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Provenance and family-within-provenance variation in *Pinus patula*, *Pinus patula* subspecies *tecunumanii* and *Pinus oocarpa* planted at Turbo, Kenya

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Abstract

Pinus patula accounts for about 26% of all forest plantations in Kenya and is used mainly for timber, pulpwood and plywood production, whereas *Pinus patula* subspecies *tecunumanii* and *Pinus oocarpa* have been planted on experimental scale only. The three close coned pines were studied in a field trial planted in 1985 at Turbo, Kenya as part of an international series of trials of the species. The study investigated variation among the species, provenances and families-within-provenances. Seven families of *P. patula*, five provenances of *P. patula* subsp. *tecunumanii* comprising of 10 families each, and three provenances of *P. oocarpa* were included in the trial. Results of assessments of height and diameter at breast height (DBH) made at 8 years of age showed significant differences ($p < 0.05$) among the species. *P. patula* was the best in both height and volume production whereas *P. patula* subsp. *tecunumanii* was best in DBH and volume per hectare. However, the differences between these two species were non-significant, despite *P. patula* being genetically improved compared to *P. patula* subsp. *tecunumanii* which is still in a relatively unimproved state. Furthermore, *P. patula* subsp. *tecunumanii* has also been shown to have a better form and lighter branching and may be more productive both in quantity and quality of products. *P. oocarpa* was poorest in all characteristics assessed. Significant differences were detected in DBH and volume production among provenances of *P. oocarpa* but not in height whereas the differences in height, DBH and volume among families of *P. patula* were non-significant. Family heritability estimates in *P. patula* subsp. *tecunumanii* were high; 0.61, 0.69 and 0.70 for height, DBH and volume production, respectively. The results suggest that *P. patula* subsp. *tecunumanii* may have potential for planting at Turbo and regions with similar conditions and also in areas currently planted with *P. patula*. *P. oocarpa* may be suitable for planting in drier parts of Turbo and sub-humid lowlands.

Keywords: *Pinus patula*; *Pinus patula* subspecies *tecunumanii*; *Pinus oocarpa*; Families; Provenances

1. Introduction

Exploration of the natural populations of *Pinus oocarpa* and subsequent seed collections made in the early 1970s led to establishment of a series of 'first stage' provenance trials in a number of countries. These trials showed provenances that were adapted to different regions (Crockford et al., 1989). The greatest source of variation was shown to be among trees within provenances rather than between prove-

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nances. Some of the provenances of *Pinus oocarpa* used have since been reclassified as *Pinus patula* subsp. *tecunumanii* (Styles, 1985). Second round seed collections were subsequently made from selected provenances and family-within-provenance trials established in a number of countries. The seed used in these trials took the form of open pollinated half-sib families with seed from individual trees being kept separate. In the Kenyan series of trials, a land race of *P. patula* collected from Zimbabwe was included.

P. patula was first introduced in Kenya in 1926 from South Africa (Wormald, 1975) and is now the second most planted softwood species. The species accounts for about 26% of all forest plantations in Kenya (MENR, 1994) and is planted for timber, pulpwood and plywood production. It dominates plantations at the Turbo afforestation scheme and the surrounding regions, and is the major species that meets most timber, pulpwood and plywood requirements of a number of sawmills, the nearby Pan African Paper Mills and a number of plywood factories in the region.

The trial reported in this paper marked the first introduction of *P. patula* subsp. *tecunumanii* in Kenya, although the species had been introduced in earlier provenance trials as Yucul, Camelias and San Raphael provenances of *P. oocarpa*. *P. patula* subsp. *tecunumanii* is a large, straight evergreen tree about 35–40 m in height and 40–80 cm in diameter. It has the best form of any Latin American pine with the straightest and largest bole and a small crown important for maximum amount of convertible timber (Kemp, 1973).

The natural occurrence of *P. oocarpa* on the other hand ranges from Mexico to Nicaragua at an altitude of 700 to 1600 m and sometimes up to 2000 m. The species is generally found on poor acidic soils and tolerates dry seasons of up to 7 months in its natural habitat. It appears to be suitable for afforestation of medium altitude sites in the tropics and produces excellent wood for construction (Robins, 1983). The species has been planted in Kenya on experimental scale only.

The three *Pinus* species were used in a trial planted in 1985 at Turbo Forest station to compare variation in growth among the species, among provenances within species and among families within provenances. Information from these trials is expected to provide valuable guidelines on the range of variation within and between the species and may prove useful for further genetic improvement and widespread plantation establishment at Turbo and other similar areas in Kenya.

2. Materials and methods

The experimental site was at Turbo Forest Station, situated on latitude 0°38′N and longitude

Table 1
Details of the seed origins of *P. patula* subsp. *tecunumanii*, *P. patula* and *P. oocarpa* planted at Turbo, Kenya

Batch no.	Country	Provenance	Families	Latitude	Longitude	Altitude
(a) P. patula subsp. tecunumanii						
25/81	Honduras	Cusuco	10	15°30′N	88°10′W	1500–1650
5/82	Honduras	Siguatepeque	10	14°33′N	87°50′W	1300–1650
6/82	Nicaragua	San Raphael	10	13°14′N	86°08′W	1200
7/82	Nicaragua	Yucul	10	12°55′N	85°47′W	900
8/82/8	Honduras	Botijas	Bulked	–	–	–
(b) P. oocarpa						
10/73	Nicaragua	Dipilto	Bulked	13°43′N	86°37′W	1200
5/74	Honduras	Pimientilla	Bulked	14°54′N	87°30′W	650–850
8/71	Guetamala	Lagunilla	Bulked	14°42′N	89°57′W	1600
(c) P. patula						
30/79–36/79	Zimbabwe	–	7	–	–	–

Table 2
Analysis of variance of height DBH and volume production in (a) three species: *P. patula*, *P. patula* subsp. *tecunumanii* and *P. oocarpa*; (b) provenances and families-within-provenances of *P. patula* subsp. *tecunumanii*; (c) provenances of *P. oocarpa*; and (d) families of *P. patula*

Source of variation	DF	Height		Diameter		Volume	
		MS	F	MS	F	MS	F
(a) Pinus patula subsp. tecunumanii, P. patula and P. oocarpa							
Block	9	20.35	129.84**	22.88	61.24**	1657.27	3.7**
Species	2	1.66	10.58**	1.20	3.21**	52759.60	117.6**
Residual	18	0.16		0.37		448.68	
(b) P. patula subsp. tecunumanii							
Block	9	15.69	8.21*	14.12	2.22*	16219.16	1.71 ns
Provenance	4	10.26	5.37**	31.51	4.95**	49811.46	5.25**
Family/provenance	36	2.52	1.32 ns	9.27	1.46*	14001.35	1.48*
Residual	328	1.91		6.36		9433.25	
(c) Pinus oocarpa							
Block	9	2.39	2.31 ns	2.14	0.94 ns	2234.65	1.36 ns
Provenance	2	2.90	2.81 ns	17.75	7.78**	18675.28	8.78**
Residual	17	1.03		2.28		2127.91	
(d) Pinus patula							
Block	9	4.43	3.83*	6.28	0.86 ns	8257.26	0.82 ns
Family	6	0.63	0.54 ns	13.64	1.87 ns	13162.14	1.30 ns
Residual	54	1.16		7.30		10097.49	

* and ** denotes significance at the 5% and 1% levels, ns denotes non-significance.

35°41′E at an altitude of 1830 m above sea level. The site is almost flat with shallow soils (< 1 m) over a murram pan (Nyandat and Oswago, 1970) and receives a mean annual rainfall of 1300 mm. The mean annual temperature is 20°C.

2.1. Seed sources

The seeds used in this trial were obtained from the Oxford Forestry Institute (OFI) and were from a collection made between 1982 and 1985 from the natural ranges of *P. patula* subsp. *tecunumanii* and *P. oocarpa*. The seeds of *P. patula* originated from Zimbabwe and consisted of seven full-sib families. There were five provenances of *P. patula* subsp. *tecunumanii*, each comprising of 10 half-sib families and three provenances of *P. oocarpa* that were bulked (Table 1).

2.2. Experimental design and establishment

The seedlings were planted on site in May 1985 using a randomised complete block design with 5-tree line plots and 10 replications. The provenances were randomised within blocks followed by randomisation of families within provenances. A spacing of 2.5 m × 2.5 m was used and a guardrow of *P. patula* planted around the experiment. The site was under a

Table 3
Mean height, diameter growth and volume production of *P. patula*, *P. patula* subsp. *tecunumanii* and *P. oocarpa* planted at Turbo, Kenya

Species	Mean height (m)	Mean DBH (cm)	Mean volume (m^3/ha)
P. patula	15.86a	18.82a	371.48a
P. patula subsp. *tecunumanii*	15.07a	19.03a	358.40a
P. oocarpa	13.09b	16.31b	236.63b

Means joined by the same letter are not significantly different at the 5% level of significance.

maize plantation at the time of planting and cultivation continued for 1 year after the seedlings were planted. The experimental site was thereafter kept clean by slashing and weeding periodically.

2.3. Assessment and data analyses

Trees in each plot were assessed for height and survival percentage at 3 months and at 1, 3, 5 and 8 years of age. Measurements of diameter at breast height (DBH) commenced at the age of 5 years. Volume per tree was calculated using the following formula (Wright, 1976) cited in Wormald (1975) $V = 0.00041 - 0.00005711D + 0.0001352DH + 0.00003313D^2H$, where V is the volume per tree, D is the diameter at breast height (cm) and H is the height (m) This paper is based on assessments made at 8 years of age.

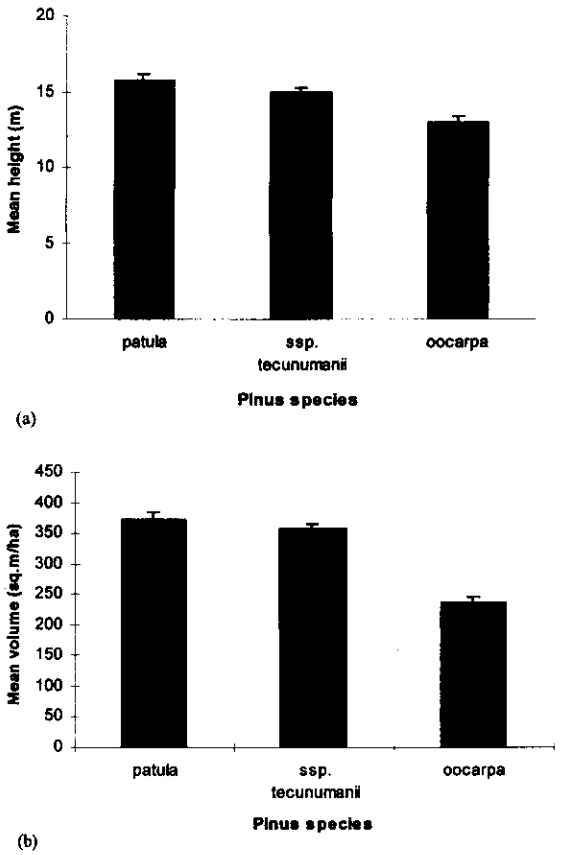

Fig. 1. (a) Mean height and (b) mean volume production per hectare of 8-year old *P. patula*, *P. patula* subsp. *tecunumanii* and *P. oocarpa* planted at Turbo, Kenya. Standard error bars are shown.

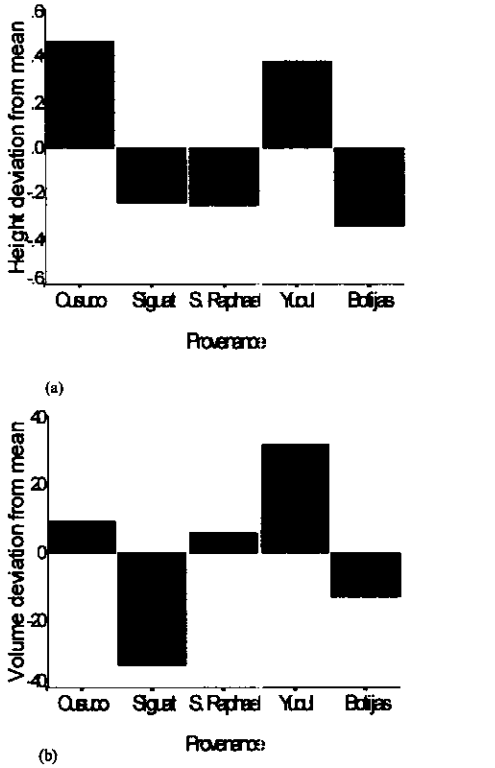

Fig. 2. Deviation from the overall provenance mean (zero) in (a) height and (b) volume production per hectare in 8-year old provenances of *P. patula* subsp. *tecunumanii* planted at Turbo.

Analyses of variance of height, DBH and volume were carried out using the SPSS computer programme (Norusis, 1994) to investigate differences among the species, among provenances of *P. patula* subsp. *tecunumanii* and *P. oocarpa* and among families of *P. patula* and *P. patula* subsp. *tecunumanii*. However, because of differences in the number of families per provenance and because the seedlots of *P. oocarpa* were bulked, data for each species were analysed separately. Analysis at the species level was carried out using provenance and family means. Families of *P. patula* were full-sibs whereas those of *P. patula* subsp. *tecunumanii* were half-sibs and this was taken into account in subsequent analysis. Tukey's *hsd* test procedure in SPSS was used to separate the means.

Family heritability for height, DBH and volume were calculated from variance components using the

following formula (Wright, 1976): $h^2_{(f)} = \sigma_f^2/(\sigma^2 + (\sigma_e^2/NB))$, where N and B are the number of trees per family and number of blocks respectively and σ_f^2 and σ_e^2 are variance components due to family and family × block (error), respectively. Variance components were calculated for the family level by equating the Expected Mean Squares to their respective mean squares obtained from analyses of variance.

3. Results

3.1. Variation among species

The results of analysis of variance showed highly significant differences among the three species in height, DBH and volume at 8 years of age (Table 2). *P. patula* was tallest, whereas *P. patula* subsp. *tecunumanii* had the largest DBH. *P. oocarpa* had the lowest height, DBH and volume (Table 3 and Fig. 1). Separation of means for height, DBH and volume per hectare showed that *P. patula* and *P. patula* subsp. *tecunumanii* were not significantly different and the significant differences detected among the species were because of slower growth of *P. oocarpa* (Table 3 and Fig. 2).

3.2. Provenance and family-within-provenance variation

Variation among provenances was tested only for *P. patula* subsp. *tecunumanii* and *P. oocarpa*. Significant differences were detected in height, DBH and volume production among provenances of *P. patula* subsp. *tecunumanii* (Table 2). The overall provenance mean height at 8 years of age was 15.03 m with a range from 14.69 m in the Botijas provenance to 15.50 m in Cusuco provenance. Mean diameter ranged from 18.15 cm in Siguatepeque provenance to 19.92 cm in the Cusuco provenance with an overall mean of 19.06 cm (Table 4). Volume production per hectare ranged from 322.44 m^3/ha in Botijas provenance to 387.23 m^3/ha in the Yucul provenance (Table 4). Significant differences were also found in DBH and volume production per hectare among families within provenances of *P. patula* subsp. *tecunumanii* but not in height (Table 2).

There were significant differences ($p < 0.05$) among provenances of *P. oocarpa* in DBH and volume per hectare but not in height (Table 2). The Lagunilla (Guatemala) provenance had the best height, DBH and volume, whereas Pimmientilla (Honduras) was the poorest (Table 4).

The results of analysis of variance showed no significant differences among families of *P. patula* in height, DBH and volume per hectare. The overall

Table 4
Height, DBH and volume and their ranking, R (in parenthesis) in 8-year old provenances of *P. patula* subsp. *tecunumanii* and *P. oocarpa* planted at Turbo, Kenya. Family heritability estimates (h^2_{fam}) for *P. patula* subsp *tecunumanii* are given

Provenance	Mean height (m)	(R)	Mean DBH (cm)	(R)	Mean volume(m^3/ha)	(R)
(a) P. patula subsp. tecunumanii						
Cusuco (Honduras)	15.50a	(1)	19.92b	(1)	364.73a	(2)
Siguatepeque (Honduras)	14.79b	(3)	18.15a	(5)	322.44a	(5)
San Raphael (Nicaragua)	14.78b	(4)	19.22ab	(3)	361.32a	(3)
Yucul (Nicaragua)	15.41a	(2)	19.72b	(2)	387.23b	(1)
Botijas (Honduras)	14.69b	(5)	18.31b	(4)	342.40a	(4)
Heritability (h^2_{fam}) ± SE	0.61 ± 0.05		0.69 ± 0.03		0.70 ± 0.06	
(b) P. oocarpa						
Lagunilla (Guatemala)	13.83	(1)	17.81a	(1)	287.73a	(1)
Dipilto (Nicaragua)	13.33	(2)	16.04b	(2)	229.21b	(2)
Pimientilla (Honduras)	12.64	(3)	15.19b	(3)	199.58b	(3)

Means joined by the same letter are not significantly different at the 5% level.

family means for height, DBH and volume at 8 years of age were 15.86 m, 18.82 cm and 371.48 m^3/ha, respectively (Table 3).

Estimates of family heritability for *P. patula* subsp. *tecunumanii* were high; with values of 0.61, 0.69 and 0.70 for height, DBH and volume, respectively (Table 4). Family heritability estimates were not calculated for *P. patula* because no significant differences were detected among the families and similarly for *P. oocarpa* because the seedlots were bulked and there was no distinction made between families.

4. Discussion

The results of this experiment showed that the three pine species differed significantly in their potential for growth at Turbo. *P. patula* showed good but not significantly better growth compared to *P. patula* subsp. *tecunumanii*. *P. patula* was introduced into Kenya and other African countries early this century and has subsequently undergone selection, improvement and extensive planting whereas *P. patula* subsp. *tecunumanii* is still in a relatively unimproved state and has been on an experimental scale only. However, the difference in genetic improvement stage between the two species did not result in significant differences in growth suggesting that genetically improved *P. patula* subsp. *tecunumanii* may be a better species for planting at Turbo and other highland regions where *P. patula* is normally planted. Results of a study using the three pine species used in this trial showed that *P. patula* subsp. *tecunumanii* had significantly better stem form and light branching compared to *P. patula* and *P. oocarpa* (KEFRI, 1995), suggesting that, because of its good stem form and very light branching habit, *P. patula* subsp. *tecunumanii* may produce more and higher quality timber compared to *P. patula*. This implies that less effort may be directed towards improvement of stem form in *P. patula* subsp. *tecunumanii*, leaving ample time and resources for improvement of growth and possibly wood quality.

P. patula is one of the main pulpwood producing species in Kenya and according to Wormald (1975), there will be major demand for pulp (1.17 million m^3, as compared to 1.07 million m^3 for sawntimber) by the turn of the century. *P. patula* subsp. *tecunumanii* may be used to complement or as a substitute for *P. patula* in meeting the demand.

Variations in the family-within-provenance and family levels in *P. patula* subsp. *tecunumanii* that was observed in this trial suggests that there may be a potential for family selection and improvement for the species. According to Burley and Wood (1976), gains of up to 15% may be obtained from family selection only. This, together with the high heritability estimates for height, DBH and volume indicates a high possibility of capturing genetic gains in operational plantations of the species.

The results also showed that the significance of the differences in growth among the three species was mainly a result of the relatively slower growth in *P. oocarpa*. This was expected because slow growth is an adaptive characteristic of species occurring in drier areas. *P. oocarpa* occurs in more harsh conditions in its natural range compared to the other two species and may therefore be suitable for planting on poorer sites of Turbo and other marginal areas where *P. patula* and *P. patula* subsp. *tecunumanii* cannot grow well.

5. Conclusion

This study has shown the existence of substantial variation among the three species and among provenances of both *P. patula* subsp. *tecunumanii* and *P. oocarpa*. Productivity in *P. patula*, evaluated as volume production per hectare was higher, but not significantly better than *P. patula* subsp. *tecunumanii*. The best provenances within the subspecies were the Yucul and Cusuco. These provenances have also proved to be among the best in earlier introductions of *P. oocarpa*. The results suggest that *P. patula* subsp. *tecunumanii* may be used for widespread planting at Turbo and other similar highland areas because it has shown growth as good as *P. patula* despite being in a relatively unselected and unimproved state. High heritability for volume and associated traits, together with comparable growth with improved *P. patula* suggested that a breeding programme for and use of improved *P. patula* subsp. *tecunumanii* may be expected to in-

crease plantation productivity very substantially. However, heritability estimates only apply to particular environments and time in which they are made and should therefore be used as an indicator of the most heritable traits (Zobel and Talbert, 1984).

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