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Provenance Trials of the Mexican Spruces in Nursery Conditions: Three Species Endangered by Climatic Variation †

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Abstract: The three Mexican spruces' distribution is fragmented, which could lead to phenological, morphological and genetic differentiations, partially caused by local adaptation. In this study we examined the effect that climatic variables have on the growth and survival of 5641 *Picea* seedlings coming from eight seed provenances of three species and produced in identical nursery conditions, as a proxy of the genetic differentiation and adaptation among populations. A cluster analysis revealed: i) significant differences in the genetic quantitative traits among the three *Picea* species and ii) significant correlations among genetic quantitative traits and climatic factors.

Keywords: phenotypic differences; genetic differences, adaptation

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1. Introduction

In Mexico, there are three endemic species of the *Picea* genus, which live in relict populations and are listed as "Endangered" on the Red List of the IUCN [1]. *P. mexicana* has only three locations, above 3000 m elevation [2,3], *P. martinezii* is in four populations between 1800 and 2500 m [4] and *P. chihuahuana* has been found at 40 sites between 2311 and 2700 m [2,5]. The Mexican spruces' distributions are fragmented in isolated populations, which could lead to phenological, morphological and genetic differentiations, partially caused by local adaptation to different soil types and climatic variables [6]. Therefore, it is important to identify the main factors responsible for such adaptation, which could be helpful in assisted migration programs, as an option for ex situ conservation. Provenance-progeny trials allow the design of conservation programs for saving genetic resources in the medium and long terms. In our experiment, we studied the genetic and environmental components of the phenotypical variation among trees of different provenances [7]. Specifically, we examined the effect that elevation and bioclimatic variables have on the survival and growth of seedlings of each *Picea* species' provenances, in equal nursery conditions, assuming that such a response could be a proxy of the adaptation or the genetic differentiation among populations.

2. Experimental Section

We based our study on eight provenances of the three Mexican spruces, located in four states of Mexico: one provenance is from Chihuahua, one from Durango, one from Coahuila and five from Nuevo Leon. The mean 100-seed weight based on three trees per provenance was measured with a digital weight balance (Velab model No. VE-5000H, Mexico). We established our provenance trial experiment in a nursery in El Salto, municipality of Pueblo Nuevo, Durango, at an elevation of 2590 m, where each seedling was put in one round container of 165 cm^3. There, we measured the survival of 5641 seedlings and their growth in diameter (mm) and height (mm), during 12 months. All these seedlings grew in the same climate and soil conditions. On the other hand, values of 14 bioclimatic variables were modeled for each provenance [8].

We used Spearman's correlation (r_s) test [9] to look for potential relationships between mean growth (diameter and height, mm), 100-seed weight (g) and each analyzed bioclimatic variable and elevation from each species and provenance. We used the same test to detect collinearity between climatic variables. The mean growth differences between the three species were tested with the Tukey and Kramer (Nemenyi) test, defining the Tukey distribution using the PMCMR package of the statistical program *R* [10]. We also applied a Bonferroni correction, with an original $\alpha = 0.05$ and a corrected $\alpha^* = 0.003$.

3. Results

The Nemenyi test indicated significant differences in diameter x height between the three spruces (Table 1).

Table 1. Absolute growth and growth differences of seedling Diameter x Height (mm) from *Picea chihuahuana*, *P. mexicana* and *P. martinezii* and their *p* values tested by Tukey and Kramer (Nemenyi) test with Tukey distribution.

Species	Mean growth (diameter x height) (mm^2)	Absolute difference in mean growth between the species (mm^2) (*p* value)	
		Picea martinezii	***Picea mexicana***
P. chihuahuana	609	792 (2×10^{-16})	324 (2.2×10^{-7})
P. mexicana	933	468 (2×10^{-16})	
P. martinezii	1401		

After the Bonferroni correction, we detected significant correlations between the seedling's genetic proxy (height) and some bioclimatic variables (Figure 1 and Table 2). We did not find any significant correlation between the mean 100-seed weight and the mean growth of the seedlings ($r_s = 0.78$, $p = 0.03$).

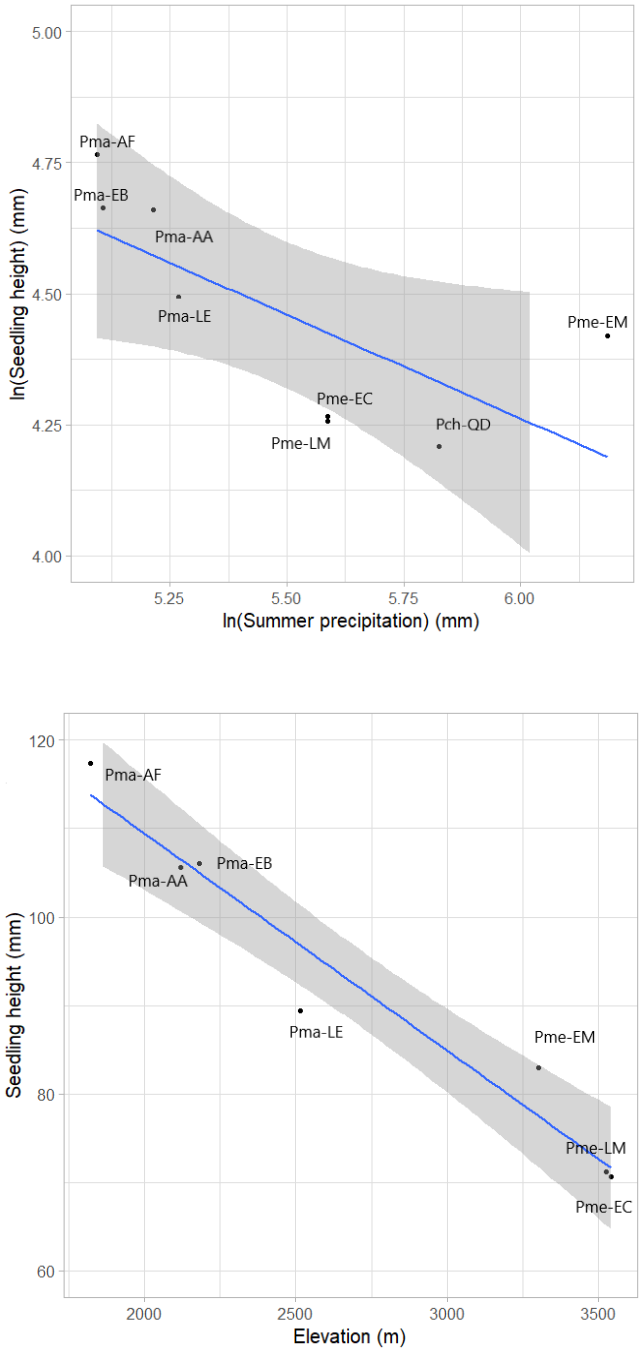

Figure 1. Linear relationships between mean seedling height and the summer precipitation (jul+aug) (mm) (with *Pch-QD*) and elevation (m) (without *Pch-QD*); *Pch-QD* = *Picea chihuahuana* - provenance *Quebrada de Duran, Pma-AF* = *P. martinezii* – provenance *Agua Fría, Pma-AA* = *P. martinezii* – provenance *Agua Alardín, Pma-EB* = *P. martinezii* – provenance *El Butano, Pma-LE* = *P. martinezii* – provenance *La Encantada, Pme-EM* = *P. mexicana* – provenance *El Mohinora, Pme-LM* = *P. mexicana* – provenance *La Marta, Pme-EC* = *P. mexicana* – provenance *El Coahuilón*.

Table 2. Spearman correlations (r_s) between mean seedling height and the most significant bioclimatic variables and elevation (*var*): Smrp = summer precipitation (mm), Smrsprpb = Summer/Spring precipitation balance: (jul+aug)/(apr+may), Elev = elevation (m), Mmax = Mean maximum temperature in the warmest month (centigrade degrees).

	Variable	r_s[*H x var*]	*p value*
With Pch-QD	Smrp	0.850	0.0074
	Smrsprpb	−0.826	0.011
	Elev	−0.833	0.015
Without Pch-QD	Elev	−0.964*	0.0028
	Mmax	0.883	0.008
	Smrp	−0.882	0.008
	Smrsprpb	−0.847	0.016

Note: *statically significant after Bonferroni correction. Pch-QD = *Picea chihuahuana* – provenance Quebrada de Duran

4. Discussion

Our results suggest that there are significant quantitative genetic differences among the three analyzed *Picea* species and that provenance differences are significantly correlated with the elevation, supporting the hypothesis of adaptation to local conditions [6]. However, a proportion of phenotypical plasticity cannot be ruled out because the provenance trial experiment was not reciprocally carried out. In another study, it was reported that precipitation was a moderately good predictor of height growth in *Picea mariana* [11], while Castellanos-Acuña et al. [12] found that the mean coldest month temperature and an aridity index are strongly related to the genetic adaptation of tree species.

5. Conclusions

Our findings about different effects of climatic variables on the three studied endangered *Picea* species and their provenances may have important practical implications for ex situ conservation strategies. Moreover, reforestation programs should be more successful if the seedlings of a given species are planted in very similar climatic conditions to those of its provenance, given the strong provenance-elevation (as climate proxy) association [13].

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Conflicts of Interest: The authors declare no conflict of interest.

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