaria palm (Figure 2) and 9.42 °C for Canary Island date palm (Figure 3).

The main germination range of Carpentaria palm at the alternating temperatures was concentrated between 24 and 34 °C during the day and 10 and 36 °C overnight. At constant temperatures, it occurred mainly between 20 and 36 °C (Figure 2a). Seeds germinated faster under warmer temperatures, especially when it was always warm (on the upper right corner) (Figure 2b).

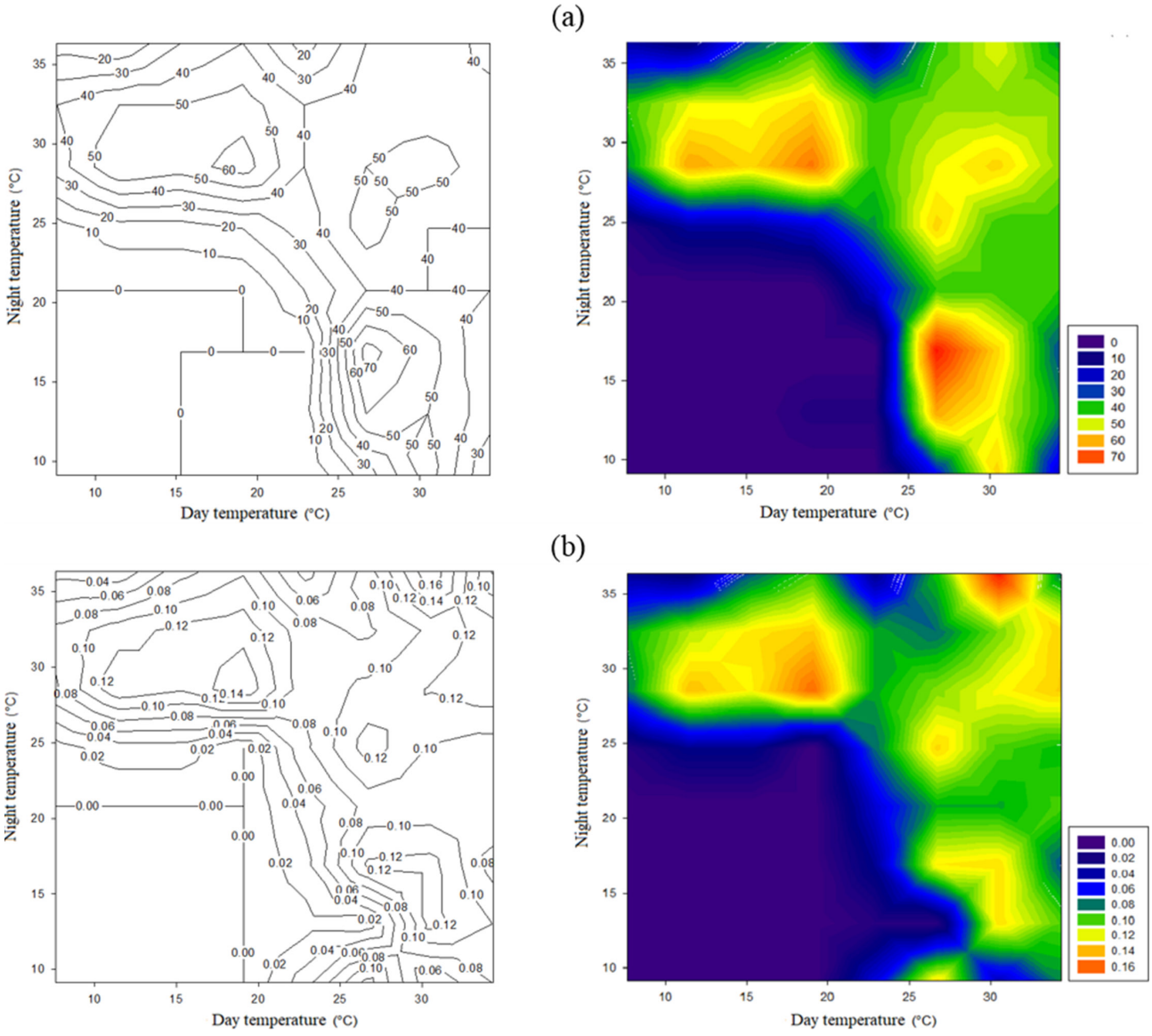

Figure 2: Germination percentage (%) (a) and germination rate ($1/T_{50}$) ($days^{-1}$) (b) of Carpentaria palm (*Carpentaria acuminata*) seeds on the two-way thermogradient plate with a 12-hour photoperiod along 50 days [numbers and colors indicate germination percentage (a) and germination rate (b); curves show limits among results obtained in the contour maps].

The main germination range of Canary Island date palm seeds at the alternating temperatures was concentrated from 22 to 35 °C during the day and from 10 to 35 °C overnight. At constant temperatures, it occurred mostly between 18 and 35 °C. There was 100% germination at the alternating temperatures varying from 24 to 32 °C during the day and at 22 °C overnight (Figure 3a). Seeds also germinated faster under warmer temperatures, especially at the alternating temperatures of 24 to 32 °C during the day and 27 to 32 °C at night (Figure 3b).

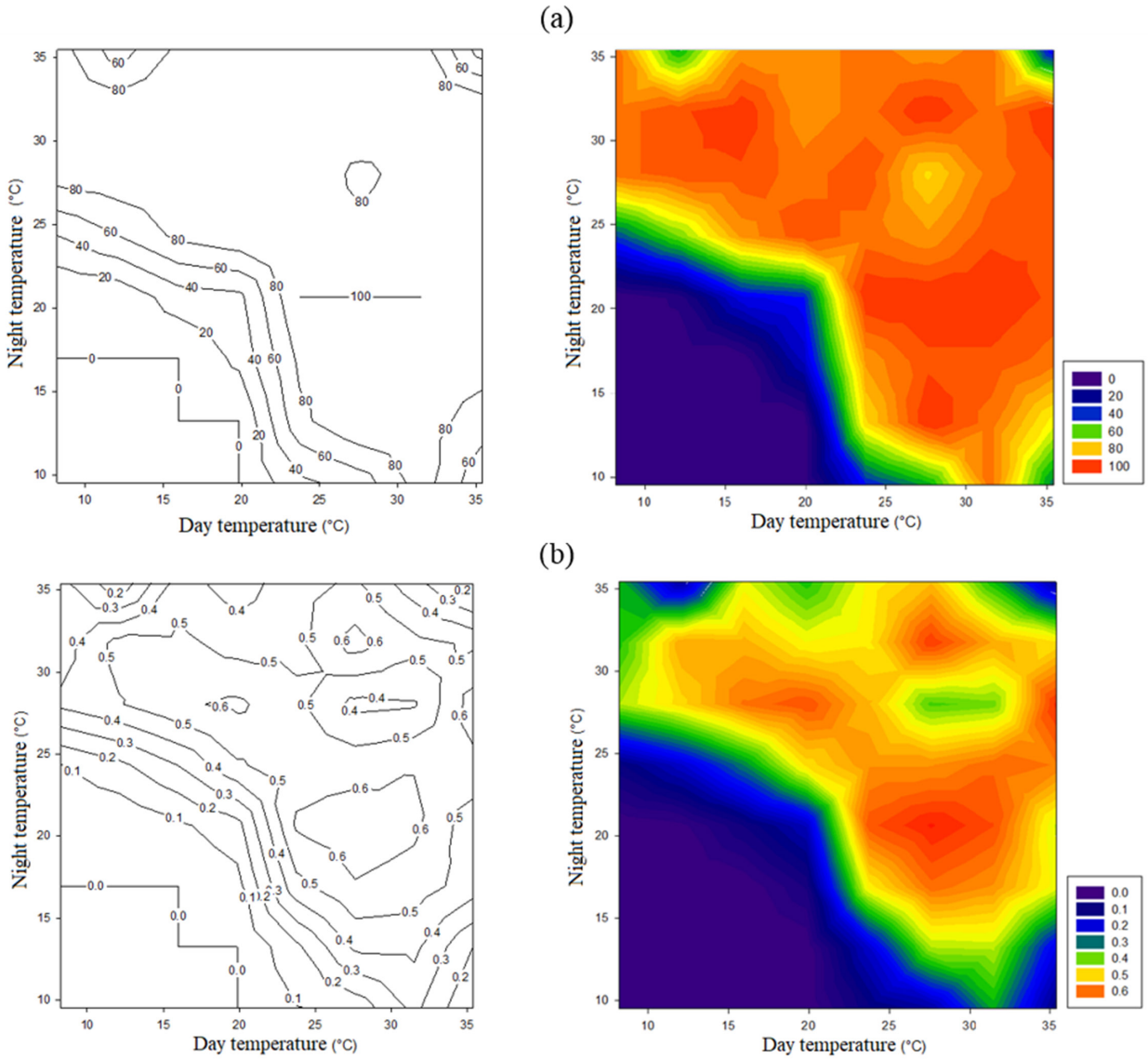

Figure 3: Germination percentage (%) (a) and germination rate ($1/T_{50}$) ($days^{-1}$) (b) of Canary Island date palm (*Phoenix canariensis*) seeds on the two-way thermogradient plate with a 12-hour photoperiod along 50 days [numbers and colors indicate germination percentage (a) and germination rate (b); curves show limits among results obtained in the contour maps].

There was a significant difference among the temperature amplitudes for germination percentage of Carpentaria palm seeds (Figure 4). The highest value (41.75 ± 2.63%) was observed at the alternating temperature of 30.45 °C during the day and 33 °C at night, which did not differ from the alternating temperatures of 31.20/9.83, 30.45/17.64, 30.39/25.43, 15.02/24.35, and 15.15/32.02 °C (day/night). There was no germination under the alternating temperatures of 14.49/9.28 and 14.65/16.92 °C (day/night) (Figure 4a). Seeds also germinated faster at the alternating temperature of 30.45 °C during the day and 33 °C at night, which did not differ from the alternating temperatures of 30.45/17.64, 30.39/25.43, and 15.15/32.02 °C (day/night) (Figure 4b).

Similarly, a significant difference was observed among temperature ranges for both germination percentage and germination rate of Canary Island date palm seeds (Figure 5). The highest germination percentage (73.07 ± 6.23%) was observed at the alternating temperature of 29.77 °C during the day and 17.93 °C at night, which did not differ from the alternating temperatures of 29.55/10.04, 29.93/25.88, 30.17/33.74, 14.77/29.37, and 14.62/33.20 °C (day/night) (Figure 5a). No germination was observed at the alternating temperatures of 15.32/10.47 and 15.11/18.02 °C (day/night). The highest germination rate occurred at the alternating temperature of 29.93 °C during the day and 25.88 °C at night, which did not differ from the alternating temperatures of 29.55/10.04, 29.77/17.93, 30.17/33.74, 14.77/29.37, and 14.62/33.20 °C (day/night) (Figure 5b).

(a)

Night temperature (°C)	7.63 – 11.45	15.26 – 19.08	22.88 – 26.70	30.51 – 34.33
36.33 / 32.44 / 28.56 / 24.67	**29.79 ± 11.79%** 31.20/9.83 °C (a)	**39.53 ± 9.00%** 30.45/17.64 °C (a)	**38.97 ± 4.72%** 30.39/25.43 °C (a)	**41.75 ± 2.63%** 30.45/33.00 °C (a)
20.79 / 16.90 / 13.01 / 9.13	**0%** 14.49/9.28 °C (b)	**0%** 14.65/16.92 °C (b)	**27.44 ± 17.56%** 15.02/24.35 °C (a)	**36.97 ± 8.00%** 15.15/32.02 °C (a)

Day temperature (°C)

(b)

Night temperature (°C)	7.63 – 11.45	15.26 – 19.08	22.88 – 26.70	30.51 – 34.33
36.33 / 32.44 / 28.56 / 24.67	**0.064 ± 0.039** 31.20/9.83 °C (b)	**0.093 ± 0.043** 30.45/17.64 °C (a)	**0.085 ± 0.018** 30.39/25.43 °C (a)	**0.117 ± 0.024** 30.45/33.00 °C (a)
20.79 / 16.90 / 13.01 / 9.13	**0** 14.49/9.28 °C (c)	**0** 14.65/16.92 °C (c)	**0.062 ± 0.039** 15.02/24.35 °C (b)	**0.092 ± 0.021** 15.15/32.02 °C (a)

Day temperature (°C)

Figure 4: Germination percentage (a) and germination rate ($1/T_{50}$) ($days^{-1}$) (b) of Carpentaria palm (*Carpentaria acuminata*) seeds on the two-way thermogradient plate with a 12-hour photoperiod along 50 days – each cell represents the mean of eight alternating and constant temperatures (Different letters indicate statistical difference among temperatures by the Tukey test at 1% significance).

(a)

Night temperature (°C)	8.21 – 12.09	15.98 – 19.86	23.74 – 27.63	31.51 – 35.40
35.43 / 31.73 / 28.03 / 24.33	**62.98 ± 13.49%** 29.55/10.04 °C (a)	**73.07 ± 6.23%** 29.77/17.93 °C (a)	**72.02 ± 5.76%** 29.93/25.88 °C (a)	**71.14 ± 9.48%** 30.17/33.74 °C (a)
20.63 / 16.93 / 13.23 / 9.53	**0%** 15.32/10.47 °C (b)	**0%** 15.11/18.02 °C (b)	**69.44 ± 17.32%** 14.77/29.37 °C (a)	**69.72 ± 10.13%** 14.62/33.20 °C (a)

Day temperature (°C)

(b)

Night temperature (°C)	8.21 – 12.09	15.98 – 19.86	23.74 – 27.63	31.51 – 35.40
35.43 / 31.73 / 28.03 / 24.33	**0.316 ± 0.137** 29.55/10.04 °C (a)	**0.472 ± 0.083** 29.77/17.93 °C (a)	**0.513 ± 0.057** 29.93/25.88 °C (a)	**0.462 ± 0.132** 30.17/33.74 °C (a)
20.63 / 16.93 / 13.23 / 9.53	**0** 15.32/10.47 °C (b)	**0** 15.11/18.02 °C (b)	**0.394 ± 0.194** 14.77/29.37 °C (a)	**0.389 ± 0.135** 14.62/33.20 °C (a)

Day temperature (°C)

Figure 5: Germination percentage (a) and germination rate ($1/T_{50}$) ($days^{-1}$) (b) of Canary Island date palm (*Phoenix canariensis*) seeds on the two-way thermogradient plate with a 12-hour photoperiod along 50 days – each cell represents the mean of eight alternating and constant temperatures (Different letters indicate statistical difference among temperatures by the Tukey test at 1% significance).

According to the models obtained, the optimal temperature for seed germination of Carpentaria palm is 28.53 °C, with minimum temperature of 9.13 °C and maximum of 36.33 °C. For Canary Island date palm, the optimum temperature for seed germination is 28.03 °C, with minimum of 9.53 °C and maximum of 35.43 °C.

Seeds of Carpentaria palm that did not germinate under cold temperatures [alternating temperatures of 14.49/9.28 and 14.65/16.92 °C (day/night) – lower right corner of the two-way thermogradient plate] did achieve germination when transferred to the constant temperature of 30 °C, considered close to the ideal, which is 28.53 °C; there was then 10 to 40% germination (Figure 6).

Similar effect was observed for Canary Island date palm seeds, which did not germinate under colder temperatures [alternating temperatures of 15.32/10.47 and 15.11/18.02 °C (day/night) – lower right corner of the two-way thermogradient plate]; when transferred to the constant temperature of 30 °C, which is close to the ideal (28.03 °C), presented 80% germination (Figure 7).

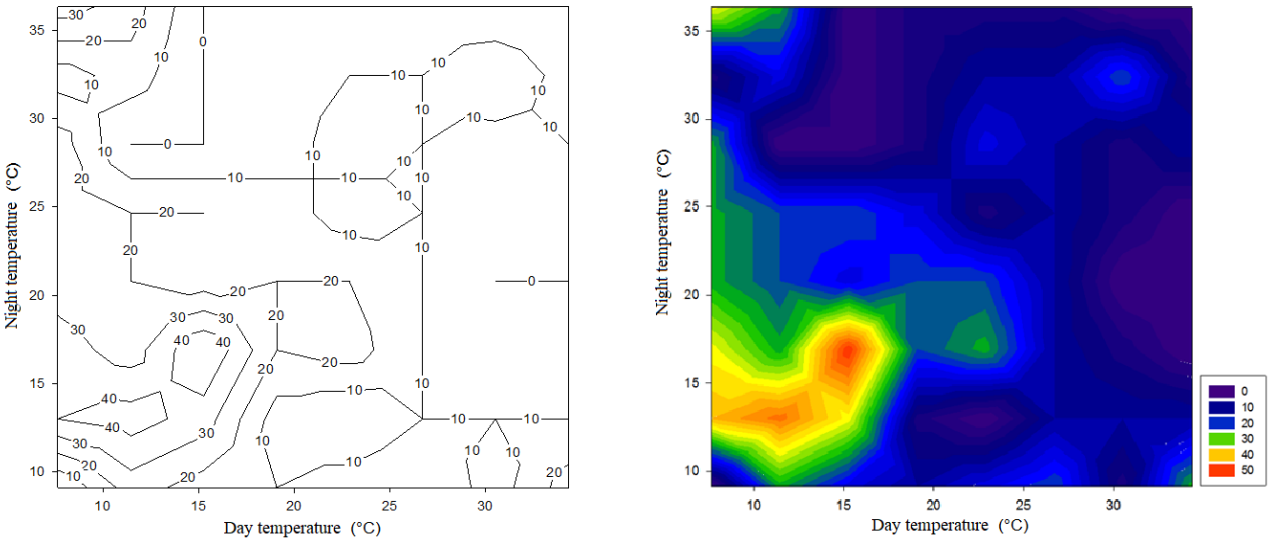

Figure 6: Germination percentage (%) of Carpentaria palm (*Carpentaria acuminata*) seeds in the BOD incubator at 30 °C with a 12-hour photoperiod [numbers and colors indicate germination percentage; curves show limits among results obtained in the contour maps].

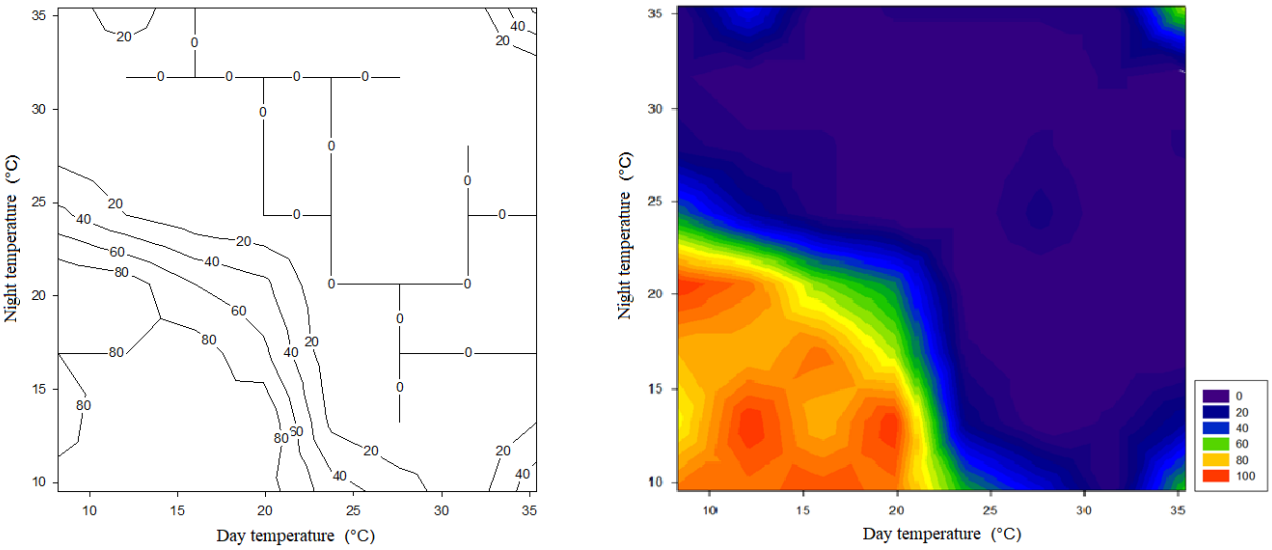

Figure 7: Germination percentage (%) of Canary Island date palm (*Phoenix canariensis*) seeds in the BOD incubator at 30 °C with a 12-hour photoperiod [numbers and colors indicate germination percentage; curves show limits among results obtained in the contour maps].

Cold temperatures were not lethal to seeds of both Carpentaria palm and Canary Island date palm, even when exposed to low temperatures for 50 days, as they did germinate when submitted to the warmer, possibly ideal, temperature.

DISCUSSION

Seeds of Carpentaria palm and Canary Island date palm germinated at different temperature regimes following their, respectively, tropical and subtropical origin that determines the ideal temperatures for germination. Seeds of both species did not germinate under cold temperatures (lower left corner of the two-way thermogradient plate) but did germinate under hot temperatures (upper right corner of the two-way thermogradient plate) or when seeds were placed under 30 °C after such cold period. However, Orozco-Segovia *et al.* (2003) report that some subtropical species do not require high temperatures for germination and, also, some even needs a period of cool temperature to reach highest germination. Nevertheless, He *et al.* (2021) mention that, for Canary Island date palm, seed germination happens when dormancy is released by a cold stratification in the soil over winter.

Sandoval (2011), when studying temperature regimes from 5.8 to 36.3 °C for seed germination of *Browningia candelaris* on the two-way thermogradient plate, also observed that there was either no germination under extreme temperatures or it was very low. Similarly, Asomaning *et al.* (2010) reported that seeds of *Khaya anthotheca*, when submitted to temperature ranges from 5 to 40 °C on the two-way thermogradient plate, did not germinate under extreme temperatures.

Seeds of both species presented an optimum temperature for germination of approximately 28 °C, either constant or alternating, although constant high temperatures may not be always appropriate for palm seed germination (Orozco-Segovia *et al.*, 2003). Nevertheless, it has been proven by several authors that temperatures close to this are favorable for seed germination of many palm species, such as 25 °C for *Syagrus coronata* (Porto *et al.*, 2018) and *Copernica prunifera* (Reis *et al.*, 2010), 30 °C for *Oenocarpus minor* (Silva *et al.*, 2006) and *Elaeis guineensis* (Norsazwan *et al.*, 2016), or 25-30 °C for *Dypsis decaryi* (Luz *et al.*, 2008). Furthermore, close temperatures may even be applied before germination to overcome dormancy, as reported by Ferreira & Gentil (2017) for *Phytelephas macrocarpa* seeds maintained under 25 °C for nine months without losing viability. Therefore, high temperatures may be necessary to overcome seed dormancy of many species (Orozco-Segovia *et al.*, 2003).

Lorenzi *et al.* (2004), for example, mention that temperatures between 24 and 28 °C are considered favorable for seed germination of several palm species, while Broschat (1994) observed that many palm seeds germinate better at 30 to 35 °C. Constant temperatures of about 30 °C also promoted seed germination of eight tropical palm species of *Phoenix* and *Syagrus* genera (Pritchard *et al.*, 2004). Similarly, seeds of four species of *Ravenea* germinated rapidly at 30 °C (Rakotondranony *et al.*, 2004).

As seeds of palm species are considered recalcitrant, Roberts (1973) and Sarasan *et al.* (2002) report that seeds shall not be exposed to low temperatures because of viability losses would occur from only few weeks to few months. This is due to high humidity present in the seeds, so cell freezing may occur and, consequently, cell disintegration, hindering germination. However, this effect may also be related to the characteristic seed dormancy of each palm species but, as reported by Orozco-Segovia *et al.* (2003), mechanisms of both seed germination and dormancy are yet poorly understood for many palms. For both Carpentaria palm and Canary Island date palm, cold temperatures were not lethal.

The low water content found in seeds of both Carpentaria palm and Canary Island date palm (18.13 ± 1.7% and 10.32 ± 1.3%, respectively) probably prevented seed degradation. However, for many palm species, such low water content is considered critical, but these seeds have been reported to be tolerant to desiccation, that is, the low seed water content does not affect germination (Batista *et al.*, 2016).

CONCLUSIONS

The temperature regime promoting highest seed germination percentage of Carpentaria palm (*Carpentaria acuminata*) was 30.45/33.00 °C (day/night), with minimum, optimum, and maximum temperatures of 9.13, 28.53, and 36.33 °C, respectively. For practical purposes, the alternating temperature of 31/33 °C (day/night) may be recommended.

For seed germination of Canary Island date palm (*Phoenix canariensis*), the most appropriate temperature regime was 29.77/17.93 °C (day/night), with minimum, optimum, and maximum temperatures of 9.53, 28.03, and 35.43 °C, respectively. For practical purposes, the alternating

temperature of 30/18 °C (day/night) may be recommended.

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REFERENCES

Asomaning JM, Sacande M & Olympio NS (2010) Germination responses of *Khaya anthotheca* seeds to a range of alternating and constant temperatures provided by the 2-way grant's thermogradient plate. Ghana Journal of Forestry, 26:74-88.

Baskin CC & Baskin JM (2014) Seeds: ecology, biogeography, and evolution of dormancy and germination. San Diego, Elsevier. 1600p.

Batista GS, Mazzini-Guedes RB, Pivetta KFL, Pritchard HW & Marks T (2016) Seed desiccation and salinity tolerance of palm species *Carpentaria acuminata*, *Dypsis decaryi*, *Phoenix canariensis*, and *Ptychosperma elegans*. Australian Journal of Crop Science, 10:1630-1634.

Bewley JD & Black M (1985) Physiology and biochemistry of seeds. Berlin, Springer-Verlag. 540p.

Bewley JD & Black M (1996) Seeds: physiology of development and germination. New York, Plenum Press. 445p.

Broschat TK (1994) Palm seed propagation. Acta Horticulturae, 360:141-147.

Carvalho NM & Nakagawa J (2000) Sementes: ciência, tecnologia e produção. Jaboticabal, Funep. 588p.

Castro RD & Hilhorst HWM (2004) Embebição e reativação do metabolismo. In: Ferreira AG & Borghetti F (Eds.) Germinação: do básico ao aplicado. Porto Alegre, Artmed. p.149-162.

Copeland LO & McDonald MB (1995) Principle of seed science and technology. New York, Chapmen & Hall. 409p.

Covell S, Ellis RH, Roberts EH & Summerfield RJ (1986) The influence of temperature on seed germination rate in grain legumes: I. A comparison of chickpea, lentil, soybean and cowpea at constant temperatures. Journal of Experimental Botany, 37:705-715.

El-Keblawy A (2017) Germination response to light and temperature in eight annual grasses from disturbed and natural habitats of an arid Arabian desert. Journal of Arid Environments, 147:17-24.

Ferreira SAN & Gentil DFO (2017) Seed germination at different stratification temperatures and development of *Phytelephas macrocarpa* Ruiz & Pavón seedlings. Journal of Seed Science, 39:20-26.

Hardegree SP (2006) Predicting germination response to temperature. III. Model validation under field-variable temperature conditions. Annals of Botany, 98:827-834.

He L, Ganesh JK & Baolin L (2021) Morphophysiological dormancy and germination ecology in diaspores of the subtropical palm *Phoenix canariensis*. Botany, 100. DOI:10.1139/cjb-2021-0126.

ISTA – International Seed Testing Association (2017) International rules for seed testing. Bassersdorf, ISTA. 296p.

Lima CMR, Borghetti F & Sousa MV (1997) Temperature and germination of the Leguminosae *Enterolobium contortisiliquum*. Revista Brasileira de Fisiologia Vegetal, 9:97-102.

Lorenzi H, Noblick L, Kahn F & Ferreira EJL (2010) Flora Brasileira: Arecaceae (Palmeiras). Nova Odessa, Plantarum. 384p.

Lorenzi H, Souza HM, Costa JTM, Cerqueira LSC & Ferreira E (2004) Palmeiras brasileiras e exóticas cultivadas. Nova Odessa, Plantarum. 416p.

Luz PB, Pimenta RS, Pizetta PUC, Castro A & Pivetta KFL (2008) Germinação de sementes de *Dypsis decaryi* (Jum.) Beentje & J. Dransf. (Arecaceae). Ciência e Agrotecnologia, 32:1461-1466.

Manger KR (1999) Use of grant thermogradient plate. Ardingly, The Royal Botanic Gardens. 2p.

Norsazwan MG, Puteh AB & Rafii MY (2016) Oil palm (*Elaeis guineensis*) seed dormancy type and germination pattern. Seed Science and Technology, 44:15-26.

Orozco-Segovia A, Batis AI, Rojas-Aréchiga M & Mendoza A (2003) Seed biology of palms: a review. Palms, 47:79-94.

Pivetta KFL, Barbosa JG, Araújo EF & Demattê MEP (2007) Propagação de palmeiras e strelitzias. In: Barbosa JG & Lopes LC (Eds.) Propagação de plantas ornamentais. Viçosa, UFV. p.43-70.

Porto JMP, Oliveira VL, Souza ML, Souza RAV, Soares A & Braga FT (2018) Pre-germination treatments, quality of light and temperature on *Syagrus coronata* (Mart.) Becc. seeds germination. Journal of Agricultural Science, 10:268-275.

Pritchard HW, Daws MI, Fletcher BJ, Gamene CS, Msanga HP & Omondi W (2004) Ecological correlates of seed desiccation tolerance in tropical African dryland trees. American Journal of Botany, 91:863-870.

Rakotondranony GL, Sacande M, Wood CB & Pritchard HW (2004) Seed storage responses in four species of the threatened genus *Ravenea* (Arecaceae). Seed Science and Technology, 34:513-517.

Reis RGE, Bezerra AME, Gonçalves NR, Pereira MS & Freitas JBS (2010) Biometria e efeito da temperatura e tamanho das sementes na protrusão do pecíolo cotiledonar de carnaúba. Ciência Agronômica, 41:81-86.

Roberts EH (1973) Predicting the storage life of seeds. Seed Science and Technology, 1:499-514.

Salomão AN, Eira MTS & Cunha R (1995) The effect of temperature on seed germination of four *Dalbergia nigra* Fr. Allem – Leguminosae trees. Revista Árvore, 9:588-594.

Sandoval AC (2011) Germination behaviour of *Browningia candelaris* (Meyen) Britton & Rose, and other four vulnerable cacti of Chile. Master Dissertation. University of Sussex, Brighton. 57p.

Sarasan V, Ramsay MM & Roberts AV (2002) *In vitro* germination and induction of direct somatic embryogenesis in 'Bottle Palm' [*Hyophorbe lagenicaulis* (L. Bailey) H.E. Moore], a critically endangered Mauritian palm. Plant Cell Reports, 20:1107-1111.

Sigma Plot (2004) Systat software. Version 9.0. Exact graphs for exact science. Palo Alto, Systat Software Inc. Available at: <https://systatsoftware.com/sigmaplot/>. Accessed on: September 15th, 2021.

Silva BMS, Cesarino F, Lima JD, Pantoja TF & Môro FV (2006) Germinação de sementes e emergência de plântulas de *Oenocarpus minor* Mart. (Arecaceae). Revista Brasileira de Fruticultura, 28:289-292.

Uhl NW & Dransfield J (1987) Genera Palmarum: a classification of palms based on the work of Harold E. Moore, Jr. Lawrence, Allen Press. 610p.

Viana FAP, Pivetta KFL & Rocha LGS (2016) Efeito da escarificação e da temperatura na germinação de sementes de *Livistona rotundifolia* (Lam.) Mart. Cultura Agronômica, 25:65-70.

Wen B (2019) Seed germination ecology of Alexandra palm (*Archontophoenix alexandrae*) and its implication on invasiveness. Scientific Reports, 4057:01-09.