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Selection of *Pinus* spp. progenies in Lavras (Minas Gerais, Brazil) at 36 months of age

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Abstract

Background: The selection of superior genotypes and adapted to the edaphoclimatic conditions of the region of the introduction produces gains in productivity for forest stands. The objective of this study was to select progenies of *Pinus* spp. planted in Lavras, Minas Gerais (MG), Brazil.

Methods: The experimental site was located on dystrophic Haplic Cambisol. The progeny test was designed as a randomised complete block with 30 replicates and single plot. The treatments corresponded to one progeny of *Pinus massoniana*, three *Pinus caribaea* var. *bahamensis* and 33 *Pinus caribaea* var. *hondurensis* arranged with a 3 x 3 m spacing. The traits height (H), diameter at breast height (DBH) and crown projection area (CPA) were measured at 36 months of age.

Results: The results showed that heritability in the narrow sense was 0.24 for DBH, 0.27 for H and 0.50 for CPA. The DBH and H traits showed a high-magnitude positive correlation. The P7, P15, P27, P31 and P33 progenies showed better performance than the other progenies for the evaluated traits. Direct and indirect selection showed similar gains, which favors the use of indirect selection; i.e., when selecting progenies for DBH, progenies with better performance in H are also selected. Additionally, DBH may be used at advanced ages given the difficulty of measuring height. The progeny of *Pinus caribaea* var. *hondurensis* showed superior performance compared with *Pinus caribaea* var. *bahamensis* and *Pinus massoniana* for the region of Lavras, MG.

Conclusions: This study suggests the possibility of expanding the production of *Pinus caribaea* var. *hondurensis* in the region of Lavras with progenies P7, P15, P27, P31 and P33, because in the initial assessments they showed greater adaptability to the edaphoclimatic conditions. Nevertheless, performing a future selection with the aim of evaluating resin production is recommended.

Keywords: Genotypes; genetic parameters; behaviour; adaptability.

Introduction

The demand for timber products in Brazil and worldwide tends to increase with increasing population growth. Globally, it is estimated that approximately 250 million additional hectares of planted forests will be needed by 2050, and to meet this demand, it will be necessary to use breeding to select for genotypes of fast-growing, productive species that are adapted to the edaphoclimatic conditions of the planted region (IBÁ 2017).

The genus *Pinus* occurs naturally throughout North America, Central America, Asia, Europe and North Africa and is considered a group of fast-growing exotic plants in Brazil. When well-managed, this genus has supplied the market with the raw material that was historically supplied by native forest species such as *Araucaria* spp. (Shimizu 2008, Corrêa et al. 2012).

The genus *Pinus* includes *Pinus caribaea*, a fast-growing species that is tropical in origin and is used for wood production and, in particular, for resin extraction. This species is among those most frequently used for homogeneous reforestation in various parts of the world due to its adaptability to diverse climates and the broad application/destination of its products, which have undergone genetic improvement over recent decades. These improvements include an increase in volumetric yield and in the yield of trees with straight trunks, fewer whorls and thicker branches, which maximise the industrial usefulness of the wood (Missio et al. 2004, Shimizu 2008, Silva et al. 2011).

Genetic breeding is a key tool that enables gains in productivity because the selection of superior genotypes involves the assessment of traits of interest by estimating parameters, correlations and genetic gains that allow the selection of superior individuals between and within *Pinus* progenies (Manfio et al. 2012).

However, genetic breeding can be very expensive, because selection is performed through evaluation stages and with adult individuals, and requires several selection cycles. To minimise this expense, several studies have attempted to select genotypes at younger ages, as this requires less time for selection and makes it possible to change the objectives of selection (Xavier et al. 2009).

Early selection enables breeders of forest species to identify the traits of juvenile trees that are of economic interest at the end of a rotation, i.e., to predict at the juvenile stage the performance of an adult individual, which reduces the time required to complete a selection cycle. By reducing the test time, more rapidly identifying inferior genotypes and more promptly recommending new genotypes for commercial cultivation, i.e., by shortening the breeding cycle, the program of obtaining more productive genotypes is accelerated and the time between generations is decreased (Gonçalves et al. 1998, Massaro et al. 2010).

Selection at younger ages has been successful for the traits of height (H) and diameter at breast height (DBH) in *Eucalyptus* spp. at two years of age (Massaro et al. 2010). These traits at young and old ages were highly positively correlated, indicating that this type of selection can generate significant gains (Moraes et al. 2014).

There are studies in the literature on *Pinus caribaea* and *Pinus massoniana* in other countries, such as those by Sanchez et al. (2014), Liu et al. (2013) and Hodge & Dvorak (2001). However, there are no studies involving the selection of genotypes in juvenile *Pinus caribaea* and *Pinus massoniana* in the region of Lavras, Minas Gerais (MG), Brazil. Thus, the aim of the present study was to select *Pinus* spp. progenies grown in Lavras at 36 months of age.

Methods

The experimental site was located on the campus of the Federal University of Lavras (Universidade Federal de Lavras, UFLA) at 21°14'19.6"S latitude and 44°58'28.5"W longitude and at 905 metres above sea level. According to the Köppen classification, the climate is Cwb (highland tropical) with mild summers and a mean annual temperature of 19.6 °C, a mean annual rainfall of 1511 mm, a mean annual relative humidity of 76.2% and a total annual evaporation of 901.1 mm (Alvares et al. 2013). The progeny test was conducted at the ecotone between the Cerrado (Brazilian savanna) and seasonal semideciduous forest on soil categorized as dystrophic Haplic Cambisol using the Brazilian soil classification system (Embrapa 2013).

The test consisted of 37 progenies, including 33 progenies of *Pinus caribaea* var. *hondurensis* (P1–P33), three progenies of *Pinus caribaea* var. *bahamensis* (FT1–FT3) and one progeny of *Pinus massoniana* (Fec) obtained from open-pollinated and phenotypically selected maternal trees located in commercial plantations of Resineves Agroflorestal Ltda., Itapeva, São Paulo, Brazil. The seedlings were produced by the company in 55 cm^3 tubes filled with commercial substrate.

A soil chemical analysis was performed on the 0-20 cm soil layer (Table 1) using random zigzag sampling. A total of 15 points were collected and a composite was then created. Soil preparation included cleaning the entire area with the aid of a tractor (4 x 2 front-wheel drive), ant control (sulfluramid baits) and weed control (broad-spectrum herbicide with postemergence action). In the month of planting, the soil was prepared by heavy harrowing of the entire area.

Planting was performed in mid-September 2015. The spacing used was 3 x 3 m, and the holes were opened at the time of planting with the aid of a dibble. In each hole, along with the *Pinus* seedling, spores of mycorrhizal fungi that had been collected from fruiting bodies found within *Pinus* spp. stands were applied, as well as 200 mL of a solution of water-retaining polymer at a concentration of 1 g of polymer per plant. After planting, a solution of termiticide was applied to the stem of each seedling for the control of subterranean termites.

The experiment was arranged in a randomised complete block design with 30 replicates and single-tree plots. To control for edge effects, the entire experiment

TABLE 1**:** Soil chemical analysis of the 0-20 cm layer of the experimental site.

pH	**K**	**P**	**Ca**	**Mg**	**Al**	**H + Al**	**V**	**Zn**	**Fe**	**Mn**	**Cu**	**B**	**S**
	mg dm^{-3}		**cmol dm^{-3}**				**%**		**mg dm^{-3}**				
6	32	1.7	1.2	0.3	0.1	1.6	48.8	2.2	59.9	3.3	2.1	0.3	7.0

V = Base saturation index.

was surrounded by two rows of plants of the same species. The treatments consisted of three progenies of *Pinus caribaea* var. *bahamensis*, 33 progenies of *Pinus caribaea* var. *hondurensis* and one progeny of *Pinus massoniana*.

During the weeks following planting, it was necessary to irrigate the seedlings using a truck with a water reservoir and irrigators to ensure the initial survival of the seedlings until the beginning of the rainy season. During the entire period, leaf-cutter ants were monitored, and weeds were controlled by mechanised mowing (4 x 2 front-wheel drive) and the use of broad-spectrum postemergence herbicides.

At 36 months after planting, the survival, H, DBH and crown projection area (CPA) were evaluated. The percent survival was quantified as the total number of initial individuals for each species divided by the number of surviving individuals at 36 months and multiplied by 100. The CPA was obtained by measuring the crown projection between plants within the planting row (CPBP) and between the planting rows (CPBR). After these measurements, the CPA was calculated using the formula presented by Nieri et al. (2018) (Equation 1).

$$\text{CPA} = [(\text{CPBR}) \times (\text{CPBP}) \times \pi]\ /\ 4 \tag{1}$$

Genetic parameters were estimated for each measured trait via the restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) method using a mixed models analysis, which was performed with the R package Asreml using the following model (Equation 2):

$$y = Xb + Za + e \tag{2}$$

where y is the vector of the observations, b is the vector of the replicate effects (fixed), a is the vector of the individual additive genetic effects (random) and e is the vector of the residuals (random). The variables X and Z represent the incidence matrices for the cited effects.

The solution of the fixed effects (b) and random effects (a) of the model was obtained by solving the following equation (Henderson et al., 1959):

$$\begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z + A^{-1}\dfrac{\sigma_e^2}{\sigma_a^2} \end{bmatrix} \begin{bmatrix} b \\ a \end{bmatrix} = \begin{bmatrix} X'y \\ Z'y \end{bmatrix}$$

where A^{-1} is the inverse matrix of the additive relationship based on the pedigree using the inbreeding index. The following distributions and mean and variance structures were assumed:

$$y|b, V \sim N(Xb, V)$$

$$a|A, \sigma_a^2 \sim N(0, A\sigma_a^2)$$

$$e|\sigma_e^2 \sim N(0, I\sigma_e^2)$$

The progenies of *Pinus caribaea* var. *bahamensis* and *Pinus massoniana* were considered fixed, obtaining the best linear unbiased estimator (BLUEs). The estimated genetic parameters were individual heritability (h_i^2), individual heritability in the narrow sense (h_r^2) (Equation 3), mean heritability of the progenies (h_m^2) (Equation 4), selective accuracy at the progeny level ($r_{\hat{g}g}$) (Equation 5), the coefficient of genetic variation (CV_g) (Equation 6) and the coefficient of residual variation (CV_e) (Equation 7).

$$\hat{h}_r = \frac{\hat{\sigma}^2{}_i}{\hat{\sigma}^2{}_g + \hat{\sigma}^2{}_e} \tag{3}$$

$$\hat{h}_m = \frac{\hat{\sigma}^2{}_g}{\frac{\hat{\sigma}^2{}_f}{nb} + \frac{\hat{\sigma}^2{}_e}{b} + \hat{\sigma}^2{}_g} \tag{4}$$

$$\hat{r}_{\hat{g}g} = (\frac{1 - PEV}{\sigma^2{}_g})^{1/2} \tag{5}$$

$$CV_g = \frac{\sqrt{\hat{\sigma}^2{}_g}}{\hat{m}}\,.100 \tag{6}$$

$$CV_e = \frac{\sqrt{\hat{\sigma}^2{}_e}}{\hat{m}}\,.100 \tag{7}$$

where $\hat{\sigma}_i{}^2$ is additive variance, $\hat{\sigma}_g{}^2$ is genetic variance, $\hat{\sigma}_e{}^2$ is residual variance, $\hat{\sigma}_f{}^2$ is phenotypic variance, PEV is the prediction error variance of genotypic values, and $\hat{\text{m}}$ is the mean of the analysed traits.

The genetic (r_g), (Eequation 8), environmental (r_e) (Equation 9) and phenotypic (r_f) (Equation 10) correlations were estimated between the H, DBH and CPA traits evaluated at 36 months after planting.

$$\hat{r}_{gXY} = \frac{\hat{\sigma}_{g_X g_Y}}{\sqrt{\hat{\sigma}^2{}_{gX}\,.\,\hat{\sigma}^2{}_{gY}}} \tag{8}$$

$$\hat{r}_{fXY} = \frac{\hat{\sigma}_{F_X F_Y}}{\sqrt{\hat{\sigma}^2{}_{F_X}\,.\,\hat{\sigma}^2{}_{F_Y}}} \tag{9}$$

$$\hat{r}_{EXY} = \frac{\hat{\sigma}_{E_X E_Y}}{\sqrt{\hat{\sigma}^2{}_{E_X}\,.\,\hat{\sigma}^2{}_{E_Y}}} \tag{10}$$

where $\hat{r}_{gXY}$, $\hat{r}_{fXY}$ and $\hat{r}_{EXY}$ are the genetic, phenotypic and environmental correlation coefficients, respectively, and $\hat{\sigma}_{gXgY}{}^2$, $\hat{\sigma}_{FXFY}{}^2$and $\hat{\sigma}_{EXEY}{}^2$ are the mean genetic, phenotypic and environmental covariances, respectively, between the traits the in pairs extracted by the model using the sum of pairs of traits as response variable (Kempthorne 1957).

The gain from direct selection (Equation 11) and indirect selection for H, DBH and CPA were calculated using the rank-summation index (I_{MM}) proposed by Mulamba & Mock (1978) for the evaluated traits (Equation 12). To calculate gain, 30.3% was used as the selection intensity.

$$SG = \frac{\sum_{i=1}^{n} BLUP}{n} \tag{11}$$

$$I_{(MM)j} = \sum_{i=1}^{n} rij \tag{12}$$

where SG is the selection gain, n is the number of selected progenies, $I_{(MM)j}$ is the index value associated with individual *j*, r*i* is the ranking of an individual relative to the jth trait and *n* is the number of traits considered in the index.

To test the significance of the random effects of the model, an analysis of deviance was performed using the likelihood ratio test (LRT) for the three traits (DBH, H and CPA).

Results

The mean percent survival of the progenies of *Pinus caribaea* var. *bahamensis*, *Pinus caribaea* var. *hondurensis* and *Pinus massoniana* was 99% (Table 2). These results were initial variables used to verify the adaptability of species to environmental conditions.

The analysis of deviance for the genetic and statistical parameters of the progenies of *Pinus caribaea* var. *hondurensis* revealed significant differences among the progenies tested for the variables DBH, H and CPA in the region of Lavras at 36 months of age (Table 3).

The random progenies of *Pinus caribaea* var. *hondurensis* had a mean ($\hat{\mu}_a$) DBH of 6.74 cm, a mean H of 4.34 m and a mean CPA of 4.18 m^2 plant^{-1}, which were considered satisfactory for the Lavras region. The estimation of heritability in the narrow sense (h_r^2) can be considered intermediate for DBH (0.24) and H (0.22) and high for the CPA (0.50).

The individual heritability and the mean heritability of progenies for DBH and H are considered intermediate and high, respectively, and for CPA, both are considered high. These parameters are fundamental and reflect that the tested genotypes have DBH, H and CPA traits that will be transmitted to their offspring and will consequently gain from the selection of superior genotypes.

When evaluating experimental precision and accuracy, the selective accuracy was 0.84 for DBH, 0.83 for H and 0.91 for CPA. The coefficient of genetic variation expresses the genetic variability found among the progenies, and the higher this coefficient, the greater the variability among the progenies. The coefficients were 19.52 for DBH, 15.80 for H and 26.44 for CPA. When considering the individual genetic variation coefficient, i.e., within the progenies, the values obtained were 9.76 for DBH, 7.90 for H and 13.22 for CPA.

Figure 1 shows that the P7, P15, P27, P31 and P33 progenies of *Pinus caribaea* var. *hondurensis* were among the 11 best progenies with regard to H, DBH and CPA. However, the progenies derived from *Pinus caribaea* var. *bahamensis* (FT1, FT2 and FT3) and *Pinus massoniana* (Fec) were ranked in the middle and lower parts of the plots.

TABLE 2: Percent survival of the progenies of *Pinus caribaea* var. *bahamensis*, *Pinus caribaea* var. *hondurensis* measured at 36 months in Lavras, MG.

Species	Survival (%)
Pinus caribaea var. *bahamensis*	99
Pinus caribaea var. *hondurensis*	98
Pinus massoniana	100
Mean	99

TABLE 3: Genetic parameters and deviance analysis for DBH, H and CPA of 33 *P. caribaea* var. *hondurensis* progenies at 36 months after planting in Lavras, MG.

Parameter	Diameter at breast height (DBH)	Height (H)	Crown projection area (CPA)
$\hat{\mu}$	5.871	4.082	3.758
$\hat{\mu}_a$	6.740	4.349	4.188
$\hat{\mu}_f$	5.002	3.814	3.327
σ_i^2	1.732**	0.472**	1.226**
σ_e^2	4.200	1.267	0.922
σ_f^2	5.932	1.739	2.148
h_i^2	0.29	0.27	0.57
h_r^2	0.24	0.22	0.50
h_m^2	0.70	0.69	0.83
r_{gg}	0.84	0.83	0.91
CV_g	19.52	15.80	26.44
CV_e	34.79	29.28	32.40
μ Fec[1]	4.03	3.73	3.46
μ FT1[2]	6.41	4.44	3.77
μ FT2[2]	3.75	2.93	2.33
μ FT3[2]	5.77	4.13	3.72

Overall mean of progenies ($\hat{\mu}$), mean of the random progenies ($\hat{\mu}_a$), mean of the fixed progenies ($\hat{\mu}_f$), additive variance (σ_i^2), environmental variance (σ_e^2), phenotypic variance (σ_f^2), individual heritability (h_i^2), individual heritability in the narrow sense (h_r^2), mean heritability of the progenies (h_m^2), selective accuracy at the progeny level (r_{gg}), genetic coefficient of variation (CV_g), residual coefficient of variation (CV_e).

** significant at 1% probability of error by the likelihood ratio test (LRT).

[1] Mean of the *Pinus massoniana* progeny.

[2] Mean of each *Pinus caribaea* var. *bahamensis* progeny.

Genetic correlation involves a mechanism that allows the explanation of the joint variation in two variables/traits. Table 4 shows a strong positive genetic correlation between DBH and H, DBH and CPA, and H and CPA.

Table 4 shows that the variables DBH and height had a strong genetic, phenotypic, and environmental correlation. The DBH and CPA had a strong genetic correlation. However, for environmental and phenotypic correlation, an average correlation was observed. When correlating H and CPA, there was a strong genetic correlation and average environmental and phenotypic correlation, as observed for DBH in correlation with the CPA.

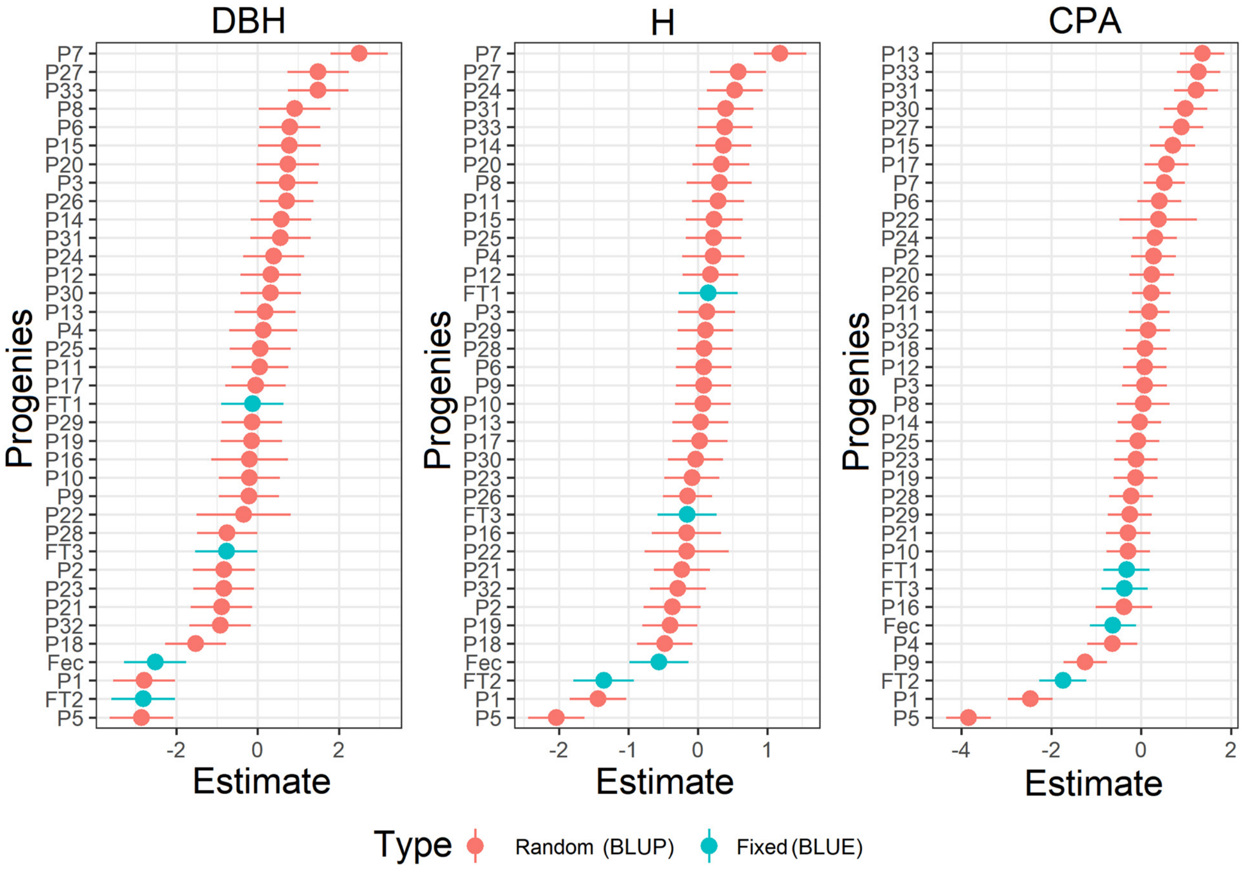

FIGURE 1: Ranking of progenies of *Pinus caribaea* var. *bahamensis*, *Pinus caribaea* var. *hondurensis* and *Pinus massoniana* for DBH, H and CPA in Lavras, MG, at 36 months of age.

When using and comparing different selection strategies and methods at the progeny level, it was observed that, as expected, the gain with direct selection was better than for indirect for all variables. However, for DBH and H, the difference was approximately 1.3% (Figure 2).

The direct selection showed greater gains for the CPA than selection by the method of the Mulamba e Mock (1978). The results of indirect selection indicate that for DBH and H, gains similar to direct selection were obtained, which reflects the high degree of correlation between the traits.

TABLE 4: Genetic, phenotypic and environmental correlations among DBH, H and CPA for progenies of *Pinus caribaea* var. *hondurensis* in the region of Lavras, MG, at 36 months after planting.

Treatment		Height	Crown projection area
DBH	r_g	0.830**	0.874**
	r_e	0.723**	0.657**
	r_f	0.822**	0.561**
Height	r_g		0.861**
	r_e		0.658**
	r_f		0.638**

**Significant by the t test at 1% probability of error.

Discussion

The observed results demonstrate the potential of these species planted in Lavras, given that Macedo et al. (2018) emphasises that survival is the initial parameter to determine the species potential for a region.

The progenies of *Pinus caribaea* var. *hondurensis* had results similar to those reported by Durigan et al. (2004) in Assis, São Paulo, at three years after planting; by Donadoni et al. (2010) in Vilhena, Rondônia, at three years of age and by Tambarussi et al. (2018) in Canoinhas, Santa Catarina, at four years after planting. The latter observed an average of 5 cm DBH, 4 m H and 1.63 m^2 $plant^{-1}$ CPA, which demonstrates the potential of the tested progenies for the region of Lavras. The growth in DBH and H for *Pinus massoniana* and *Pinus caribaea* var. *bahamensis* were similar in comparison with studies by Liu et al. (2013) and Romanelli & Sebbenn (2004), respectively.

According to the classification of Resende (2002), heritabilities below 0.15 were classified as low magnitude, heritabilities between 0.15 and 0.50 are classified as intermediate magnitude, and heritabilities above 0.50 are classified as high magnitude. The heritabilities observed were similar to those obtained by Tambarussi et al. (2010), Souza et al. (2017) and Tambarussi et al. (2018) and are higher than those reported by Silva et al. (2011).

According to Ramalho et al. (2012), heritability can be conceptualised as the proportion of genetic

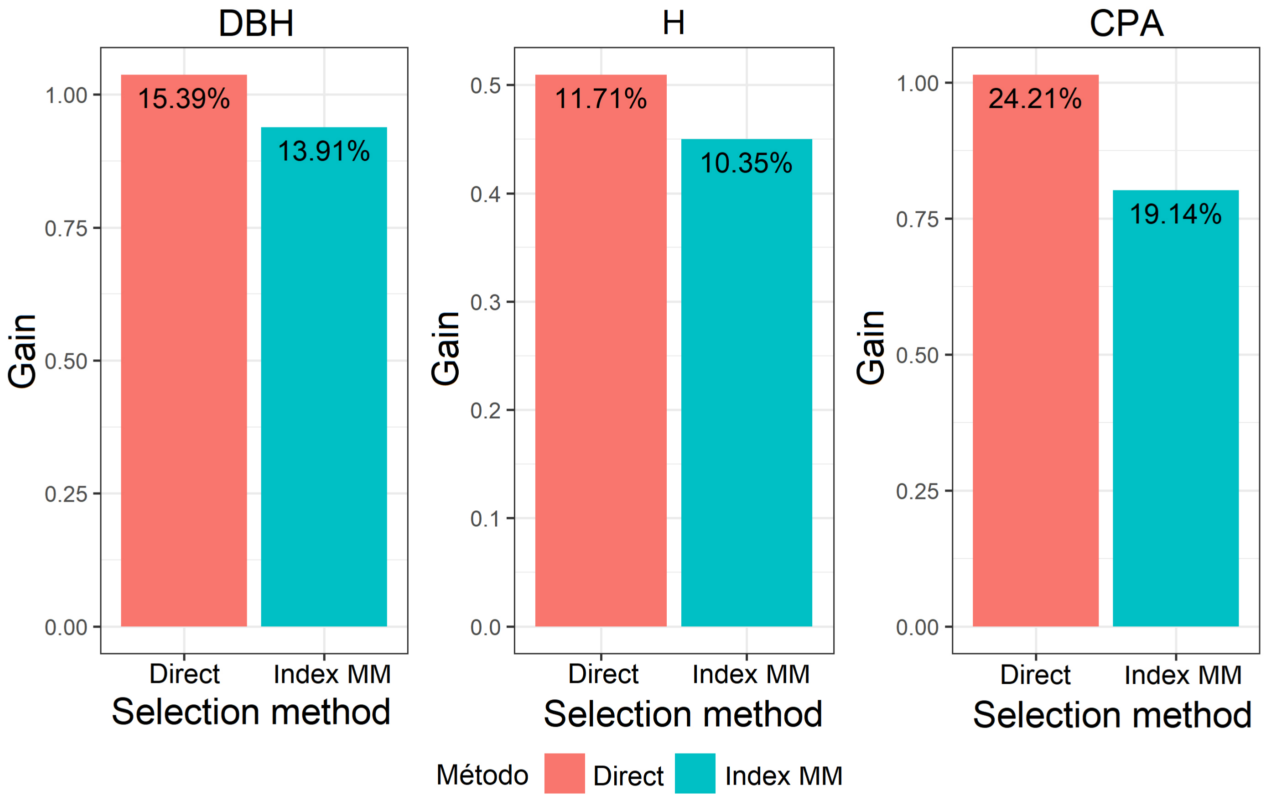

FIGURE 2: Gains from selection for DBH, H and CPA using the direct method and the method of Mulamba & Mock (1978) for progenies of *Pinus caribaea* var. *hondurensis* in Lavras, MG, at 36 months.

variation present in the total phenotypic variance, which according to Souza et al. (2017), estimates the reliability of the phenotypic value as an indicator of reproductive value; for this reason, the mentioned heritabilities are frequently included in expressions aimed at gain prediction, which in turn assists breeders in making decisions in genetic improvement programs.

Resende & Duarte (2007) reported that, to promote selection and recombination for plant breeding, recommended selection accuracy values are above 0.70. The selective accuracy values were similar to those obtained by Tambarussi et al. (2018), who selected *Pinus elliottii* x *Pinus caribaea* hybrids at four years after planting and found an accuracy of 0.91 for DBH and 0.93 for H. Souza et al. (2017), working with *Pinus caribaea* var. *hondurensis* at five years old, obtained values of 0.53 for DBH and 0.70 for H.

The results obtained for the evaluated traits were higher than those reported by Silva et al. (2011), Souza et al. (2017) and Pires et al. (2013). Coefficients above 7% are considered high, and the higher this coefficient is, the greater the genetic variability among progenies (Sebbenn et al. 1998).

Consistent with the present study, Sebben et al. (2010) conducted a survey at an altitude of 562 m with a mean annual rainfall of 1400 mm on soils classified as Typic Allic Dystrophic Red Latosol (according to the Brazilian soil classification system) and found that *Pinus caribaea* var. *hondurensis* exhibited growth in DBH and H of 2.6% and 4%, respectively, which were higher values than those observed in *Pinus caribaea* var. *bahamensis*.

For DBH and H, strongly positive genetic, phenotypic and environmental correlations were observed. These results favored the use of indirect selection, where progenies ranked with high DBH values consequently showed high H values (Sebbenn et al. 2010). Consistent with these results, Tambarussi et al. (2018) found a strong genetic correlation between DBH and H (0.84). For the correlation between CPA and DBH or H, intermediate phenotypic and environmental correlations were observed, which indicates that these variables are similarly influenced by the environment, as the correlation corresponding to environmental causes is considered the total effect of all the variable factors in the environment that caused a positive correlation (Falconer & Mackay 1996).

A highly correlated response to selection is expected when it is performed on variables with high-magnitude positive correlations; i.e., selecting for one trait will result in a similar response for the other trait (Macedo et al. 2013). Based on these results, it is recommended to use and measure only the DBH to select the best progenies in stands with advanced ages, because determining plant height requires increased time and labor, and can therefore increase the cost of the evaluation.

Direct selection performed on one trait can affect gains in other traits (Missio et al. 2004). When selecting *Pinus elliottii x Pinus caribaea* hybrids using DBH, Tambarussi et al. (2018) noted that the genetic correlations indicated probable positive selection effects for both DBH and H as well as for tree CPA (Falconer & Mackay 1996). These results suggest that selection using the method of Mulamba & Mock (1978)–indirect selection–enables gains because the traits have a strong genetic correlation (Missio et al. 2004, Bhering et al. 2012). The gains obtained under direct and indirect selection were higher than those reported by Tambarussi et al. (2010), who found gains of 5.99% for DBH and 5.82% for H for *Pinus caribaea* var. *hondurensis* at 14 years of age.

According to Macedo et al. (2018) and Nieri et al. (2018), the DBH and H measurements enable evaluation of the adaptability of genotypes introduced to exotic environments and their potential for establishment, as they express the adaptability and vigor of the seedlings under ecological conditions observed in the field after planting, given the magnitude of genotype x environment interactions in loco.

To obtain progenies with greater adaptability for the Lavras region, and because the genetic breeding program is in its early stages, it is recommended to select 30.3% of the progenies for future crossings to obtain greater gains. However, for this to occur, genetically different progenies must be selected. The progenies of *Pinus caribaea* var. *hondurensis* showed greater genetic variability and higher performance and consequently better adaptability, thus, it is recommended to continue genetic improvement with the progenies of *Pinus caribaea* var. *hondurensis*. Tests with more families are recommended to certify the competitiveness and suitability of the progenies of *Pinus caribaea* var. *bahamensis* and *Pinus massoniana* in Lavras. However, the superiority of *Pinus caribaea* var. *hondurensis* is indicative of its better performance in the region.

Most studies claim that there is a positive correlation between resin yield and growth in DBH and CPA (Liu et al. 2013). According to these same authors, DBH has a higher correlation with resin production (0.70) and therefore should be considered when selecting superior progenies for resin production.

It is essential to select the progenies that showed the best adaptability to the Lavras region, because the breeding program begins with the selection of promising progenies with adaptability using basic traits such as DBH and H. Therefore, an initial selection using DBH may include progenies with high resin yield, as the progenies were initially selected by resin production. Therefore, selection at a younger age is recommended to determine the resin yield among the best progenies selected.

Conclusions

The progenies of *Pinus caribaea* var. *hondurensis* showed higher performance than *Pinus caribaea* var. *bahamensis* and *Pinus massoniana* for the region of Lavras, Minas Gerais, Brazil, at 36 months after planting.

The progenies of *Pinus caribaea* var. *hondurensis* have significant genetic variation, which allows for the continuity of the genetic breeding programme.

Indirect selection was adequate for the DBH and H traits, mainly due to the high genetic correlation between these traits.

Based on this study, the expansion of *Pinus caribaea* var. *hondurensis* in the region of Lavras, MG, is suggested using the progenies P7, P15, P27, P31 and P33, because in the initial assessments, these progenies showed greater adaptability to the local edaphoclimatic conditions. Future selection should be performed at a more advanced age to include the evaluation of resin production.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

EMN, LAM and GAN designed the study. EMN, LAM, RSA, EWR, LMS and JCTF participated in the experimental part. EMN, ACP, LAM, LMS and RSA analysed the data and wrote the manuscript. EMN and LAM reviewed the manuscript. All authors read and approved the final manuscript.

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