BioOne COMPLETE

# High-temperature tolerance by the endangered Mexican Mayflower orchid, Laelia speciosa

Authors: Gudiño, Whaleeha, Ávila-Díaz, Irene, Oyama, Ken, and Barrera de la, Erick

Source: Tropical Conservation Science, 8(4) : 983-991

Published By: SAGE Publishing

URL: https://doi.org/10.1177/194008291500800408

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

**Short Communication**

# High-temperature tolerance by the endangered Mexican Mayflower orchid, *Laelia speciosa*

**Whaleeha Gudiño[1], Irene Ávila-Díaz[2], Ken Oyama[1,3] and Erick de la Barrera[1]**

[1]Instituto de Investigaciones en Ecosistemas y Sustentabilidad, Universidad Nacional Autónoma de México, Morelia, Michoacán, Mexico

[2]Facultad de Biología, Universidad Michoacana de San Nicolás de Hidalgo, Morelia Michoacán, Mexico

[3]Escuela Nacional de Estudios Superiores, Unidad Morelia, Universidad Nacional Autónoma de México, Morelia, Michoacán, Mexico

Author for correspondence: Erick de la Barrera, e-mail: delabarrera@unam.mx

**Abstract**

The Mayflower orchid, *Laelia speciosa,* is an endangered orchid endemic to oak forests of central Mexico. Because of extractive pressure on remaining natural populations, *in vitro* propagation has been proposed as an alternative for the massive propagation of this plant for conservation and commercial purposes. However, it is unknown whether this orchid will be able to tolerate the increased air temperature that is projected to occur during the present century, especially for *in vitro* propagated individuals at early developmental stages. A laboratory assay that measured electrolyte leakage, a common indicator of cell membrane integrity, was utilized to determine the high-temperature tolerance for 8-year-old individuals rescued from a wild population and for 2-year-old micropropagated individuals of the Mayflower orchid. The plants were incubated under day/night air temperatures of 25/15, 30/20, or 35/25 °C. Chlorophyll fluorescence measurements of the quantum yield of photosystem II (Fv/Fm) averaged 0.74 ± 0.01, except for the micropropagated individuals incubated under 35/25 °C, whose quantum yield of 0.64 ± 0.02 was indicative of stress. Electrolyte leakage also responded to incubation temperature. An observed increase of temperature tolerance of 0.6–1.0 °C per increased degree of incubation temperature indicates an ability to acclimate to rising air temperatures. However, the $LT_{50}$ (the temperature that causes half of the maximum electrolyte leakage to occur) dramatically decreased (by 6.7-10.9 °C) for plants kept under 35/25 °C. In this case, the *in vitro* propagated individuals were less able to resist high air temperatures. It appears that the Mayflower will be able to survive climate change, provided that *in vitro* propagated individuals are sufficiently hardened.

Keywords: Conservation physiology, ecological niche, tissue culture, assisted migration, global warming



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

Received: 21 October 2015; Accepted 26 October 2015; Published: 14 December 2015

**Copyright**: © Whaleeha Gudiño, Irene Ávila-Díaz, Ken Oyama and Erick de la Barrera. This is an open access paper. We use the Creative Commons Attribution 4.0 license http://creativecommons.org/licenses/by/3.0/us/. The license permits any user to download, print out, extract, archive, and distribute the article, so long as appropriate credit is given to the authors and source of the work. The license ensures that the published article will be as widely available as possible and that your article can be included in any scientific archive. Open Access authors retain the copyrights of their papers. Open access is a property of individual works, not necessarily journals or publishers.

**Cite this paper as:** Gudiño, W., Ávila-Díaz, I., Oyama, K. and de la Barrera, E. 2015. High-temperature tolerance by the endangered Mexican Mayflower orchid, *Laelia speciosa*. Tropical Conservation Science Vol.8 (4): 983-991. Available online: www.tropicalconservationscience.org

**Disclosure**: Neither Tropical Conservation Science (TCS) or the reviewers participating in the peer review process have an editorial influence or control over the content that is produced by the authors that publish in TCS.

## Introduction

Illegal harvesting from their native habitat is a leading cause for diversity loss among tropical epiphytes [1]. This is the case for the Mayflower, *Laelia speciosa*, an endemic orchid from central Mexico that has great cultural significance in the state of Michoacán (Fig. 1) [2,3].The plant produces attractive flowers during the spring (hence its common name of *flor de mayo*; translation: Mayflower) that are illegally harvested and sold in streets and markets of the state capital. In addition, a mucilaginous juice is extracted from its pseudobulbs (the water- and nutrient-storing organs that many epiphytic orchids produce during their development) and mixed into a paste with the pith of dry maize stalks to craft religious art that is displayed in numerous Roman Catholic temples throughout Mexico. Because extensive harvesting has reduced its distribution range by 11% over the past two decades, the Mayflower has been classified as endangered by the Mexican environmental authority [4,5].




**Fig. 1. The Mayflower orchid (*Laelia speciosa*) in bloom. A) *In vitro* propagated individuals and B) rescued individuals are currently kept in a shadehouse at the Instituto de Investigaciones en Ecosistemas y Sustentabilidad, Universidad Nacional Autónoma de México. Photograph in panel A kindly provided by Ms. Leonor Solís.**



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

The conservation of endangered plant species can be aided by *in vitro* propagation, a technique that enables the massive production of plants for reintroduction or commercial purposes, thus relieving pressure on natural populations [6–8]. Species-specific protocols for *in vitro* propagation have been developed for several epiphytic orchids, including the Mayflower [6,7,9]. Numerous individuals resulting from *in vitro* propagation can be contained in relatively small spaces, at relatively low costs, and plant development can be arrested until the regeneration of fully formed plants is desired. However, as with most conservation practices, restricted genetic diversity ensues from use of a limited number of genotypes, although it can be artificially enhanced via artificial mutagenesis, as has been done for *Agave victoria-reginae*; once thought extinct, this species was rescued from a single individual identified in a home garden in west-central Mexico [8,10].

The eventual release of *in vitro* propagated plants requires a relatively long process of acclimation to natural or semi-natural environmental conditions in order to improve the chances of plant survival and establishment. This is especially true for epiphytes, because their environment is highly fluctuating, in stark contrast with the stable conditions prevailing in tissue culture rooms [11,12]. How well young propagated plants might withstand the natural environment needs to be determined so that their release can occur at the youngest age that yields adequate survival rates.

Global climate change poses an additional threat to the persistence of *L. speciosa* and other epiphytic vascular plants. On the one hand, the oak forests of central Mexico, to which *L. speciosa* is restricted, are among the most endangered ecosystems in the country under various climate change scenarios [3,13–16]. On the other hand, epiphytes such as the Mayflower are especially exposed to changing environmental factors, such as insolation, changes in temperature, severe and frequent droughts, and even atmospheric pollution [11,12,17–19]. Higher exposure leads to increased risk unless a species is tolerant of stress, but studies of environmental stress tolerance are scant for non-timber species from oak forests. Moreover, besides broad biogeographical and morpho-physiological patterns, high-temperature tolerance is unknown for orchids in general [18,20].

Air temperature influences all biological processes, from controlling the rates of enzymatic activity, to determining plant phenology over the course of a year, to limiting the distribution of a species [21]. For plants, high air temperature, which is often coupled with high insolation, can range from temporary inhibition of photosynthesis to permanent physiological damage [22,23]. These processes can be monitored by means of chlorophyll fluorescence [24,25]. High quantum yields can be indicative of growth for orchids [26]. In contrast, the quantum yield (Fv/Fm) shrinks by half for epiphytic orchids from the Yucatán Peninsula during the dry season, when air temperatures are the highest [18].

While mean air temperatures are a most useful predictor of plant performance in the field, extreme air temperature events (very high or very low), however rare, can actually kill an entire population [21,27], and plant responses to extreme events can be delayed up to several years [28,29]. Therefore, a useful laboratory method for quickly determining extreme temperature tolerance by plants has been developed that measures cell viability following the exposure of plant tissue to increasingly extreme high or low temperatures [21,27]. By expressing cell viability—scored as electrolyte leakage or as cells taking up a vital stain—as the proportion of cells that remain viable after exposure to extreme temperatures, a parameter can be found, $LT_{50}$, which is a good predictor



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

of tolerance to extreme temperature. The high-temperature $LT_{50}$ can reach values of up to 70 °C for *Cylindropuntia acanthocarpa*, 64 °C for *Agave americana*, 55 °C for the hemiepiphytic cactus *Hylocereus undatus*, and 43 °C for the understory legume *Lupinus elegans* [27,30,31]. When plants are incubated at different mean air temperatures, differences in the $LT_{50}$ indicate a plant's ability to acclimate to changing environments. In particular, the $LT_{50}$ for *C. acanthocarpa* increases by 0.6 °C for each degree that the incubation temperature is raised; acclimation is 0.3, 0.1, and 0 °C per degree that the incubation temperature is raised for *A. americana*, *H. undatus*, and *L. elegans*, respectively [31–33]. Alas, both the $LT_{50}$ and the acclimation capacity of orchids are unknown.

Because it is uncertain whether the Mayflower will be able to survive the substantially warmer environment projected to occur during the present century or increasingly frequent high air temperature episodes, we tested its high-temperature tolerance and acclimation for two-year-old *in vitro* propagated plants and adult individuals of natural origin, to evaluate the utility of *in vitro* propagation for conservation of this endangered orchid.

## Methods

High-temperature tolerance was determined for *in vitro* propagated individuals of Mayflower (*Laelia speciosa* (Kunth) Schltr.) and compared with that of mature individuals that were originally obtained from a wild population. In particular, one-year-old *in vitro* propagated individuals of *L. speciosa* were acclimated to greenhouse conditions (mean air temperature of 25 °C, ranging from 15 to 38 °C) at the Instituto de Investigaciones en Ecosistemas y Sustentabilidad (19°38'55.9"N; 101°13'45"W; 1967m), Universidad Nacional Autónoma de México, for an additional year prior to the start of the experiment [9,34]. The mature wild-grown individuals had been rescued in 2004 from a construction site about 7 km from campus. These plants were kept on their original substrate, *i.e.,*, branches of *Quercus deserticola*, and placed on a mesh bench inside a shadehouse (mean air temperature of 23 °C, ranging from 15 to 35 °C), allowing the plants to remain under semi-natural conditions. The individuals used in this experiment had an average of eight pseudobulbs, and were presumably eight years old, as this species produces one new pseudobulb every year [3].

On 23-26 April 2008, 10 individuals from each age group were placed inside growth chambers (Percival Scientific, Boone, Iowa, USA) according to a randomized block design, where they were exposed to a 12-h photoperiod and allowed to acclimate to three day/night air temperature regimes: 25/15, 30/20, and 35/25 °C, for 30 days under 50% relative humidity. The plants' photosynthetic performance under the experimental temperature regimes was assessed with measurements of chlorophyll fluorescence (quantum yield, $F_v/F_{max}$) conducted with a FluorPen Handheld Fluorometer (Qubit Systems, Kingston, Ontario, Canada).

Plant tolerance to high temperatures was also determined by electrolyte leakage, an indicator of cell viability that increases as the membrane degrades in response to stress [27,31,35]. In particular, several leaf discs (6 mm in diameter) were obtained with a cork borer from each plant and placed in 1.5 ml microcentrifuge tubes that contained cotton damped with distilled water to prevent tissue desiccation. The tubes were placed in a Tropicooler benchtop cooler/heater (Boekel Scientific, Feasterville, Pensilvania, USA) for exposure to high temperatures. A given high temperature was maintained during one hour, following which a leaf disc was removed from the tube, placed in a glass vial containing 15 ml of deionized distilled water and placed for 40 min in an orbital shaker set at 200 rpm. At the same time, a second disc was removed from the vial and boiled for 5 min to fully disrupt cell membranes and obtain the maximum electrolyte leakage, before being placed in the



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

orbital shaker as described above. Electrical conductivity of the incubation solutions was measured following agitation with an Orion 3 Star conductivimeter (Thermo Electron Corporation, Waltham, Massachusetts, USA), and electrolyte leakage was expressed as percentage of the maximum. For the remaining leaf discs, the incubation temperature was progressively raised in 5 °C increments (rate of 0.5 °C $min^{-1}$) for additional successive 1-h incubation periods. This process was repeated until the electrolyte leakage reached 100% of the maximum. The temperature at which half of the maximum electrolyte leakage occurred (lethal temperature-50, $LT_{50}$) was identified for both the propagated and the rescued individuals as an indicator of temperature tolerance in the field [27].

Chlorophyll fluorescence and $LT_{50}$ were analyzed with a two-way ANOVA (factors were plant age × air temperature) followed by pairwise Tukey Tests ($p < 0.05$) [36]. Statistical analyses were performed with SigmaStat 3.5 (SYSTAT Software, Point Richmond, CA, USA). Data are shown as mean ± s.e. (n = sample size).

## Results

The experimental temperature regimes had an effect on both chlorophyll fluorescence and high-temperature tolerance of the Mayflower orchid, which depended on plant age (Table 1). In particular, the photosynthetic quantum yield (Fv/Fm) tended to be higher for the mature plants than for the propagated individuals, especially under the warmest treatment. Indeed, Fv/Fm ranged from 0.64 ± 0.02 for the propagated plants under 35/25 °C, to 0.77 ± 0.01 for the mature plants growing under 25/15 °C. The $LT_{50}$ also changed with incubation temperature for both the propagated and the mature individuals (Table 1). In this case, some acclimation occurred as the $LT_{50}$ was 47.67 ± 0.40 °C for plants incubated under 20/10 °C, increasing by 3.34 °C for plants incubated under 25/15 °C, *i.e.,* 0.67 °C for each degree that the incubation temperature was raised. The highest experimental incubation temperature led to a dramatic decrease of the $LT_{50}$ regardless of plant age.

**Table 1.** Acclimation parameters for micropropagated one-year-old and rescued three-year-old individuals of *Laelia speciosa* kept at the indicated day/night temperature regime during 4 weeks. $LT_{50}$ refers to the temperature at which half of the cell membrane viability, expressed as percent of maximum, is lost. Acclimation refers to the displacement of the $LT_{50}$ relative to that for plants kept at 25/15 °C. Data are shown as mean ± 1 S.E. (n = 10). For a given parameter different letters indicate a statistical difference with ($p < 0.05$).

| Temperature (day/night °C) | Chlorophyll fluorescence (Fv/Fm) | | $LT_{50}$ (°C) | |
|---|---|---|---|---|
| | Young | Mature | Young | Mature |
| 25/15 | 0.74 ± 0.01 *a,b* | 0.77 ± 0.01 *b* | 47.55 ± 0.73 *a* | 47.78 ± 0.06 *a* |
| 30/20 | 0.72 ± 0.01 *a* | 0.74 ± 0.01 *a,b* | 50.87 ± 0.26 *b* | 51.17 ± 0.16 *b* |
| 35/25 | 0.64 ± 0.02 *c* | 0.72 ± 0.01 *a,b* | 39.99 ± 1.32 *c* | 44.48 ± 0.66 *d* |

## Discussion

High-temperature tolerance tended to be greater for the mature Mayflower individuals than for the two-year old plants from *in vitro* propagation. This agrees with a frequently found pattern among various life-forms, in which increasing plant age leads to greater tolerance of environmental stress [37]. For instance, cuttings of the hemiepiphytic cactus *Hylocereus undatus* are not able to withstand air temperatures above 45 °C, but adult individuals are often exposed to this temperature in



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

commercial plantations from the Yucatán Penninsula, Mexico [30,38,39]. Also, the high temperature $LT_{50}$ for young stems of *Opuntia ficus-indica* is 6.5 °C lower than for those that are 10 years old [40].

The quantum yield (Fv/Fm) was relatively stable for the Mayflower, except for the *in-vitro* propagated individuals incubated under the highest temperature treatment, which had a substantial reduction in variable fluorescence. Similarly, the quantum yield is reduced for epiphytic orchids from the Yucatán Peninsula during the time of year when the air temperatures are highest [18]. In contrast, high quantum yields can be indicative of growth for some orchids [26]. If this was the case for the Mayflower orchid, even the highest temperature treatment of 35/25 °C could lead to some growth for the mature individuals considered in the present study, but not for the two-year old plants from *in vitro* propagation. For the latter, the quantum yield was consistent with that of plants subjected to environmental stress [25].

While plant performance is greatly influenced by mean air temperature, extreme events, even if rare, can actually kill individuals that should otherwise be able to survive or even thrive at a given location [27,32]. It is likely that an increase in the frequency and the magnitude of high-temperature events will develop during the current century, including within the distribution range for the Mayflower [14,16,41]. However, the $LT_{50}$ determined here for the Mayflower was the lowest among 31 succulent plant species of different growth forms; the closest species is the hemiepiphytic cactus *Hylocereus undatus*, whose $LT_{50}$ is still 5-16 °C higher than the one determined here for the orchid [30,33]. However, the $LT_{50}$ for the Mayflower orchid as higher than that of the sympatric understory shrub *Lupinus elegans* ($LT_{50}$ = 43°C) [31].

Incubation temperatures, including the prevalent mean air temperature at a given site, can influence plant extreme temperature tolerance. Indeed, for 31 succulents, the $LT_{50}$ increases by 0.42 ± 0.04 °C for each degree that the incubation temperature increases [27]. For the Mayflower orchid, the $LT_{50}$ increased by 0.6-1.0 °C for each degree that the incubation temperature increased, up to 30/20 °C, indicating a higher acclimation capacity for this orchid than for some of the other succulent species [30]. However, the fact that a further increase of the incubation temperature led to a substantially lower $LT_{50}$ suggests that the Mayflower requires a fairly stable air temperature to remain physiologically active. The ability to acclimate to changing environmental conditions will be crucial for the survival of species that will be exposed to the accelerated temperature increase projected to occur during the present century.

## Implications for conservation

*In vitro* propagation can be a useful tool for the conservation of plant species [8,10]. Consequently, specific propagation protocols have been developed for numerous species of orchids, including for the Mayflower orchid [6,42–44]. At least for the orchid considered in our study, high-temperature tolerance of *in vitro* propagated individuals is fairly similar to that of mature individuals, except under the highest experimental treatment, as discussed above. Either an acclimation protocol needs to be developed that induces temperature hardening for *in vitro* propagated individuals, or the actual age when acclimation becomes possible needs to be determined if a reintroduction program is to be implemented. However, because the lethal temperatures determined here are still rare in its area of distribution, including the city of Morelia, where most of the illegal trade in wild Mayflowers occurs, marketing of *in vitro* propagated individuals able to tolerate current environmental conditions could relieve extractive pressure on wild populations.



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

## Acknowledgements

Financial support for this project was provided by the "Macroproyecto sobre Manejo de Ecosistemas y Desarrollo Humano" and Dirección General del Personal Académico (PAPIIT RN204013), Universidad Nacional Autónoma de México. We thank the personnel of the IIES Botanical Gardens for maintenance of the plants prior to the experiment, especially Ms. MD Lugo and Mr. J. Martínez-Cruz. Ms. Leonor Solís kindly took the photograph for panel A. This work was completed while EdlB held a generous Fulbright NEXUS Fellowship at the hospitable International Food Policy Research Institute.

## References

[1] Mondragon, D., Valverde, T. and Hernandez-Apolinar, M. 2015. Population ecology of epiphytic angiosperms: a review. *Tropical Ecology* **56**: 1–39.

[2] Ávila-Díaz, I. and Oyama, K. 2007. Conservation genetics of an endemic and endangered epiphytic *Laelia speciosa* (Orchidaceae). *American Journal of Botany* **94**: 184–93.

[3] Soto-Arenas, M.A. and Solano-Gómez, A.R. 2007. Ficha técnica de *Laelia speciosa*. In: Soto-Arenas MA, ed. *Información Actualizada Sobre Las Especies de Orquídeas Del PROY-NOM-059-ECOL-2000*, Instituto Chinoin A.C., Herbario de la Asociación Mexicana de Orquideología. Bases de datos SNIB-CONABIO. Proyecto No. W029., México, D.F.

[4] NOM-059-SEMARNAT-2010. 2010. Norma Oficial Mexicana NOM-059-SEMARNAT-2010: Protección ambiental-especies nativas de México de flora y fauna silvestres-categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-lista de especies en riesgo. Diario Oficial de la Federación.

[5] Flores Tolentino, M. 2015. Distribución geográfica potencial de *Laelia speciosa* en México: una evaluación de su estado de conservación. Bachelor's Thesis. Universidad Michoacana de San Nicolás de Hidalgo.

[6] Ávila-Díaz, I., Oyama, K., Gómez-Alonso, C. and Salgado-Garciglia, R. 2009. *In vitro* propagation of the endangered orchid *Laelia speciosa*. *Plant Cell, Tissue and Organ Culture (PCTOC)* **99**: 335–43.

[7] Díaz-Álvarez, E.A., Torres-Galeano, C., Rojas-Cortés, A.P. and de la Barrera, E. 2015. In-vitro germination and development of two endangered endemic Colombian orchids, Cattleya mendelii and Cattleya quadricolor. *Gayana Botánica* **72**: 303-310.

[8] Santacruz-Ruvalcaba, F., Gutiérrez-Mora, A. and Rodriguez-Garay, B. 1998. Somatic embryogenesis in some cactus and agave species. *Journal of the Professional Association for Cactus Development* **3**: 15–26.

[9] Ávila-Díaz, I. and Salgado-Garciglia, R. 2006. Propagación y mantenimiento *in vitro* de orquídeas mexicanas, para colaborar en su conservación. *Biológicas* **8**: 138–49.

[10] Rodríguez-Garay, B., Gutiérrez-Mora, A. and Acosta-Duefias, B. 1996. Somatic embryogenesis of Agave victoria-reginae Moore. Plant Cell, Tissue and Organ Culture **45**: 85–87.

[11] Andrade, J.L. and Nobel, P.S. 1997. Microhabitats and water relations of epiphytic cacti and ferns in a lowland neotropical forest. *Biotropica* **29**: 261–70.

[12] Nobel, P.S. and de la Barrera, E. 2004. $CO_2$ uptake by the cultivated hemiepiphytic cactus, *Hylocereus undatus*. *Annals of Applied Biology* **144**: 1–8.

[13] Villers-Ruiz, L. and Trejo-Vázquez, I. 2000. El cambio climático y la vegetación en México. In:



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

Gay-García C, editor. *México: Una Visión Hacia El Siglo XXI El Cambio Climático En México*, Universidad Nacional Autónoma de México, México, D.F. p. 57–66.

[14] Sáenz-Romero, C., Rehfeldt, G.E., Crookston, N.L., Duval, P., St-Amant, R., Beaulieu, J. et al. 2010. Spline models of contemporary, 2030, 2060 and 2090 climates for Mexico and their use in understanding climate-change impacts on the vegetation. *Climatic Change* **102**: 595–623.

[15] Trejo, I., Martínez-Meyer, E., Calixto-Pérez, E., Sánchez-Colón, S., Vázquez de la Torre, R. and Villers-Ruiz, L. 2011. Analysis of the effects of climate change on plant communities and mammals in Mexico. *Atmósfera* **24**: 1–14.

[16] Rehfeldt, G.E., Crookston, N.L., Sáenz-Romero, C. and Campbell, E.M. (2012) North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* **22**: 119–41. http://dx.doi.org/10.1890/11-0495.1

[17] Díaz-Álvarez, E.A., Lindig-Cisneros, R., Reyes-García, C. and de la Barrera, E. 2014. Effects of simulated nitrogen deposition and a stable isotopic assessment for the neotropical epiphytic orchid Laelia speciosa. *PeerJ PrePrints* **2**: e771v1. http://dx.doi.org/10.7287/peerj.preprints.771v1

[18] de la Rosa-Manzano, E., Andrade, J.L., Zotz, G. and Reyes-García, C. 2014. Respuestas fisiológicas a la sequía, de cinco especies de orquídeas epífitas, en dos selvas secas de la península de Yucatán. *Botanical Sciences* **92**: 607–16.

[19] Reyes-García, C. and Griffiths, H. 2009. Ecophysiological studies of perennials of the Bromeliaceae family in a dry forest: strategies for survival. In: de la Barrera E, and Smith WK, editors. *Perspectives in Biophysical Plant Ecophysiology: A Tribute to Park S Nobel*, Universidad Nacional Autónoma de México, México, D.F. p. 121–51.

[20] Silvera, K., Santiago, L.S. and Winter, K. 2005. Distribution of crassulacean acid metabolism in orchids of Panama: evidence of selection for weak and strong modes. *Functional Plant Biology* **32**: 397–407.

[21] Nobel, P. 2009. Physicochemical and Environmental Plant Physiology. 4th ed. Academic Press / Elsevier.

[22] Nobel, P.S. and de la Barrera, E. 2004. $CO_2$ uptake by the cultivated hemiepiphytic cactus, Hylocereus undatus. *Annals of Applied Biology* **144**: 1–8.

[23] Taiz, L. and Zeiger, E. 1998. Plant Physiology. 2nd ed. Sinauer Associates Sunderland.

[24] Schreiber, U. 1983. Chlorophyll fluorescence yield changes as a tool in plant physiology I. The measuring system. *Photosynthesis Research* **4**: 361–73.

[25] Ritchie, G.A. 2006. Chlorophyll fluorescence: What is it and what do the numbers mean. *National Proceedings: Forest and Conservation Nursery Associations-2005*, 34–42.

[26] Hsu, B.D. 2007. On the possibility of using a chlorophyll fluorescence parameter as an indirect indicator for the growth of Phalaenopsis seedlings. *Plant Science* **172**: 604–608.

[27] Drennan, P.M. 2009. Temperature influences on plant species of arid and semi-arid regions with emphasis on CAM succulents. In: de la Barrera E, and Smith WK, editors. *Perspectives in Biophysical Plant Ecophysiology: A Tribute to Park S Nobel*, Universidad Nacional Autónoma de México. p. 57–99.

[28] Steenbergh, W. and Lowe, C. 1976. Ecology of th saguaro I. The role of freezing weather in a warm-desert population. *Research in the Parks, National Park Servic Symposium Series, Number 1*, US Government Printing Office, Washington, D.C. p. 49–92.

[29] Steenbergh, W. and Lowe, C. 1983. Ecology of the Saguaro. III. Growth and Demography. *National Park Service Scientific Monograph Series Number 17*, US Government Printing



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

Office, Washington, D.C.
[30] Nobel, P.S. and de la Barrera, E. 2002. High Temperatures and Net CO2 Uptake, Growth, and Stem Damage for the Hemiepiphytic Cactus *Hylocereus undatus*. *Biotropica* **34**: 225–31.
[31] Soto-Correa, J.C., Sáenz-Romero, C., Lindig-Cisneros, R. and de la Barrera, E. 2013. The neotropical shrub *Lupinus elegans*, from temperate forests, may not adapt to climate change. *Plant Biology* **15**: 607–10. http://dx.doi.org/10.1111/j.1438-8677.2012.00716.x
[32] Nobel, P.S. 1988. Environmental Biology of Agaves and Cacti. Cambridge University Press.
[33] Nobel, P.S., de la Barrera, E., Beilman, D.W., Doherty, J.H. and Zutta, B.R. 2002. Temperature limitations for cultivation of edible cacti in California. *Madroño* **49**: 228–236.
[34] Ortega Loeza, M.M. 2003. Aclimatación de plántulas cultivadas *in vitro* de *Laelia speciosa* (H.B.K.) Schlechter. Bachelor's Thesis. Universidad Michoacana de San Nicolás de Hidalgo.
[35] Didden-Zopfy, B. and Nobel, P.S. 1982. High temperature tolerance and heat acclimation of *Opuntia bigelovii*. *Oecologia* **52**: 176–80.
[36] Sokal, R.R. and Rohlf, F.J. 2012. Biometry. 4th ed. MacMillan Education.
[37] de la Barrera, E., Pimienta-Barrios, E. and Schondube, J.E. (2009) Reproductive ecophysiology. In: de la Barrera E, and Smith WK, editors. *Perspectives in Biophysical Plant Ecophysiology: A Tribute to Park S Nobel*, Universidad Nacional Autónoma de México. p. 301–35.
[38] Andrade, J.L., Rengifo, E., Ricalde, M.F., Sima, J.L., Cervera, J.C. and Vargas-Soto, G. 2006. Light microenvironments, growth and photosynthesis for pitahaya (*Hylocereus undatus*) in an agrosystem of Yucatan, Mexico. *Agrociencia* **40**: 687–97.
[39] Servicio de Información Agroalimentaria y Pesquera. 2015. Producción agrícola anual. Available online at http://www.siap.gob.mx/ [Accessed on 19 October 2015].
[40] Nobel, P.S. and De La Barrera, E. 2003. Tolerances and acclimation to low and high temperatures for cladodes, fruits and roots of a widely cultivated cactus, *Opuntia ficus-indica*. *New Phytologist* **157**: 271–279. http://dx.doi.org/10.1046/j.1469-8137.2003.00675.x
[41] Intergovernmental Panel on Climate Change (IPCC). 2012. Managing the Risks of Extreme Events and Disasters to Advance Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, et al., editors. Cambridge University Press.
[42] Rubluo, A., Chávez, V., Martínez, A.P. and Martínez-Vázquez, O. 1993. Strategies for the recovery of endangered orchids and cacti through in vitro culture. *Biological Conservation* **63**: 163–169.
[43] Arditti, J. and Krikorian, A.D. 1996. Orchid micropropagation: the path from laboratory to commercialization and an account of several unappreciated investigations. *Botanical Journal of the Linnean Society* **122**: 183–241.
[44] Buyun, L., Laverentyeva, A., Kovalska, L. and Ivannikov, R. 2004. In vitro germination of seeds of some rare tropical orchids. *Acta Universitatis Latviensis* **676**: 159–62.



Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use