Optimal Temperature for Germination of *Zephyra compacta* (Tecophilaeaceae)

Carlos De la Cuadra, Alexis K. Vidal, and Leví M. Mansur¹

Escuela de Agronomía, Pontificia Universidad Católica de Valparaíso, Avenida San Francisco s/n, La Palma, Casilla 4-D, Quillota, Chile

Additional index words. geophyte, seed germination, coastal desert with abundant cloudiness, Atacama Desert

Abstract. *Zephyra compacta* is a geophyte plant endemic to Chile with the potential to be used as an ornamental crop. Its natural habitat is the coastal plains of the Atacama Desert, with a climate described as coastal desert with abundant cloudiness. This work analyzes the germination of *Z. compacta* seeds at 10, 15, 20, and 25 °C. Seeds were collected in 2011 and stored for 2 years and 4 months at 5 °C, until sowing. A mathematical model was used for germination analysis, $p = A\{1 - \exp[-k(t - t_0)]\}$, where p is the germination percentage at a certain time t , A is the final germination percentage, t_0 is the estimated time of germination of the first seed, and k is the measure of the spread of the time to germination. Furthermore, the rate of germination of the median seed to germinate ($1/t_{A/2}$) was included. The germination curves showed a coefficient of determination (R^2) between 0.86 and 0.99. The results show that temperature range for germination is from 10 to 20 °C, where A is over 90%. In this range, other evaluated parameters (t_0 , k , and $1/t_{A/2}$) show no significant difference, with the exception of k at 15 °C. At this temperature, germination is obtained in a shorter period of time and could be considered as the optimal temperature within the range. Finally, 25 °C is a supraoptimal temperature, where the value of A decreased to 30%.

The *Zephyra* genus, of the Tecophilaeaceae family, is endemic to Chile's Atacama Desert (Muñoz and Moreira, 2000) and comprises four species: *Z. compacta*, *Zephyra cyanocrocus*, *Zephyra elegans*, and *Zephyra violiflora* (Buerki et al., 2013; Ravenna, 1988). The species *Z. cyanocrocus* and *Z. violiflora* characteristically have one or two flowers per inflorescence and three sterile stamens, as opposed to *Z. compacta* and *Z. elegans*, which have branched or paniculate inflorescences and two sterile stamens (Buerki et al., 2013; Simpson and Rudall, 1998). *Zephyra compacta* was the last species of the genus to be described and, according to Ehrhart (2001), it differs from *Z. elegans* because of its compact growth, wider and succulent leaves, more branched inflorescence, and that it has only pure white flowers, with smaller and curved back tepals (Figs. 1–2).

The *Zephyra* genus has a high ornamental value, where the best-known and studied species are *Z. cyanocrocus* and *Z. elegans* (Eyzaguirre and García de la Huerta, 2002; Kim and Ohkawa, 1999, 2001; Kim et al., 1996, 1998; Vidal et al., 2012; Yáñez et al.,

2005). *Zephyra compacta*, as opposed to *Z. elegans*, has the potential to be used as a potted plant because of its compact growth.

However, key aspects that contribute to the domestication and ornamental use of *Z. compacta* are unknown, such as the environmental conditions for its germination, especially the temperature.

Zephyra compacta's natural habitat (29°17'S–71°18'W, Quebrada Los Choros, Atacama Desert) corresponds to the coastal plains formed by fluvio-marine sediment with a coastal desert climate with abundant cloudiness (Cereceda et al., 2008; Novoa and López, 2001). The monthly average temperatures vary between 13.0 and 20.5 °C with a diurnal temperature variation of 7.5 °C; the monthly high and low temperatures are 24.5 and 9.8 °C, that occur in January and July, respectively (Fig. 3). The average of clear days per year is only 44. The precipitations are in the form of rainfall and are scarce and extremely variable. They usually occur at the end of autumn and winter (May to August) and are uncommon in spring (Antonioletti et al., 1972; Juliá et al., 2008). The annual precipitation is between 25 to 50 mm, with seasonal variations in dry and humid years that range from zero to 100 mm. According to the records, average rainfall occurs in no more than 4 d a year (Antonioletti et al., 1972; DGA, 2004). Irregularly high rainfall (>15 mm) normally occurs during the phenomena of El Niño–Southern Oscillation, and as a consequence, the emergence of more than 200 species of annual plants and geophytes occur, including *Z. compacta* (Gutiérrez, 2008).

Fig. 1. *Zephyra compacta* at flowering stage in its natural habitat (29°10'S–71°29'W, Caleta Apollillado, Atacama Desert, Chile).

Received for publication 5 Dec. 2016. Accepted for publication 11 Jan. 2017.

We are sincerely grateful to Michail Belov of Chileflora (www.chileflora.com) who made the seeds of *Z. compacta* available to carry out this investigation and for the image in Fig. 2. Our thanks to María Teresa Eyzaguirre from the R.A. Philippi Foundation (www.fundacionphilippi.cl) for the image in Fig. 1.

¹Corresponding author. E-mail: levi.mansur@pucv.cl

Fig. 2. *Zephyra compacta* at fruiting stage in its natural habitat (29°17'S–71°18'W, Quebrada Los Choros, Atacama Desert, Chile).

Fig. 3. Climograph of coastal Atacama Desert, adapted from Novoa and Villaseca (1989). Precipitation (solid bars), monthly average temperature (solid line), monthly maximum temperature (segmented line), and monthly minimum temperature (dot line).

In desert climates, the germination and emergence of seedlings is sporadic since this process is associated with water availability (Black et al., 2006). With few exceptions, rainfall occurs only in winter and therefore it

can be expected that the seeds require temperatures typical of this season to germinate (Baskin and Baskin, 2014). Therefore, we hypothesize that the germination temperature of *Z. compacta* seeds should correspond to

winter temperatures of 10 to 15 °C in its natural habitat, which is the season when the records show there is a higher probability of rainfall (Novoa and Villaseca, 1989). Considering the previous background, the objective of this study is to determine the temperature range and optimal temperature for germination of *Z. compacta*.

Materials and Methods

Zephyra compacta seeds were collected by Mr. Michail Belov of Chileflora (www.chileflora.com) in Nov. 2011 in Quebrada Los Choros (29°17'S–71°18'W), Atacama Desert, Chile, and, to preserve seed vigor, stored at 5 °C (Black et al., 2006) until germination trials were conducted (Apr. 2014).

The germination trials were conducted in growth chambers units at 10, 15, 20, and 25 ± 2 °C. For each of these treatments, four replicates were used, each consisting of 50 seeds in a petri dish with absorbent paper (9-cm diameter). Seeds were disinfected for 3 min in a solution of Captan® at 1% (Captan® 50WP; N-(trichloromethylthio)-4-cyclohexene-1,2-dicarboximide; Arysta LifeScience, Cary, NC), later rinsed three times and then sown. Three to four milliliters of water were added to each petri dish and then sealed with plastic paraffin tape. During germination time, additional water was added only if necessary. Germination was recorded every 2 d for a period of 4 weeks. A seed was considered to be germinated when the emergent radicle was at least 2 mm.

The germination data for each treatment was fitted to the model $p = A\{1 - \exp[-k(t - t_0)]\}$ used by Mobayen (1980), where p is germination percentage at a determined time t , A is the final germination percentage, t_0 is the estimated time of germination of the first seed, and k is a measure of the spread of the time to germination. Parameter k expresses time required from the first to the last seed to germinate, where values of near one and values near zero indicate short and long time, respectively. Furthermore, the rate of germination of the median seed to germinate ($1/t_{A/2}$) was included, where $t_{A/2}$ is the time required to reach median seed germination and is calculated as $t_0 + 0.693/k$.

Statistical test used for comparisons was the confidence interval for the difference of two proportions at $P \leq 0.05$ for the final germination percentage A . Differences for t_0 , k , and $1/t_{A/2}$ were tested by calculating the confident intervals related to the corresponding regression coefficients obtained from the model $p = A\{1 - \exp[-k(t - t_0)]\}$ at $P \leq 0.05$ (Walpole et al., 2012).

Results and Discussion

The germination curves produced by the data fitted to the model used by Mobayen (1980) had coefficients of determination (R^2) ranging from 0.86 to 0.99 (Table 1; Fig. 4).

Final germination percentage (A) for germination temperature treatments of 10, 15,

and 20 °C was over 90%, and showed no differences between them (Table 1). According to these data, temperature range for germination of *Z. compacta* is 10 to 20 °C. In this temperature range, with the exception of the value of the spread of the time to germination (k), the value of the rest of the parameters (t_0 and $1/t_{A/2}$) also showed no significant differences. At 15 °C, the value of the spread of the time to germination (k) reaches its highest value (0.692/d) when compared with 10 and 20 °C, and therefore, 15 °C should be considered as the optimal temperature for germination of *Z. compacta*.

It is worth mentioning that the temperature range (10 to 20 °C) in which *Z. compacta* reaches 90% germination or higher, coincides

with the monthly average temperature range present during the entire year in its natural habitat (Novoa and López, 2001). When monthly higher and lower temperatures are considered, favorable temperature conditions for germination occur from April to November. However, the greatest probability for precipitation only occurs from May to August (Juliá et al., 2008; Novoa and Villaseca, 1989). Therefore, it is reasonable to infer that in a coastal desert climate with abundant cloudiness, temperature should not be the limiting factor for germination of *Z. compacta* at any time of the year. Instead, we propose that the limiting factor is the availability of water via rainfall, as occurs with other desert plants (Black et al., 2006;

Gutiérrez et al., 2000; Vidiella and Armesto, 1989).

Zephyra compacta presents a temperature range for germination of 10 to 20 °C similar to species coexisting in the same habitat such as *Pasithea coerulea* and *Schizanthus litoralis* (Jara et al., 2006; Schiappacasse et al., 2005). Interestingly, other species from the same habitat have a more restrictive temperature range for germination (10 to 15 °C) such as *Leucocoryne dimorphopetala* (De la Cuadra et al., 2016). According to Schiappacasse et al. (2005), *Z. violiflora* also has a temperature range for germination similar to *L. dimorphopetala*; however, this species inhabits sites with Mediterranean climate (Buerki et al., 2013).

The final germination percentage (A) at 25 °C decreased significantly to 30%. In its natural habitat, high daily temperatures of 25 °C or more are typical in summer, during the months of December to March and normally coinciding with the absence of precipitations (Novoa and Villaseca, 1989). Similar behavior is observed in *Z. elegans*, species that coexist in the same habitat, which under in vitro conditions at 25 °C and darkness, maximum germination was only 40% (Vidal et al., 2012). Thus, 25 °C seems to be a supraoptimal temperature for *Z. compacta*.

For determination of optimal temperature, other parameters (t_0 , k , and $1/t_{A/2}$) could be useful. In this investigation, when final germination percentage (A) of *Z. compacta* reached its maximum, but was similar at different temperatures, the highest value of parameter k , which indicates the shortest time from first to last seed to germinate, was helpful as a second parameter to determine optimal temperature. Similar situation was observed in several species of *Leucocoryne* where the optimal temperatures were determined by the highest values of k (De la Cuadra et al., 2016).

In conclusion, *Z. compacta* seeds have a high germination in the temperature range of 10 to 20 °C, with 15 °C being optimal, congruent with the environmental conditions of its natural habitat.

Literature Cited

- Antonioletti, R., H. Schneider, J.L. Borcosque, and E. Zarate. 1972. Características climáticas del Norte Chico (26° a 33° latitud sur). Instituto de Investigación de Recursos Naturales (IREN), Santiago, Chile.
- Baskin, C.C. and J.M. Baskin. 2014. Seeds: Ecology, biogeography, and evolution of dormancy and germination. 2nd ed. Academic Press, San Diego, CA.
- Black, M., J.D. Bewley, and P. Halmer. 2006. The encyclopedia of seeds: Science, technology and uses. CABI, Wallingford, UK.
- Buerki, S., J.C. Manning, and F. Forest. 2013. Spatio-temporal history of the disjunct family Tecophilaeaceae: A tale involving the colonization of three Mediterranean-type ecosystems. *Ann. Bot. (Lond.)* 111:361–373.
- Cereceda, P., H. Larrain, P. Osses, M. Farías, and I. Egaña. 2008. The climate of the coast and fog zone in the Tarapacá region, Atacama Desert, Chile. *Atmos. Res.* 87(3):301–311.

Table 1. Temperature effect on germination of *Zephyra compacta*, where parameter A is the final germination percentage, t_0 is the estimated time of germination of the first seed, k is a measure of the spread of the time to germination, and $1/t_{A/2}$ is the rate of germination of the medians seed to germinate. Seeds were stored at 5 °C for 2 years and 4 months until sowing.

Temperature	R^2	A (%)	t_0 (d)	k (d ⁻¹)	$1/t_{A/2}$ (d ⁻¹)
10 °C	0.95	92 a ^z	9.9 ab ^y	0.291 b ^y	0.081 a ^y
15 °C	0.99	97 a	6.3 ab	0.692 a	0.137 a
20 °C	0.99	93 a	5.4 a	0.338 b	0.134 a
25 °C	0.86	31 b	16.0 b	0.040 c	0.030 b

^zValues in the same column with different letters are significantly different by confidence interval for the difference of two proportions at $P \leq 0.05$.

^yValues in the same column with different letters are significantly different by confidence intervals related to the corresponding regression coefficients obtained from the model $p = A\{1 - \exp[-k(t - t_0)]\}$ at $P \leq 0.05$.

Fig. 4. Germination curves fitted to the model $p = A\{1 - \exp[-k(t - t_0)]\}$ used by Mobayen (1980). Seeds of *Zephyra compacta* germinated at 10 °C (□), 15 °C (◇), 20 °C (Δ), and 25 °C (○) after 2 years and 4 months in storage (5 °C).

- De la Cuadra, C., A.K. Vidal, S. Lefimil, and L. Mansur. 2016. Temperature effect on seed germination in the genus *Leucocoryne* (Amaryllidaceae). *HortScience* 51:412–415.
- DGA. 2004. Modelo de simulación Quebrada Los Choros. Evaluación de los Recursos Hídricos en la Quebrada Los Choros, IV región de Coquimbo. Informe Técnico. Realizado por: Departamento de Estudios y Planificación de los Recursos Hídricos. Dirección General de Aguas. Ministerio de Obras Públicas. Gobierno de Chile. S.I.T. N°96. Septiembre 2004.
- Ehrhart, C. 2001. *Zephyra compacta* (Tecophilaeaceae): Eine neue Art aus Chile. *Sendtnera* 7:47–52.
- Eyzaguirre, M.T. and R. García de la Huerta. 2002. *Tecophilaea cyanocrocus* Leyb. (Tecophilaeaceae) rediscovered in its natural habitat. *Gayana Bot.* 59(2):73–77.
- Gutiérrez, J.R. 2008. El desierto florido de la región de Atacama, p. 285–291. In: F.A. Squeo, G. Arancio, and J.R. Gutiérrez (eds.). Libro rojo de la flora nativa y de los sitios prioritarios para su conservación: Región de Atacama. Ediciones Universidad de La Serena, La Serena, Chile.
- Gutiérrez, J.R., G. Arancio, and F.M. Jaksic. 2000. Variation in vegetation and seed bank in a Chilean semi-arid community affected by ENSO 1997. *J. Veg. Sci.* 11:641–648.
- Jara, P., G. Arancio, R. Moreno, and M. Carmona. 2006. Factores abióticos que influyen la germinación de seis especies herbáceas de la zona árida de Chile. *Rev. Chil. Hist. Nat.* 79:309–319.
- Juliá, C., S. Montecinos, and A. Maldonado. 2008. Características climáticas de la región de Atacama, p. 25–42. In: F.A. Squeo, G. Arancio, and J.R. Gutiérrez (eds.). Libro rojo de la flora nativa y de los sitios prioritarios para su conservación: Región de Atacama. Ediciones Universidad de La Serena, La Serena, Chile.
- Kim, H.H. and K. Ohkawa. 1999. Growth and flowering of *Zephyra elegans* D. Don grown in greenhouse or growth chamber. *HortScience* 34:476.
- Kim, H.H. and K. Ohkawa. 2001. Introduction of two Chilean geophytes, *Leucocoryne coquimbensis* F. Phil. and *Zephyra elegans* D. Don. as new ornamentals. *Acta Hort.* 552:179–183.
- Kim, H.H., K. Ohkawa, and K. Sakaguchi. 1996. Effects of storage temperature and duration on flower bud development, emergence and flowering of *Zephyra elegans* D. Don. *Scientia Hort.* 67:55–63.
- Kim, H.H., K. Ohkawa, and K. Sakaguchi. 1998. Effects of corm weight on the growth and flowering of *Zephyra elegans* D. Don. *Acta Hort.* 454:335–340.
- Mobayen, R.G. 1980. Germination and emergence of citrus and tomato seeds in relation to temperature. *J. Hort. Sci.* 55:291–297.
- Muñoz, M. and A. Moreira. 2000. Géneros endémicos monocotiledóneas, Chile. *Chloris chilensis*. 17 Feb. 2016. <<http://www.chlorischile.cl/Monocotiledoneas/tecophilaea.htm>>.
- Novoa, J.E. and D. López. 2001. IV Región: El escenario geográfico físico, p. 13–28. In: F.A. Squeo, G. Arancio, and J.R. Gutiérrez (eds.). Libro rojo de la flora nativa y de los sitios prioritarios para su conservación: Región de Coquimbo. Ediciones Universidad de La Serena, La Serena, Chile.
- Novoa, R. and S. Villaseca. 1989. Mapa agroclimático de Chile. Inia, Santiago, Chile.
- Ravenna, P. 1988. New or noteworthy Tecophilaeaceae. *Phytologia* 64(4):288–289.
- Schiappacasse, F., P. Peñailillo, P. Yáñez, and M. Bridgen. 2005. Propagation studies on Chilean geophytes. *Acta Hort.* 673:121–126.
- Simpson, M.G. and P.J. Rudall. 1998. Tecophilaeaceae, p. 429–436. In: K. Kubitzki (ed.). The families and genera of vascular plants III. Flowering plants. Monocotyledons. Liliaceae (except Orchidaceae). Springer, Heidelberg, Germany.
- Vidal, A.K., D.S. Han, M. Nakano, and Y. Niimi. 2012. Decreased time from seed to flowering corm size in *Zephyra elegans* via in vitro cultivation. *Cien. Inv. Agr.* 39:577–584.
- Vidiella, P.E. and J.J. Armesto. 1989. Emergence of ephemeral plant species from the north-central Chilean desert in response to experimental irrigation. *Rev. Chil. Hist. Nat.* 62:99–107.
- Walpole, R.E., R.H. Myers, S.L. Myers, and K. Ye. 2012. Probability and statistics for engineers and scientists. 9th ed. Prentice Hall, Boston, MA.
- Yáñez, P., H. Ohno, and K. Ohkawa. 2005. Temperature effects on corm dormancy and growth of *Zephyra elegans* D. Don. *Sci. Hort.* 105:127–136.