Crop Breeding and Applied Biotechnology 5:1-8, 2005
Brazilian Society of Plant Breeding. Printed in Brazil

Genetic variation in *Araucaria cunninghamii* provenances in Luiz Antonio-SP, Brazil

Alexandre Magno Sebbenn, Antonio Carlos Scatena Zanatto, Miguel Luiz Menezes Freitais, Aida Sanae Sato, and Lígia de Castro Ettori

Received 1 September 2005

Accepted 19 October 2005

ABSTRACT - *The genetic variation in traits of growth and shape and their distribution among and within ten Australian provenances of* Araucaria cunninghamii *was studied under the environmental conditions of Luiz Antonio, state of São Paulo (SP). The provenance test was implanted in 1985 with ten provenances in six replications and row plots of four plants each. The* F *test of the analysis of variance showed significant differences at 1% probability among provenances for height and DBH at 20 years old. Of the total variation in height, DBH and trunk shape, variation among provenances accounted for 14.59%, 23.01% and 2.04%, respectively, after 20 years. At the same tree age, provenance Langkelly Creek performed best for traits DBH and height and Imbil Seed Orchard for trunk shape, while Bulburin performed worst for height and trunk shape and Jimna for DBH.*

Key words: Araucaria, conifers, provenance test, genetic correlations, forest improvement.

INTRODUCTION

The most important information evaluated in the area of forest improvement is related to the origin of seeds (Zobel and Talbert 1984). Forest geneticists are well aware of the fact that different geographic origins of seeds used for reforestation can entail substantial differences in growth, shape and health of the reforested stands (Eldridge et al. 1993). The difference among populations of a single species can be so great that stands with a particular origin of seeds can produce highly successful results while such from other origins can be a complete failure. It is therefore fundamental to know the origin of the seeds used for planting (Eldridge et al. 1993). Which origin of seeds is the best can only be determined after intensive tests of provenances that evaluate most part of the species' rotation age (Zobel and Talbert 1984).

Araucaria cunninghamii Aiton ex D. Don is a wind-pollinated dioic conifer (Nikles 1996) of great commercial value for tropical and subtropical regions. The species naturally presents a broad geographic distribution (Nikles and Newton 1983) which extends discontinuously from lat 1° S in the west of Irian Jaya in Indonesia to lat 31 °S in New South Wales, Australia (Nikles and Newton 1983, Nikles 1996). The distribution is mainly concentrated in the subtropical areas of the southeast of Queensland and northeast of New South Wales, within an extension of about 400 km from 24° 30' S to 28° 10' S, from 1.200 m altitude asl, in the surroundings or interior of rain forests. In Papua New Guinea it reaches 2.500m altitude, which demonstrates morphological, adaptive and growth variations (Nikles 1996). The climatic variations in this great natural distribution can include from sometimes severe dry seasons in Australia to high precipitations in Papua New Guinea (over 1929 mm), occurrence of cyclones and strong wind in the coastal areas, to which the once well-established species is resistant, and frosts in mountainous areas, to which it is moderately resistant (Nikles and Newton 1983).

The importance of studying this species for the state of São Paulo is associated to the possibility of planting it in a large part of the area, and motivated by the similarity of the edaphic and climatic conditions of great part of the state to the conditions of the occurrence area in Australia. *A. cunninghamii* is emergent in the tropical and subtropical Australian rain forests, grows to a height of 30 to 50 m, and can reach 60 m and a DBH of 1.8 m (Hall et al. 1970, Kanowski et al. 1985, Nikles 1996). Well-developed stands in Queensland are 25.5m high after 25 years and 36 to 37.5m at an age of 50 years. *A. cunninghamii* is considered adequate for planting in subtropical areas with precipitation between 968 and 1936mm without frosts or only few light frosts (Hall et al. 1970). Its timber has a high commercial value and is indicated for wooden lining, construction of barrels, broomsticks, match boxes, cases, boxes, etc (Hall et al. 1970).

A. cunninghamii populations present great genetic variability and adaptability to a wide range of sites and climatic conditions (Kanowski et al. 1985). This is a favorable aspect for the use of the species in genetic improvement programs in Brazil and the state of São Paulo. *A. cunninghamii* is cultivated in many areas, despite its subtropical/tropical origin (Nikles 1996). In a study realized in Itapetininga – SP, with six *A. cunninghamii* provenances from Queensland, the four-year-old trees presented a mean height of 2.06 m, DBH of 2.32 cm and grade of trunk straightness of 1.68. The results were considered inferior to those observed in *Pinus* and *Eucalyptus* stands in the region (Pires et al. 1980).

The objectives of this study were to investigate the silvicultural performance and quantify the genetic variation and its distribution among and within *A. cunninghamii* provenances under the environmental conditions of Luiz Antonio-SP, aiming at the selection of a base population to initiate a genetic improvement program with the species. Specific objectives were: *i*) to study the genetic variations in *A. cunninghamii* progenies for the main silvicultural traits in the region of Luiz Antonio - SP; *ii*) study the correlations between growth traits and geographic and climatic features in the species' natural occurrence area; *iii*) classify provenances according to their silvicultural performance e; *iv*) select superior trees.

Material and Methods

The seeds for this trial were collected from open pollination of trees of ten *A. cunninghamii* provenances in Australia by the Department of Forestry of Brisbane. All provenances were originated from Queensland (Table 1). The provenances Benarkin, St. Agnes, Brooweena L. A., St. John, Jimna, Bulburin, Clifford and Langkelly Creek were collected from natural populations, Imbil Seed Orchard in a seed orchard and Yarraman from a commercial stand. The seeds were sent to the Instituto Florestal in 1984 and in November 1985 the provenance test was installed at the Experimental station of Luiz Antonio (lat 21° 40' S, long 47º 49' W and alt 550 m asl). The annual precipitation mean at the station is 1280 mm, the soil is a Latosol and the climate of the Cwa type (Ventura et al., 1965-1966). The experiment was set up in the field in an experimental design of complete randomized blocks with ten treatments (provenances), six replications and row plots of four plants in a spacing of 3 x 2 m plus two external border rows.

The evaluated traits were total tree height at five (height5) and 20 years of age (height20), DBH after five (DBH5) and 20 years (DBH20) and the trunk shape at 20 years of age (TRS20). The tree trunk shape was evaluated based on criteria of subjective grades (varying from one to five, considering the trunk straightness, bifurcations, lateral shoots and branches, where 1 is the worst and 5 the best grade). For analysis of variance, the variable trunk shape was transformed by ($\sqrt{TRS20}$), in order to approximate the data distribution to normal distribution.

The analyses of variance for each trait and age were realized at the individual plant level, considering only the general mean as fixed effect and using the following statistical model $Y_{ijk} = m + b_j + t_i + e_{ij} + d_{ijk}$, where Y_{ijk} is the phenotypic value of the k^{th} individual of the j^{th} block of the i^{th} provenance; m is the general mean; b_j is the effect of the j^{th} block; t_i is the effect of the i^{th} provenance; e_{ij} is the effect of the interaction between the i^{th} provenance and the j^{th} block (error among); d_{ijk} is the effect of the error within the provenance; where $j = 1....J$, $J = 6$ (J is the number of blocks); $i = 1....I$, $I = 10$ (I is the number of provenances); $k = 1....K$, $K \approx 4$ (K is the number of trees per plot).

The F test of the analyses of variance was obtained using the Glm procedure of the software SAS (SAS Institute Inc. 1989). To estimate the components of

Table 1. Number of trees from which seeds were collected, geographic coordinates, altitude and precipitation of the area of *A. cunninghamii* seed collection in Australia

Provenances	Nr. of mother trees	Latitude S	Longitude E	Altitude (m)	Mean annual precipitation (mm)
Benarkin	10	26° 55'	152° 09'	440	992
St. Agnes	42	25° 20'	151° 50'	280	930
Brooweena L. A.	20	25° 32'	150° 13'	122	1056
St. John	20	27° 14’	152° 40’	400	1200
Jimna	20	26° 42'	152° 20'	600	817
Bulburin	-	24° 25'	151° 30'	540	1447
Clifford	10-20	24° 40'	151° 00'	810	1200
Imbil Seed Orchard	20	26° 27'	152° 40'	105	1200
Yarraman	20	26° 51'	152° 10'	435	1000
Langkelly Creek	20	13° 54'	143° 15'	500	1200

variance, we used the Reml method (Restricted Maximum Likelihood) in combination with the Varcomp procedure of SAS, since the trial was unbalanced due to the unequal number of surviving trees per plot. The estimated components of variance were: σ_p^2 = genetic variance among provenances; σ_e^2 = environmental variance; σ_w^2 = phenotypic variance within provenances. The genetic divergence among populations was estimated with an intra-class correlation by $Q_{ST} = \sigma_p^2 / (\sigma_w^2 + \sigma_e^2 + \sigma_p^2)$.

The genetic correlations (r_g) between traits of the same and different ages were estimated at the individual plant level, using the equation $r_g = \sigma_{pxpy} / \sqrt{\sigma_{px}^2 . \sigma_{py}^2}$, where σ_{pxpy} is the crossed genetic product of the traits *x* and *y*; σ_{px}^2 and σ_{py}^2 are the genetic variances among provenances for the traits *x* and *y*, respectively. The crossed products were estimated by the analysis of covariance using SAS.

The multi-trait index was constructed to select the best trees: $I_S = x_A a + x_D d + x_F f$, where x_A, x_D and $x_{F'}$ are the weights of the traits height (*a*), DBH (*d*) and trunk shape (*f*) and $x_A + x_D + x_F = 1$. The highest weight was attributed to the trait trunk shape (0.5) in order to improve the trunk shape of the population. Height and DBH were given the same weight, 0.25. Based on this index, the phenotypic value of the trees was determined as well as the trees to be selected to compose the recombination population.

The expected response with mass selection for height and DBH (R) was estimated by $R = i\sigma_F h_i^2$, where *i* is the selection intensity in standard deviation units, σ_F is the estimate of the standard deviation of the phenotypic variance and h_i^2 is the estimate of the coefficient of heritability at the level of individual plants. Since we are dealing with a provenance test, the coefficients of heritability at the level of individual plants were inferred from a study of Eisemann et al. (1990) who estimated these parameters at 0.19 for height and 0.22 for DBH in a progeny test carried out near Imbil in the southeast of Queensland, Australia. The gains were estimated for mass selection at 27% (*i*=1.2022, Hallauer and Miranda Fo 1988) of the best trees of the trial at the age of 20 years. The response to selection in percentage [R(%)] was calculated by $R(\%) = (R / \bar{x}).100$, where $\bar{x}$ is the trait mean.

RESULTS AND DISCUSSION

Genetic variation

Survival rates were relatively high in the experiment, varying from 93.7% in five to 86.7% in 20-year-old trees (Table 2), indicating good adaptation of the plant material and its potential for reforestation in the environmental conditions of Luiz Antonio.

Table 2. Estimates of mean squares, coefficient of experimental variation (CV_{exp}) and components of variances for height (height5 and height20), DBH (DBH5 and DBH20) and trunk shape (TRS20) of *A. cunnunghannii*

Sources of variation	height5 (m)	height20 (m)	DBH5 (cm)	DBH20 (cm)	TRS20
Block	4.0560	16.3625	7.7119	28.0026	0.0360
Provenance	4.9127	43.5600 **	9.4918	221.4256 **	0.0848
Error	2.9627	9.1138	6.0954	18.1636	0.0657
CV_{exp}	12.4%	15.8%	16.8%	29.7%	29.2%
Mean	6.39	19.68	7.81	19.25	3.26
Survival	93.7%	86.7%	-	-	-
σ_p^2 [1]	0.0976	1.6345	0.1584	8.7619	0.0016
σ_e^2	0.6288	-	1.1815	-	-
σ_w^2	0.6239	9.5652	1.7234	29.3211	0.0749
Q_{ST}	0.0723	0.1459	0.0517	0.2301	0.0204

** $P < 0.01$

[1] σ_p^2, σ_e^2 and σ_w^2 are the estimates of the genetic variance among provenances, environmental variance and phenotypic variance within provenances, respectively; Q_{ST} = genetic divergence among provenances

The *F* test of the analysis of variance (Table 2) showed significant differences at the level of 1% probability among provenances for height and DBH at the age of 20 years, suggesting that there are genetic differences among provenances and, thus, potential for the selection of more productive provenances under the environmental conditions of Luiz Antonio.

Genetic divergence among provenances (Q_{ST}) varied from 2.04% (TRS20) to 23.01% (DBH20), indicating that the greatest part of genetic variation is found within provenances. Comparing the genetic divergence observed for DBH and height at the age of five years (DBH: $Q_{ST} = 0.0517$; height: $Q_{ST} = 0.0723$) with the one observed after 20 years (DBH: $Q_{ST} = 0.2301$; height: $Q_{ST} = 0.1459$) one notes that there was an expressive increase in divergence among provenances with increasing tree age. The increase of genetic variation among provenances is the reflex of the natural selection pressure, favoring the growth of the most adapted and disfavoring the least adapted provenances.

In turn, the low genetic divergence detected among provenances for trunk shape, associated to the absence of significant differences among provenances and the high trait mean (3.26) indicate that the tested material generally has a good shape and that it is possible to select superior trees for trunk shape in all provenances. The low genetic variation among provenances for trunk shape is probably a reflex of previous mass selection during the process of seed collection for the implantation of the provenance test. This would explain the good shape observed in the test.

The genetic divergence detected among *A. cunninghamii* provenances is comparable to the one observed in other studies with the species and with other species of the genus *Araucaria*. Pires et al. (1980) studied six Australian provenances of *A. cunninghamii* in Itapetininga-SP to up to four years of experimentation and observed high levels of genetic divergence in the provenances for the traits height (Q_{ST} = 42%), DBH (Q_{ST} = 60%) and trunk shape (Q_{ST} = 72%); these values were much higher than those found in the present study at all evaluated ages. This suggests that the selection pressure was higher under the conditions of Itapetininga than in Luiz Antonio, resulting in a clearer differentiation among provenance in the first.

On the other hand, comparing the genetic divergence observed here with the one related in studies realized with *Araucaria angustifolia*, it is verified that the divergence detected in *A. cunninghamii* is much higher. Shimizu (1999) detected genetic divergence among eighteen 23-year-old *A. angustifolia* provenances grown in Ribeirão Branco-SP, in a range from 4.5% (commercial volume without bark) to 7.3% (height). Sebbenn et al. (2003) studied fifteen 21-year-old *A. angustifolia* provenances in Itapeva and observed a maximum genetic divergence of 6.2% among provenances (height). *A. cunninghamii* therefore apparently has a greater genetic variation among its provenances for growth traits than *A. angustifolia*, indicating a high potential for the achievement of genetic gains by selection of the best provenances.

Provenance performance

Based on a comparison of the provenances' mean growth in height (19.68 m) and DBH (19.25 cm) in 20 years with the growth means observed in *A. angustifolia* (Sebbenn et al. 2003) after 21 years in Itapeva (height = 6.93 m; DBH = 10.2 cm), we concluded that *A. cunninghamii* has a quicker growth. The relative superiority in growth for height is 64.8% and 47% for DBH. The growth of *A. cunningamii* also outmatches the growth of 17-year-old *Cariniana legalis* (Sebbenn et al. 2002) in Luiz Antonio (height = 12.26 m; DBH = 13.49 cm), demonstrating its silvicultural potential that exceeds native Brazilian conifers and leafy species. On the other hand, compared with DBH growth of 12-year-old *Pinus elliottii* var. *elliottii* (Romanelli and Sebbenn 2004) trees grown in Angatuba (19.3 cm), Itapetininga (19.7 cm) and Itapeva (18.2 cm) and *P. caribaea* var. *bahamensis* (Romanelli and Sebbenn 2004) trees of the same age, grown in Angatuba (24.2 cm), Itapetininga (26.5 cm) and Itapeva (24.3 cm), the conclusion may be drawn that *A. cunninghamii* has slow growth and its yield much lower than that presented by these Pinacea.

The growth of the provenances varied with the time of experimentation (Table 3). At the age of five years, the best provenance for growth in height and DBH was Imbil Seed Orchard and the worst was Jimna. At the age of 20, the performance changed. The best provenance for height and DBH was Langkelly Creek, followed by Brooweena L.A. and the worst was Bulburin for height and Jimna for DBH. Taking the error of the mean estimates into consideration, it can be verified that the growth in height and DBH of provenance Langkelly Creek differs from the growth of the second provenance after 20 years (Brooweena L.A.), indicating provenance Langkelly Creek as the best for the conditions of Luiz Antonio.

For trunk shape, provenance Imbil Seed Orchard had the best performance, followed by Yarraman, while provenance Bulburin had the worst trunk shape (Table 3). These two provenances of best performance represent a plant material with some degree of improvement. Provenance Imbil Seed Orchard, as the proper name says, originates from a seed orchard and Yarraman from a commercial plantation. Since the trait trunk shape presents an intermediate heritability (0.3 to 0.5) its selection is effective, so one or a few generations of mass selection are enough to practically fix the trait. This would explain the best performance of the trait trunk shape in the provenances Imbil Seed Orchard and Yarraman.

For trunk shape, the provenances Langkelly Creek and Brooweena L.A., with best growth in height and DBH at 20 years of age were classified in seventh and fourth place, respectively (Table 3). The trunk shape of the provenance Imbil Seed Orchard, according to the standard deviation, differs from that observed in the provenance Langkelly Creek but not from provenance Brooweena L.A. This indicates the need of prioritizing the trait trunk shape in the individual selection within provenance Langkelly Creek in order to obtain plant material with a high growth rate and good trunk shape. Summing up, based on the results of the means of tree growth in height and DBH, provenance Langkelly Creek can be indicated as the most adequate for stands in the region of Luiz Antonio, although a previous selection for trunk shape would be necessary.

Correlations

The genetic correlations for height was 0.44 between the ages of five and 20 years, and for DBH it was 0.54, both low and statistically not significant. This indicates that the young trees of greatest or least growth are not necessarily the same trees as those of greatest or least growth at the age of 20 years.

The estimate of the genetic correlation between height and DBH at the age of five years was equally low and not significant ($\hat{r}_g = 0.30$; $P < 0.01$). On the other hand, the genetic correlation between height and DBH at the age of 20 years was high and significant ($\hat{r}_g = 1.04$; $P < 0.01$), demonstrating the possibility of capitalizing on indirect genetic gains in one trait based on direct selection for another trait. Evidently, in this case the most indicated trait for direct selection is DBH, owing to the greater precision of its measurement.

Table 3. Estimates of means (± standard error) for height (height5 and height20), DBH (DBH5 and DBH20) and trunk shape (TRS20) in ten *A. cunninghamii* provenances planted at the experimental station of Luiz Antonio

Provenance	height5 (m)	height20 (m)	DBH5 (cm)	DBH20 (cm)	TRS20
Benarkin	6.73 ± 0.21	18.48 ± 0.73	7.87 ± 0.30	16.79 ± 0.88	2.95 ± 0.16
St. Agnes	6.24 ± 0.28	19.15 ± 0.66	7.44 ± 0.36	19.25 ± 0.96	3.29 ± 0.19
Brooweena L.A.	6.30 ± 0.27	20.13 ± 0.48	7.56 ± 0.31	20.02 ± 0.99	3.43 ± 0.20
St. John	5.64 ± 0.31	19.56 ± 0.75	7.09 ± 0.50	18.13 ± 1.25	3.44 ± 0.18
Jimna	5.64 ± 0.35	18.64 ± 0.71	6.84 ± 0.52	16.33 ± 1.20	3.00 ± 0.21
Bulburin	6.18 ± 0.24	17.94 ± 0.86	7.48 ± 0.39	16.58 ± 1.13	3.00 ± 0.26
Clifford	6.59 ± 0.16	19.86 ± 0.92	8.38 ± 0.33	18.88 ± 1.44	3.24 ± 0.23
Imbil Seed Orchard	6.94 ± 0.14	19.63 ± 0.55	8.92 ± 0.26	18.89 ± 1.01	3.65 ± 0.18
Yarraman	6.80 ± 0.13	19.64 ± 0.57	8.08 ± 0.22	18.66 ± 1.07	3.45 ± 0.18
Langkelly Creek	6.60 ± 0.15	23.25 ± 0.61	8.26 ± 0.30	27.43 ± 1.72	3.05 ± 0.23

The correlation coefficient of Spearman for the association between the traits and geographic and climatic features (latitude, longitude, altitude and mean annual precipitation) of the local of origin of the provenances is presented in Table 4. At the age of 20 years, the correlations with the latitude and longitude of origin of the provenances were high, negative (> -0.8) and statistically significant ($P < 0.01$) for height (ALT20) and DBH (DBH20). These results suggest that the growth of 20-year-old provenances was affected by the geographic origin of the seeds. According to the correlations, seeds originated from lower latitudes and longitudes tend to perform better in height and DBH growth under the environmental conditions of Luiz Antonio and vice versa. This agrees with the results observed for the growth mean of the provenances. At the age of 20 years, the provenance of best growth was Langkelly Creek, exactly the one of lowest latitude (13º 54') and longitude (143º 15').

Genetic gain

The expected gains with the mass selection of 59 of the 209 surviving trees (28%) were estimated (Table 5). The selection scheme involved trees of all provenances in order to obtain a base population with an effective size of at least 50. The selection of only provenance Langkelly Creek trees would result in an orchard formed by only 24 trees. Besides, this provenance did not present the best trunk shape among the tested provenances. We therefore decided to use phenotypic selection based on the construction of an index that attributed a higher weight to trunk shape and equal weights to the traits height and DBH growth. Based on this index, 11 trees of the best provenance for height and DBH (Langkelly Creek) and only two trees with best growth and trunk shape of the worst provenance (Bulburin) were selected. Using the coefficients of heritability estimated by Eisemann et al. (1990) for height and DBH, the expected gains with selection were estimated. A gain of 3.88% for height and 8.47% for DBH can be expected in 20-year-old stands of the species in areas that present the same environmental features as Luiz Antonio.

ACKNOWLEDGEMENTS

The author AM Sebbenn would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for granting him a scholarship for Achievements in Research.

Table 4. Estimates of the coefficient of correlation of Spearman (r) between traits and geographic features of the origins of *A. cunninghamii* provenances

Trait	Latitude S	Longitude W	Altitude (m)	Annual mean precipitation (mm)
height5	-0.29	-0.29	-0.29	0.31
height20	-0.82**	-0.87**	-0.35	0.33
DBH5	-0.19	-0.23	-0.32	0.00
DBH20	-0.90**	-0.92**	-0.34	0.31
TRS20	0.04	0.15	-0.55	0.35

** P £ 0.01

Table 5. Estimates of expected gains with a selection of 27% of the best trees for the traits height (height20) and DBH (DBH20) in 20-year-old *A. cunninghamii* provenances

Parameters	Height (m)	DBH20 (cm)
Mean of traits in original population	19.68	19.25
Mean of trait in selected population	22.6	25.6
Phenotypic variance - σ_F^2	11.20	38.08
Heritability in levels of plant - h_i^2 *	0.19	0.22
Expected gains by massal selection - *R*	3.88%	8.47%

* Eisemann et al. (1990)

Variação genética em procedências de *Araucaria cunninghamii* em Luiz Antonio, Brasil

RESUMO - *A variação genética de caracteres de crescimento e forma e a sua distribuição entre e dentro de dez procedências australianas de* Araucaria cunninghamii *foram estudadas nas condições ambientais de Luiz Antonio, estado de São Paulo. O teste de procedências foi implantado em 1985 em blocos casualizados com seis repetições e parcelas lineares de quatro plantas. O teste* F *da análise de variância revelou diferenças significativas a 1% de probabilidade entre procedências para altura e DBH aos 20 anos de idades. Aos 20 anos de idade, da variação total para altura, DBH e forma do fuste, a variação entre procedências acomodou 14,59%, 23,01% e 2,04%, respectivamente. Aos 20 anos de idade, a procedência Langkelly Creek teve o melhor desempenho para os caracteres DBH e altura e a Imbil Seed Orchard para forma do fuste. A procedência Bulburin teve o pior desempenho para altura e forma, enquanto a procedência Jimna foi a pior para DBH.*

Palavras-chave: Araucaria, coníferas, teste de procedências, correlações genética, melhoramento florestal.

REFERENCES

Eisemann RL, Harding KJ and Eccles DB (1990) Genetic parameters and predicted selection responses for growth and wood properties in a population of *Araucaria cunninghamii*. **Silvae Genetica 39**: 206-220.

Eldridge KG, Davidson J, Harwood C and Van Wyk G (1993) **Eucalypt domestication and breeding**. Clarendon Press, Oxford, 300p.

Hall N, Johnston RD and Chippendale GM (1970) **Forest trees of Australia**. Australian Government Publishing Service, Canberra, p. 290-292.

Hallauer AR and Miranda Fo JB (1988) **Quantitative genetics in maize breeding**. State University Press, Ames, 468p.

Kanowski PJ, Fergusn IS, Wood GB, Nikles DG and Matheson AC (1985) Variation of stem and grown characteristics between selected families of hoop pine (*Araucaria Cunninghamii* Ait. Ex D. Don). **Australian Forest Resources 15**: 449-461.

Nikles DG (1996) The first 50 years of the evolution of forest tree improvement in Queensland. In: Dieters MJ, Matheson AC, Nikles DG, Haedwood CE and Walkers SM (eds.) **Tree improvement for sustainable tropical forestry**. Proceedings of IUFRO conference in 1996, Queensland, p. 51-64.

Nikles DG and Newton RS (1983) Distribuição da variação genética, melhoramento genético e conservação da *Araucaria cunninghamii* Aiton ex D. Don. In: Simpósio IUFRO em melhoramento genético e produtividade de espécies florestais de rápido crescimento**. Vol 2, Silvicultura, São Paulo, p. 276-286.**

Pires SLS, Kalil Filho NA, Gianotti E and Romanelli RC (1980) Teste de procedências de *Araucaria cunninghamii* Ait. Ex Don e *Araucaria angustifolia* (Bert.) O.K. na região de Itapetininga-SP. In: **IUFRO meeting on forestry problems of the genus Araucaria in 1979**. UFPR, Curitiba, p. 235-239.

Romanelli RC and Sebbenn AM (2004) Parâmetros genéticos e ganhos na seleção para produção de resina em *Pinus elliottii* var. *elliottii*. no sul do Estado de São Paulo. **Revista do Instituto Florestal 16**: 11-23.

SAS Institute Inc. (1989) **SAS/STAT user's guide**. Version 6, 4^{th} ed., vol. 2, SAS Institute, Cary, 846p.

Sebbenn AM, Kageyama PY and Zanatto ACS (2002) Estimativas de ganhos genéticos na seleção em populações de *Cariniana legalis* (Mart.) O. Ktze. incorporando informações do sistema misto de reprodução. **Revista do Instituto Florestal 14**: 65-77.

Sebbenn AM, Pontinha AA, Gianotti E and Kageyama PY (2003) Genetic variation in provenance-progeny test of *Araucaria angustifolia* in São Paulo state. Brazil. **Silvae Genetica 52**: 181-184.

Shimizu JY (1999) Variação entre procedências de Araucária em Ribeirão Branco (SP) aos vinte e três anos de idade. **Boletim de Pesquisa Florestal 38**: 89-102.

Ventura A, Berengut G and Victor MAM (1965/1966) Características edafoclimáticas das dependências do Serviço Florestal do Estado de São Paulo. **Silvicultura 4**: 57-139.

Zobel B and Talbert J (1984) **Applied forest tree improvement**. John Wiley & Sons, New York, 496p.