Abstract: The three Mexican spruces’ distributions are fragmented, which could lead to phenological, morphological and genetic differentiation, partially caused by local adaptation. In this study, we examined the effect that climatic variables had on the survival and growth of 5641 Picea seedlings, coming from eight seed provenances of three species and produced in identical nursery conditions. The respective responses of each species and provenance can be considered as a proxy of the genetic differentiation and adaptation of each population. A cluster analysis revealed: (i) significant differences in genetic quantitative traits among the three Picea species and (ii) significant correlations between genetic quantitative traits and climatic factors.

Keywords: phenotypic differences; genetic differences, adaptation

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 climatic 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 cm³. 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 22 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 x Height, mm²), 100-seed weight and each analyzed climatic variable 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 $\alpha^* = 0.002$.

3. Results

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

| Species          | Mean growth (Diameter x Height) | Absolute Difference in Mean Growth between the Species (mm²) ($p$-value) |
|------------------|---------------------------------|-------------------------------------------------------------------------|
| $P. \text{chihuahuana}$ | 461                             | 765 ($2.8 \times 10^{-14}$) 367 ($1.3 \times 10^{-7}$)                  |
| $P. \text{mexicana}$    | 828                             | 398 ($2 \times 10^{-19}$)                                               |
| $P. \text{martinezii}$  | 1226                            |                                                                         |

After the Bonferroni correction, we detected significant correlations between the seedling’s genetic proxy (Diameter × Height) and some climatic 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 ($r_s = 0.69, p = 0.069$).

| Variable       | Units | $r_s$ | $p$-value |
|----------------|-------|-------|-----------|
| Smrsprpb       | mm    | -0.97 | 0.00007   |
| Mmin           | °C    | 0.90  | 0.00244   |

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

Table 2. Significant Spearman’s correlations ($r_s$) found between growth (Diameter × Height) and the climatic variables $M\text{min} = \text{Mean minimum temperature in the coldest month (Celsius degrees)}$, and $S\text{msprpb} = \text{Summer/spring precipitation balance: (Jul + Aug)/(Apr + May)}$. 


4. Discussion

Our results suggest that there are significant quantitative genetic differences among the three analyzed *Picea* species and that these differences are correlated with two climate variables (the mean minimum temperature in the coldest month and the summer/spring precipitation balance), supporting the hypothesis of adaptation to local conditions [6]. However, a proportion of phenotypical plasticity cannot be ruled out because the provenience 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-Acuna 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–climate association [13].

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