Table A5. – Correlation matrix, model C1, clonal site-site correlations were structured to be equal among trials within cycles and equal among trials within pairs of cycles with the same difference in cycle number. The same letter indicates that the correlations were constrained to be equal in the model.

	F1011	F1012	F1013	F1106	F1107	F1185	F1186	F1243	F1244
F1011		1	1	A	A	B	B	C	C
F1012			1	A	A	B	B	C	C
F1013				A	A	B	B	C	C
F1106					1	D	D	E	E
F1107						D	D	E	E
F1185							1	F	F
F1186								F	F
F1243									1
F1244									

Provenance Productivity of High and Low Elevation *Pinus tecunumanii* in Zimbabwe

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Abstract

The productivity potential of provenances and families of *Pinus tecunumanii* were determined across a range of environments in four orthogonal field trials in Zimbabwe. Provenances of *P. tecunumanii* from altitudes above 1500 m (High Elevation) in natural stands in Mexico and Central America were significantly superior ($P < 0.05$) to provenances from altitudes below 1500 m (Low Elevation) when planted in Zimbabwe in eight-year mean individual tree volume (1729.2 versus 1588.6 dm^3) at 1760 m a.s.l.; were not significantly different (1163.1 versus 1143.9 dm^3) at 1450 m a.s.l.; but the latter was significantly superior (1756.4 versus 1468.6 dm^3) at 1050 m a.s.l., and (720.7 versus 531.5 dm^3) at 780 m a.s.l. The most productive provenances were Juquila (26.1 $m^3ha^{-1}yr^{-1}$) at 1760 m, Yucul (17.3 $m^3ha^{-1}yr^{-1}$) at 1450 m, San Francisco (24.9 $m^3ha^{-1}yr^{-1}$) at 1050 m and Villa Santa (11.1 $m^3ha^{-1}yr^{-1}$) at 780 m a.s.l. Improved *P. patula* was significantly superior to *P. tecunumanii* at 1760 m a.s.l but the differences were nonsignificant at 1450 m a.s.l. In the warm lower altitude sites, *P. tecunumanii* was not significantly different from improved *P. oocarpa*, the commonly planted species, although some provenances of *P. tecunumanii* were significantly superior by as much as 31%. The top 10 ranked families of the high elevation *P. tecunumanii* had an eight-year volume advantage of 1% and 23% over *P. patula* at Stapleford and Cashel, and 40% and 34% over *P. oocarpa* at Gungunyana and Maswera respectively. Genotype-environment interaction was significant by elevation group, provenance and family level. The interaction at the family level was however largely contributed by families from the high elevation *P. tecunumanii*. Opportunities exist for immediate deployment of seed of selected provenances of *P. tecunumanii* in medium and low altitude areas to improve plantation productivity. There is however, no immediate yield advantage of using *P. tecunumanii* seed in high potential environments currently planted to *P. patula*. Breeding and selection could also bring about the planting of *P. tecunumanii* in the higher altitudes in the near future.

Key words: Low and High Elevation *P. tecunumanii*, provenance, productivity.

Introduction

The Tecun Umán pine, *Pinus tecunumanii* Eguiluz & J. P. Perry is a closed-cone pine that occurs from southern Mexico to central Nicaragua in a series of disjunct populations (Styles and McCarter, 1988; Dvorak *et al.,*

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Table 1. – Geographic details of the provenances of *P. tecunumanii* used in the study.

Provenance	Code	Elevation group	Country	Altitude (m)	Latitude °N	Longitude °W	Rainfall (mm)	Temperature (°C)
Yucul	Yuc	LE	Nicaragua	850-1000	12°55'	85°48'	1394	22.4
Culmí	Cul	LE	Honduras	550-650	15°06'	85°21'	1325	24.3
Villa Santa	Vil	LE	Honduras	850-950	14°11'	86°20'	1348	22.4
Mt. Pine Ridge	Mpr	LE	Belize	700-720	17°00'	88°55'	1558	23.9
San Esteban	Est	LE	Honduras	700-800	15°22'	85°35'	1400	25.0
Jocón	Joc	LE	Honduras	850-1100	15°16'	86°55'	1400	21.7
San Francisco	Fra	LE	Honduras	870-1100	15°05'	86°20'	1600	20.0
Finca Victorias	Vic	LE	Guatemala	1200-1300	15°12'	89°22'	1700	22.4
Cusuco	Cus	HE	Honduras	1500-1650	15°30'	88°10'	2500	17.0
La Paz	Paz	HE	Honduras	1750-2000	14°19'	87°45'	1619	20.0
Guajiquiro	Gua	HE	Honduras	1835-2250	14°11'	87°50'	2000	15.0
San Jerónimo	Jer	HE	Guatemala	1700-2000	15°03'	90°18'	1600	17.0
Montana Sumpul	Sum	HE	Honduras	1950-2050	14°24'	89°08'	2200	16.0
Juquila	Juq	HE	Mexico	2000-2250	16°15'	97°17'	1400	14.0
La Soledad	Sol	HE	Guatemala	2000-2300	14°35'	90°25'	1543	15.0
Las Piedrecitas	Pie	HE	Mexico	2300-2600	16°46'	92°35'	1228	14.8

HE, LE – High Elevation and Low Elevation *P. tecucunumanii.*

2000a). It has been described as a magnificent tree, which usually forms mixed or pure stands of great commercial value in its natural range (EGUILUZ, 1986). Mature naturally-occurring stands of *P. tecunumanii* possess phenotypes with straight, clear boles and light narrow crowns. Twenty years ago, specimens that reach over 50 m in height and over 1 m diameter at breast height were not uncommon on good sites making this one of the largest of any of the tropical pines (STYLES and MCCARTER, 1988). However, many of the old growth forests have now been harvested by wood cutters.

The species has been separated into two subpopulations referred to as high and low elevation *P. tecunumanii*, based on the altitude of their occurrence in natural stands as well as subtle morphological differences in bark and cone characteristics (DVORAK, 1986; DVORAK *et al.,* 2000a). Subsequent molecular marker analysis using RAPD (FURMAN *et al.,* 1997; FURMAN and DVORAK, 2005) and microsatellites (DVORAK *et al.,* 2009) has confirmed that genetic differences between the two groups are apparent. Disease screening of seedlings of *P. tecunumanii* from HE and LE for Pitch canker (*Fusarium circinatum*) resistance has also shown significant differences (HODGE and DVORAK, 2007). High elevation (HE) populations generally occur above 1500 m a.s.l and low elevation (LE) populations occur below 1500 m.a.s.l. In the natural range, trees of the HE sources reach heights of up to 55 m, while trees of the LE sources only reach heights of about 30 m.

The first reports of growth performance of *P. tecunumanii* in the tropics were those of provenances of the LE *P. tecunumanii*, which were originally introduced and evaluated as *P. oocarpa*. Subsequent tests included seed sources of both HE and LE *P. tecunumanii*. Most of these sources were found to outperform provenances of true *P. oocarpa* in volume production (CROCKFORD *et al.,* 1988; BIRKS and BARNES, 1990; CROCKFORD *et al.,* 1990; NYOKA and BARNES, 1995). In other studies elsewhere, DVORAK and SHAW (1992) found that HE *P. tecunumanii* families were more productive than commercial seedlots of *P. patula* and *P. oocarpa* by as much as 20 and 40 percent respectively in Brazil, Colombia and South Africa. More recently, MOURA and DVORAK (1998) also found that HE Central American provenances were more productive than HE Mexican sources in Brazil.

The Zimbabwe Forest Research Centre established four trials of *P. tecunumanii* across four diverse sites in the 1990s. What makes these trials unique is that they included good representation of both HE and LE populations across the entire natural range of *P. tecunumanii* on the same site. Furthermore, the inclusion of two commercially grown species, *P. patula* and *P. oocarpa* as controls also provided an opportunity to compare the growth performance of the LE and HE *P. tecunumanii* provenances against these widely planted species.

The objectives of this study were to use field trials in Zimbabwe to: (a) compare the productivity of the LE and HE *P. tecunumanii* for which differentiation was originally hypothesised based on subtle morphological differences (DVORAK, 1986), monoterpene composition (SQUILLACE and PERRY, 1992) and unique RAPD (GRATTAPAGLIA et al., 1993; FURMAN *et al.,* 1997) and microsatellite markers (DVORAK *et al.,* 2009); (b) contrast the performance of the LE *P. tecunumanii* Belize provenance against the other LE *P. tecunumanii*; (c) contrast the performance of the isolated HE *P. tecunumanii* Mexican provenances against the other HE *P. tecunumanii*; and to (d) compare the productivity of *P. tecunumanii* with that of *P. patula* and *P. oocarpa* in respectively high and low altitude environments.

In this paper, the Juquila source is referred to as *P. tecunumanii* which is how it was originally described in the 1990s when the field trials were established. Since then, it has been shown not to carry markers for *P. tecunumanii* and has been reclassified as atypical *P. herrerae*/*P. pringlei* (DVORAK *et al.,* 2001; DVORAK, 2008).

Materials and Methods

Open-pollinated seeds were collected by the Oxford Forestry Institute from 160 mother trees representing 16 provenances of *P. tecunumanii* in its natural range. The mother trees were selected on the basis of pheno-

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Table 2. – Details of climatic and geographic factors of the four test sites.

Site	Altitude a.s.l.	Latitude	Longitude	Rainfall Annual	Mean Temperature °C		
					Annual	Maximum	Minimum
	(m)	°S	°E	(mm)	(°C)	(°C)	(°C)
Stapleford	1760	18°41	32°51	2159	15.1	19.2	11.1
Gungunyana	1050	20°24	32°43	1097	18.1	24.0	13.9
Cashel	1450	19°25	32°45	891	19.5	24.4	14.6
Maswera	780	18°41	32°55	1498	20.7	28.4	13.0

typic superiority in branch quality, stem form, tree size and taper. The selected mother trees in the wild were separated by a minimum distance of 100 m to avoid possibility of excessive neighbourhood inbreeding. Eight provenances were from altitudes above 1500 m a.s.l. (HE *P. tecunumanii*) and the other eight where from below this elevation (LE *P. tecunumanii*). Ten mother trees were selected in each provenance making a total of 80 families each for the LE and HE *P. tecunumanii*. *Table 1* shows summaries of geographic location and climatic data of the provenances. One of the eight LE *P. tecunumanii* provenances (Mt Pine Ridge) is from Belize, while two of the eight HE *P. tecunumanii* are from Mexico (Las Piedrecitas and Juquila).

For the controls, *P. patula* seed was collected from 10 second generation clones in a clonal seed orchard that was available for commercial planting while seed for *P. oocarpa* was collected from 10 first generation selection clones in clonal seed orchards that were also currently being planted. The seed was sown at the Mukandi nursery near John Meikle Forest Research Station, Penhalonga (altitude 1246 m a.s.l.; rainfall 1778 mm; temperature 18 °C). Sufficient seedlings were raised to establish orthogonal trials at four sites, ranging in altitude from 780 to 1760 m a.s.l. in the pine plantation growing areas of the eastern border of Zimbabwe. The details of geographic location and climatic factors of the test sites are shown in *Table 2*.

Stapleford is considered a favourable environment because of the high rainfall, deep, fertile and well drained soils. Although, rainfall at this site is received in summer, significant amounts are also received during the winter months. Although Cashel receives less than 1000 mm per annum, the cooler temperatures, moderated by altitude improve the effectiveness of the rainfall, making it an above average site. Gungunyana is considered an average environment as the soils are shallow and less fertile and rainfall is only received in summer, and significant winter rains are infrequent. Despite Maswera being a fairly wet site, the high temperatures that promote excessive water loss by evaporation coupled with insignificant precipitation in winter make this environment the least favourable among the four sites.

Trial Design

The trial design was a split plot in a randomised complete block with five replications at each site. Two commercial species, *P. patula* and *P. oocarpa* each with 10 families were included as control checks. The 16 provenances and the 2 species controls were randomised in main plots and the 10 families of each provenance and species were in turn randomised in subplots of each of the main plots. Each family subplot was a five tree line with a spacing of 3m between rows and 3m within the row. The main plot was therefore a 10 x 5 rectangular tree plot. There were a total 18 main plot treatments (16 provenances and 2 species) and 180 family subplots. The trial design was balanced at establishment for all the sites. The four trials were assessed for survival (sur2) and height (hgt2) at two years; height (hgt5), diameter at breast height (dbh5) and stem straightness (str5) at five years; and height (hgt8), diameter at breast height (dbh8) and stem straightness (str8) at eight years. Stem straightness was assessed on a scale of 1 to 7. A rating of 1 represented the most crooked stem and 7 represented a very straight stem (BARNES and GIBSON, 1986).

Statistical Analysis

Trees that had severe stem breakage were excluded from the analysis. These were trees that had abnormal height:dbh ratios. Stem breakage averaged less than 10 percent at the worst affected site. Individual tree volume (dm^3) over bark at ages five and eight years was calculated using a formula for juvenile pines (DVORAK and SHAW, 1992):

vol = 0.3 *(dbh)2 * height

where

vol = volume in cubic decimetres (dm^3) at five or eight years

dbh = diameter at breast height (1.3 m) in cm at five or eight years

height = Height in metres at five or eight years.

The statistical analysis was conducted using PROC GLM in Statistical Analysis System (SAS, 1998). All the analyses were based on family subplot means rather than individual trees. The first analysis was on the individual site data and the following model was fitted to test the significance of all the effects and the contrasts:

$$y_{ijk} = \mu + b_i + p_j + bp_{ij} + f(p)_{j(k)} + \varepsilon_{ijk}$$

where

y_{ijk} = observation in the ijkth plot

μ = general trial mean

b_i = effect of the ith block

p_j = effect of the jth provenance

bp_{ij} = interaction effect between the ith block and the jth provenance or main plot error

$f(p)_{jk}$ = effect of the kth family of jth provenance

ε_{ijk} = plot error.

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The four orthogonal contrasts tested with the model were:

(a) LE *P. tecunumanii* vs HE *P. tecunumanii*

(b) LE *P. tecunumanii* vs LE Belize sources (Mt Pine Ridge)

(c) HE *P. tecunumanii* vs HE Mexican sources (Las Piedrecitas and Juquila)

(d) *P. tecunumanii* vs *P. patula* (at Stapleford and Cashel) or *P. oocarpa* (at Gungunyana and Maswera).

The data was further analysed across sites to test the significance of the interactions. Data from the two controls were not used in the across site analysis. The appropriate model for this analysis was:

$$y_{ijklm} = \mu + s_i + b(s)_{ij} + a_k + sa_{ik} + ab(s)_{ijk} + p(a)_{kl} + sp(a)ikl + bp(sa)_{ijkl} + f(pa)_{klm} + sf(pa)_{iklm} + e_{ijklm}$$

where

y_{ijklm} = the observation in the ijklmth family subplot
μ = the general mean
s_i = the effect of the ith site
$b(s)_{ij}$ = the effect of the jth block in the ith site
a_k = the effect of the kth *P. tecunumanii* type
sa_{ik} = the interaction of ith site and kth *P. tecunumanii* type
$ab(s)_{ijk}$ = the interaction of kth *P. tecunumanii* type and jth block in the ith site
$p(a)_{kl}$ = the effect of the lth provenance within the kth *P. tecunumanii* type
$sp(a)_{ikl}$ = the interaction of the ith site with the lth provenance of the kth *P. tecunumanii* type
$bp(sa)_{ijkl}$ = the interaction of the jth block of the ith site with the lth provenance within the kth *P. tecunumanii* type
$f(pa)_{klm}$ = the effect of the mth family within the lth provenance within the kth *P. tecunumanii* type
$sf(pa)_{iklm}$ = the interaction of the mth family of the lth provenance of the kth *P. tecunumanii* type with the ith site
e_{ijklm} = plot error.

Results

Tree survival at two years was above 92% for both the LE and HE *P. tecunumanii* at Stapleford and Cashel, but was down to 89% and 83% respectively at Gungunyana and Maswera (*Table 3*). Four HE provenances namely Guajiquiro, San Jeronimo, La Soledad and Las Piedrecitas had survival rates below 80%. These provenances contributed to the overall lower mean survival rate of the HE *P. tecunumanii* at Maswera.

Table 4 shows the variance ratios of different sources of variation together with the four contrasts for two-, five- and eight-year growth and stem straightness at individual sites. Provenance effects were significant ($P < 0.001$) at all the four sites for the growth and stem straightness traits. The LE and HE *P. tecunumanii* were significantly different from each other at lower altitude test sites (Gungunyana and Maswera) for all of the traits except stem straightness at eight years but the differences were often non-significant for some of the traits at the higher altitude sites (Stapleford and Cashel). The two Mexican HE *P. tecunumanii* provenances (Juquila and Las Piedrecitas) were significantly different from the other HE *P. tecunumanii* for most of the traits. The differences were more apparent at Gungunyana and Maswera but less pronounced at higher altitude sites of Stapleford and Cashel. The contrast between the Mt Pine Ridge and other LE *P. tecunumanii* was non-significant at Maswera, but was however significant at the other three sites for some of the traits. Also, the contrasts (*P. patula* versus *P. tecunumanii*) at Stapleford and Cashel and (*P. oocarpa* versus *P. tecunumanii*) at Gungunyana and Maswera were significant at varying probability levels for most of the traits.

Table 3. – Mean percent survival of *P. tecunumanii* provenances at individual sites at age two years.

Provenance	Site			
	Stapleford	Cashel	Gungunyana	Maswera
Yucul	93.2ab	94.0a	93.2abcd	86.4bcd
Culmi	88.0b	92.0a	84.0ef	80.4de
Villa Santa	96.0ab	90.0a	89.2bcde	86.4bcd
Mt Pine Ridge	98.0a	95.2a	87.6cde	92.8abc
Estaban	87.6b	90.4a	94.0abc	89.2abcd
Jocón	91.6ab	94.4a	95.6ab	89.2abcd
San Francisco	92.4ab	95.2a	94.8ab	96.8a
Las Victorias	92.0ab	92.8a	88.0cde	87.2abcd
Cusuco	89.6ab	92.8a	96.8a	86.0bcd
La Paz	93.6ab	94.8a	94.0abc	85.6bcd
Guajiquiro	88.0b	91.2a	84.8ef	79.2de
Jerónimo	94.4ab	96.0a	85.2ef	79.2de
Montana Sumpul	96.8ab	92.4a	97.2a	93.2ab
Juquila	94.8ab	96.8a	86.8def	82.8cde
La Soledad	88.8ab	92.4a	80.4fg	80.0de
Las Piedrecitas	96.4ab	94.4a	74.4g	75.2e
LE *P. tecunumanii*	92.4	93.0	90.8	88.6
HE *P. tecunumanii*	93.1	93.9	87.5	82.7

Means in a column followed a common letters do not differ significantly at 5%.

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Table 4. – ANOVA F-values for two-, five- and eight-year height, diameter, volume and stem straightness at individual sites.

Source of Variation	DF	hgt2	hgt5	dbh5	vol5	str5	hgt8	dbh8	vol8	str8
Stapleford										
Block	4	123.7***	67.36***	25.96***	58.76***	12.56***	60.50***	12.78***	39.12***	32.16***
Provenance	17	4.69***	6.95***	5.48***	9.13***	15.29***	9.85***	3.09***	6.34***	20.41***
HE vs LE *P. tecunumanii*	1	33.87***	3.21^{ns}	0.84^{ns}	7.22^{ns}	73.28***	9.54**	1.52^{ns}	7.69**	108.5***
Mexico vs HE *P. tecunumanii*	1	4.12^{a}	0.29^{ns}	1.72^{ns}	0.79^{ns}	10.90**	4.68*	4.53*	4.83*	23.20***
Belize vs LE *P. tecunumanii*	1	7.87**	0.03^{ns}	2.02^{ns}	2.07^{ns}	8.25**	5.35*	6.14*	8.27**	14.40***
P. tecunumanii vs *P. patula*	1	0.06^{ns}	42.65***	40.14***	78.45***	104.7***	54.75***	11.75***	32.22***	126.2***
Block*Provenance	68									
Family(Provenance)	161	2.38***	1.73***	1.53***	1.71***	1.19^{ns}	1.76***	1.59***	1.94***	2.14***
Plot error	649									
Cashel										
Block	4	21.87***	19.69***	27.92***	23.97***	5.23***	4.69**	12.91***	11.67***	8.65***
Provenance	17	7.47***	5.53***	5.34***	7.58***	18.92***	5.06***	3.42***	4.67***	20.11***
HE vs LE *P. tecunumanii*	1	41.13***	28.93***	25.95***	37.83***	76.80***	3.49^{ns}	0.85^{ns}	0.06^{ns}	121.6***
Mexico vs HE *P. tecunumanii*	1	4.69*	3.93^{ns}	0.40^{ns}	1.36^{ns}	45.99***	1.08^{ns}	1.59^{ns}	0.21^{ns}	32.28***
Belize vs Low *P. tecunumanii*	1	1.78^{ns}	0.08^{ns}	2.52^{ns}	4.45*	9.02**	15.51***	8.84**	14.15***	14.28***
P. tecunumanii vs *P. patula*	1	27.53***	7.16**	17.34***	14.61***	120.0***	3.76^{ns}	0.52^{ns}	0.06^{ns}	141.1***
Block*Provenance	68									
Family(Provenance)	161	3.76***	2.73***	2.42***	2.32***	1.75***	2.51*	2.54***	2.17***	1.95***
Plot error	649									
Gungunyana										
Block	4	8.12***	8.61***	11.05***	15.98***	2.21^{ns}	8.02***	9.03***	12.17***	17.07***
Provenance	17	18.41***	17.98***	11.41***	15.20***	4.67***	12.13***	2.50**	5.02***	7.24***
HE vs LE *P. tecunumanii*	1	81.17***	135.4***	65.11***	82.62***	11.54***	85.22***	19.33***	36.50***	9.44**
Mexico vs HE *P. tecunumanii*	1	12.75***	54.28***	25.97***	27.57***	0.36^{ns}	48.09***	3.99*	12.86***	2.50^{ns}
Belize vs LE *P. tecunumanii*	1	6.87*	16.04***	10.67**	15.16***	6.68*	38.93***	7.77**	15.10***	24.49***
P. tecunumanii vs *P. oocarpa*	1	28.00***	1.01^{ns}	6.43*	7.35**	1.95^{ns}	5.60*	0.23^{ns}	1.38^{ns}	1.63^{ns}
Block*Provenance	68									
Family (Provenance)	161	2.18***	2.41***	2.19***	2.17***	1.72**	2.49***	1.91***	2.05***	1.79***
Plot error	649									
Maswera										
Block	4	47.31***	146.1***	132.1***	121.1***	84.63***	86.57***	55.15***	66.73***	20.08***
Provenance	17	19.59***	19.67***	19.79***	18.13***	8.78***	17.86***	15.65***	14.73***	3.07***
HE vs LE *P. tecunumanii*	1	132.4***	120.4***	81.28***	84.38***	29.90***	91.75***	68.69***	75.85***	0.20^{ns}
Mexico vs HE *P. tecunumanii*	1	25.37***	40.78***	30.78***	23.70***	5.00*	43.81***	18.93***	23.94***	1.34^{ns}
Belize vs LE *P. tecunumanii*	1	3.02^{ns}	0.78^{ns}	0.00^{ns}	2.13^{ns}	1.47^{ns}	0.20^{ns}	2.33^{ns}	0.00^{ns}	6.67*
P. tecunumanii vs *P. patula*	1	11.40**	9.12**	26.30***	21.15***	20.69***	7.82**	16.17***	11.77***	2.86^{ns}
Block*Provenance	68									
Family(Provenance)	161	3.15***	2.41***	2.16***	2.09***	1.58**	2.06***	1.85**	1.91**	1.44**
Plot error	649									

ns, a, b, c for not significant at 5%, significant at 5, 1 and 0.1% respectively.
Belize refers to the Mt Pine Ridge provenance.
Mexico refers to the Las Piedrecitas and Juquila provenance.

Tables 5 to *8* show the two-, five- and eight-year provenance means of growth and stem straightness together with the means of the LE and HE *P. tecunumanii* at individual sites. Family ranges in these same traits are shown in *Table 9*. Provenance rank changes in height, diameter and volume growth with age was evident at all the four sites, with provenances from the LE *P. tecunumanii* showing exceptional growth in the early years. The most notable provenance for changing rank with age was Mt Pine Ridge, which was among the top

Table 5. – Means of growth and stem straightness of *P. tecunumanii* provenances at Stapleford.

Provenance	Means																	
	vol8 (dm^3)	dbh8 (cm)	rk	hgt8 (m)	rk	str8 (1-7)	rk	vol5 (dm^3)	rk	dbh5 (cm)	rk	hgt5 (m)	rk	str5 (1-7)	rk	hgt2 (m)	rk
Juquila	2089.2a	20.2a	1	13.5a	1	4.2a	1	486.2ab	2	12.6a	1	7.8a	4	3.8a	1	1.2ab	13
Guajiquiro	1861.0ab	19.5ab	2	13.0ab	3	3.7bcde	5	440.9abc	5	11.9a	6	7.9a	3	3.6abc	4	1.2ab	13
La Soledad	1791.3abc	19.0abcd	5	12.7ab	7	3.5defg	9	432.5abcd	6	11.9a	6	7.4ab	10	3.5abcd	5	1.1b	16
Villa Santa	1788.0abc	19.3abc	3	12.7ab	7	3.5defg	9	468.0abcd	3	12.5a	2	7.7ab	5	3.3bcde	9	1.5a	1
San Jerónimo	1784.3abc	18.6abcd	8	13.5a	1	4.1ab	2	495.7a	1	12.5a	2	8.2a	1	3.7ab	2	1.3ab	7
Yucul	1740.7cbc	19.labcd	4	12.7ab	7	3.3efgh	11	405.5abcd	9	11.7a	8	7.7ab	5	3.3bcde	9	1.3ab	7
San Estaban	1645.2bcd	19.0abcd	5	12.0b	14	3.0h	16	405.7abcd	8	12.0a	5	7.2ab	13	3.1dc	15	1.4ab	3
Jocón	1638.8bcd	18.6abcd	8	12.2ab	12	3.2fgh	13	386.4abcd	11	11.5a	10	7.2ab	13	3.2cde	12	1.4ab	3
Las Piedrecitas	1637.5bcd	18.4abcd	10	12.8ab	5	4.0abc	3	387.3abcd	12	11.4a	12	7.6ab	8	3.5abcd	5	1.2ab	13
San Francisco	1587.4bcd	18.1bcd	12	12.8ab	5	3.6cdef	6	330.5d	16	11.1a	13	6.7b	16	3.3bcde	9	1.4ab	3
Montana Sumpul	1581.3bcd	18.1bcd	12	12.6ab	10	3.9abcd	4	412.0abcd	7	11.7a	8	7.7ab	5	3.7ab	2	1.3ab	7
Cusuco	1580.0bcd	18.7abcd	7	11.8b	15	3.3efgh	11	391.2abcd	10	11.5a	10	7.3ab	11	3.2cde	12	1.4ab	3
Las Victorias	1573.5bcd	18.2bcd	11	12.9ab	4	3.6cdef	6	447.2abcd	4	12.2a	4	8.la	2	3.5abcd	5	1.3ab	7
La Paz	1551.5cd	17.8bcd	15	12.4ab	11	3.6cdef	6	373.3bcd	13	11.0a	16	7.2ab	13	3.4abcde	8	1.3ab	7
Culmi	1463.5cd	17.9bcd	14	12.2ab	12	3.lgh	14	355.7bcd	14	11.1b	13	7.5ab	9	3.2cde	12	1.3ab	7
Mt Pine Ridge	1340.7d	17.3d	16	11.8b	15	3.lgh	14	352.5cd	15	11.1b	13	7.3ab	11	3.1e	15	1.5a	1
Low Elevation	1588.6	18.4		12.4		3.5		393.4		11.6		7.4		3.2		1.4	
High Elevation	1729.2	18.7		12.8		4.0		428.1		11.8		7.6		3.6		1.2	

Means in a column followed by a common letter do not differ significantly at 5%; rk = rank.
Low Elevation and High Elevation = Low and High Elevation *P. tecunumanii.*

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Table 6. – Means of growth and stem straightness of *P. tecunumanii* provenances at Cashel.

Provenance	Means																
	vol8 (dm³)	dbh8 (cm)	rk	hgt8 (m)	rk	str8 (1-7)	rk	vol5 (dm³)	rk	dbh5 (cm)	rk	hgt5 (m)	rk	str5 (1-7)	rk	hgt2 (m)	rk
Yucul	1383.6a	17.5a	1	11.9a	2	3.9bcd	1	296.6a	1	10.0a	1	7.5a	1	3.5abc	5	1.3abc	3
Las Victorias	1365.6a	17.2a	3	12.2a	1	3.2bcd	9	269.5ab	3	9.6a	2	7.1ab	2	3.5abc	5	1.3abc	3
Guajiquiro	1298.4a	17.3a	2	11.3a	6	3.4abc	4	201.5bc	8	8.7a	9	6.4ab	10	3.8ab	3	1.1bc	11
San Jerónimo	1226.0ab	16.7ab	5	11.3a	6	3.4abc	4	196.Sbc	11	8.6a	10	6.5ab	6	3.7abc	4	1.2bc	8
Juquila	1224.2ab	16.9ab	4	11.4a	4	3.8a	2	182.5bc	12	8.5a	12	6.2ab	13	4.0a	1	1.1bc	11
San Francisco	1216.4ab	16.5ab	7	11.6a	3	2.9cd	14	271.1ab	2	9.5a	3	6.8ab	3	3.3bc	12	1.6a	1
Villa Santa	1214.8ab	16.7ab	5	11.3a	6	3.0bcd	11	234.5abc	4	9.4a	4	6.5ab	6	3.3bc	12	1.2bc	8
Las Piedrecitas	1161.6ab	16.4ab	8	10.8a	14	3.5ab	3	166.5c	16	8.0a	15	5.9b	15	3.9ab	2	1.0c	15
La Paz	1155.1ab	16.1ab	10	11.3a	6	3.3abc	6	207.3bc	7	8.8a	6	6.5ab	6	3.6abc	5	1.3abc	3
La Soledad	1147.3ab	16.2ab	9	11.3a	6	3.3abc	6	182.3bc	13	8.3a	13	6.1b	14	3.6abc	5	1.1bc	11
Cusuco	1116.3ab	15.7ab	13	11.1a	11	3.2bcd	9	209.0bc	6	8.6a	10	6.5ab	6	3.3bc	12	1.2bc	8
San Estaban	1113.5ab	15.9ab	11	11.4a	4	3.0bcd	11	219.3abc	5	9.0a	5	6.6ab	4	3.3bc	12	1.3abc	3
Montana Sumpul	1077.2ab	15.9ab	11	10.8a	15	3.3bc	6	176.7c	14	8.0a	15	5.9b	15	3.5abc	5	1.0c	15
Jocón	1055.6ab	15.6ab	14	11.1a	11	3.0bcd	11	200.9bc	10	8.8a	6	6.4ab	10	3.5abc	5	1.3abc	3
Culmi	953.9b	15.1b	15	11.0a	13	2.9cd	14	166.6c	15	8.1a	14	6.3ab	12	3.4abc	11	1.1bc	11
Mt Pine Ridge	927.1b	15.1b	15	10.6a	16	2.7d	16	201.3bc	9	8.8a	6	6.6ab	4	3.1c	16	1.4ab	2
Low Elevation	1143.9	16.2		11.4		3.0		233.8		9.2		6.7		3.4		1.4	
High Elevation	1163.1	16.4		11.2		3.4		191.4		8.5		6.3		3.7		1.2	

Means in a column followed by a common letter do not differ significantly at 5%; rk = rank.
Low Elevation and High Elevation = Low and High Elevation *P. tecunumanii.*

Table 7. – Means of growth and stem straightness of *P. tecunumanii* provenances at Gungunyana.

Provenance	Means																
	vol8 (dm³)	dbh8 (cm)	rk	hgt8 (m)	rk	str8 (1-7)	rk	vol5 (dm³)	rk	dbh5 (cm)	rk	hgt5 (m)	rk	str5 (1-7)	rk	hgt2 (m)	rk
S. Francisco	1995.9a	18.7a	1	15.1ab	2	3.7ab	9	382.2a	3	10.7a	1	8.4a	1	3.4a	7	2.2a	1
Yucul	1958.7ab	18.3ab	2	15.4a	1	3.9ab	2	289.1bc	2	9.6ab	2	7.8ab	2	3.5a	4	1.5bc	3
Las Victorias	1794.3abc	17.7abcd	4	14.9ab	3	3.8abc	6	269.3bcd	5	8.9bcd	6	7.7ab	3	3.5a	4	1.5bc	3
Villa Santa	1791.1abc	17.9abc	3	14.5abc	5	3.7abc	9	226.4def	8	8.7bcd	8	7.2bc	6	3.3a	15	1.3cde	8
Cusuco	1758.9abc	17.3abcd	8	14.1abc	7	3.6bc	14	297.2b	1	9.6ab	2	7.5ab	5	3.4a	7	1.5bc	3
San Estaban	1745.2abc	17.6abcd	6	14.7abc	4	3.7abc	9	278.7bc	4	9.5abc	4	7.6ab	4	3.4a	7	1.6b	2
Culmi	1700.8bcd	17.7abcd	4	14.2abc	6	3.6bc	14	222.8def	9	8.7bcd	8	7.2bc	6	3.4a	7	1.3cde	8
La Paz	1649.8cde	17.3abcd	8	14.1abc	7	3.9ab	2	236.7cde	7	8.9bcd	6	7.2bc	6	3.4a	7	1.3cde	8
San Jerónimo	1633.3cde	17.5abcd	7	14.0abc	10	3.9ab	2	185.7cfg	11	8.2cdef	11	6.5cde	11	3.6a	1	1.2de	12
Jocón	1623.1cde	17.1abcd	10	14.1abc	7	3.7abc	9	237.9cde	6	9.3bc	5	7.1bc	9	3.4a	7	1.5bc	3
Mt Pine Ridge	1457.8def	17.1bcd	10	13.2cd	13	3.4c	16	206.8ef	10	8.6bcd	10	7.0bcd	10	3.2a	16	1.4bcd	7
Guajiquiro	1455.9def	16.6bcd	12	13.3cd	12	3.8abc	6	148.2gh	14	7.3c	14	6.1def	14	3.6a	1	1.1ef	13
La Soledad	1439.3def	16.6bcd	12	13.6bcd	11	3.9ab	2	177.7fg	13	7.9de	13	6.5cde	11	3.5a	4	1.1ef	13
Montana Sumpul	1418.7ef	16.4cd	14	13.2cd	13	3.7abc	9	182.8efg	12	8.2cde	11	6.4cde	13	3.4a	7	1.3cde	8
Juquila	1252.1f	16.0d	16	12.3d	15	4.1a	1	129.6gb	15	7.1e	15	5.1ef	16	3.6a	1	1.1ef	13
L as Piedrecitas	1262.0f	16.1d	15	11.9d	16	3.8abc	6	117.4h	16	7.0e	16	5.4f	15	3.4a	7	0.9f	16
Low Elevation	1756.4	17.7		14.5		3.7		265.4		9.3		7.5		3.4		1.5	
High Elevation	1468.6	16.6		13.3		3.8		183.8		8.0		6.4		3.5		1.2	

Means in a column followed by a common letter do not differ significantly at 5%; rk = rank.
Low Elevation and High Elevation = Low and High Elevation *P. tecunumanii.*

Table 8. – Means of growth and stem straightness of *P. tecunumanii* provenances at Maswera.

Provenance	Means																
	vol8 (dm³)	dbh8 (cm)	rk	hgt8 (m)	rk	str8 (1-7)	rk	vol5 (dm³)	rk	dbh5 (cm)	rk	hgt5 (m)	rk	str5 (1-7)	rk	hgt2 (m)	rk
Villa Santa	890.6a	13.8a	1	12.1ab	1	4.3a	2	138.3a	2	7.1ab	2	6.5ab	2	3.2abc	3	1.1b	3
San Francisco	873.1ab	13.6a	2	12.2a	2	4.2a	5	157.9a	1	7.6a	1	6.9a	1	3.6a	1	1.5a	1
Jocón	762.6abc	12.9ab	4	11.5abc	3	4.3a	2	93.6bc	6	6.1bc	6	5.6bc	7	3.1abc	5	1.0cb	5
Cusuco	727.5abcd	12.7ab	5	11.2abc	5	4.4a	1	100.5b	4	6.2bc	4	5.7bc	6	3.2abc	3	1.0cb	5
Mt Pine Ridge	711.7abcde	13.1ab	3	11.0abcd	6	3.9a	13	96.2bc	5	6.3bc	3	5.8bc	3	3.3ab	2	1.2b	2
San Estaban	702.4abcde	12.5abc	6	11.3abc	4	4.1a	7	102.5b	3	6.1bc	6	5.8bc	3	3.0abc	8	1.0cb	5
Culmi	658.7cde	12.2abcd	7	10.6abcde	8	4.0a	11	89.4bcd	7	5.8cde	9	5.6bc	7	3.1abc	5	0.9cd	8
Montana Sumpul	636.8cdef	12.0acd	9	10.7abcde	7	4.3a	2	87.1bcd	8	6.0bcde	8	5.4cd	9	3.1abc	5	0.9cd	8
Yucul	610.5cdef	12.1abcd	8	10.6abcde	8	4.2a	5	80.5h	9	6.2bc	4	5.8bc	3	3.0abc	8	1.1b	3
La Paz	568.5cdefg	11.1bcd	12	10.2abcde	10	4.0a	11	76.9bcde	10	5.3cdefg	11	5.1cd	10	2.8bc	11	0.9cd	8
San Jerónimo	568.4cdefg	11.7abcd	10	10.1bcde	11	4.1a	7	72.2bcde	11	5.5cdef	10	5.1cd	10	3.0abc	8	0.8de	12
Las Victorias	556.6defg	11.2bcd	11	9.9cde	12	3.9a	13	59.9cdef	13	4.9defg	13	4.9cde	12	2.8bc	11	0.9cd	8
La Soledad	518.1efg	11.1bcd	12	9.8cde	13	4.1a	7	66.5def	12	5.2cdfg	12	4.9cde	12	2.7bc	13	0.8de	12
Guajiquiro	442.7fg	10.5cd	14	9.2de	14	3.8a	16	51.1ef	14	4.6fg	15	4.5de	14	2.6c	16	0.7e	14
Las Piedrecitas	398.4fg	10.2d	16	8.7e	16	3.9a	13	37.7f	16	4.1g	16	3.9e	16	2.7bc	13	0.6e	16
Juquila	391.0g	10.3d	15	8.8e	15	4.1a	7	50.0ef	15	4.8efg	14	4.5de	14	2.7bc	13	0.7e	14
Low Elevation	720.7	12.7		11.1		4.1		104.8		6.3		6.3		3.1		1.1	
High Elevation	531.5	11.2		9.8		4.1		67.8		5.2		5.2		2.9		0.8	

Means in a column followed by a common letter do not differ significantly at 5%; rk = rank.
Low Elevation and High Elevation = Low and High Elevation *P. tecunumanii.*

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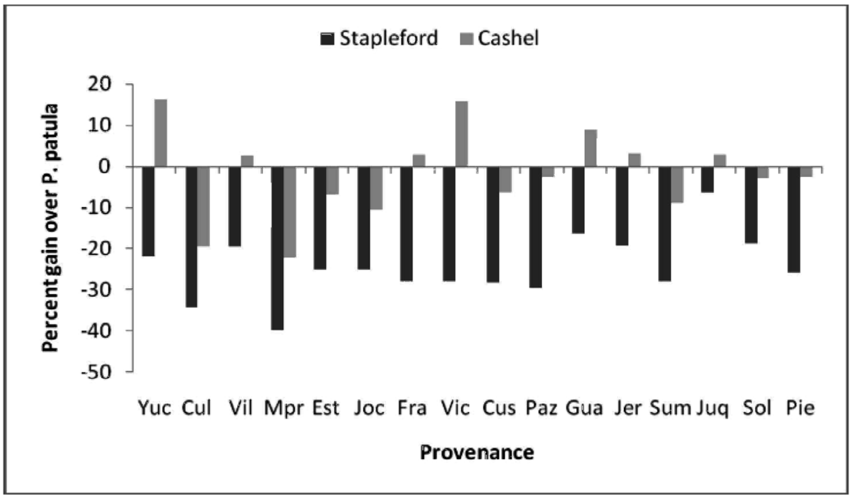
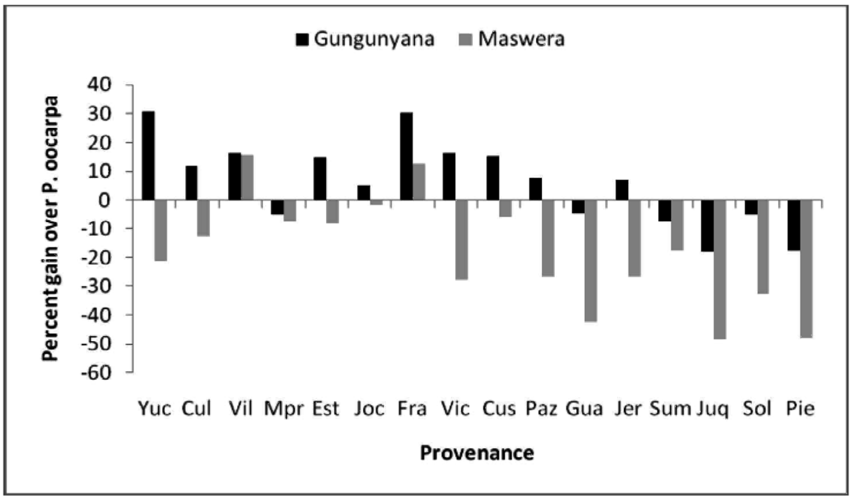
Table 9. – Family ranges of two-, five- and eight-year growth and stem straightness traits for LE and HE *P. tecunumanii* at individual sites.

Site	*P. tecunumanii*	Range	Trait								
			hgt2 (m)	hgt5 (m)	hgt8 (m)	dbh5 (cm)	dbh8 (cm)	vol5 (dm^3)	vol8 (dm^3)	str5 (1-7)	str8 (1-7)
Stapleford	LE	from	1.00	5.70	10.41	11.0	15.3	254.57	1031.66	2.5	2.7
		to	1.90	8.51	13.72	14.5	20.6	500.82	2099.33	3.7	4.3
	HE	from	0.89	5.94	10.42	8.8	21.9	277.62	1093.51	3.0	3.0
		to	1.54	8.95	14.61	13.6	15.5	602.00	2581.54	4.1	4.9
Gungunyana	LE	from	0.99	6.34	12.43	7.4	15.5	141.80	1220.34	3.0	2.8
		to	2.75	8.72	16.46	11.4	19.7	440.08	2297.86	4.0	4.3
	HE	from	0.70	4.54	9.44	5.4	11.6	62.44	589.23	2.7	2.7
		to	1.87	8.49	15.82	11.0	20.4	388.50	2400.56	4.0	4.4
Cashel	LE	from	0.90	5.74	9.43	7.1	13.6	126.83	724.12	2.8	2.2
		to	2.02	7.71	12.63	11.3	18.5	362.43	1558.7	4.0	3.8
	HE	from	0.64	4.27	7.82	5.0	10.2	76.38	526.80	2.6	2.7
		to	1.69	7.46	12.44	10.3	19.2	291.92	1692.52	4.6	4.1
Maswera	LE	from	0.64	4.32	8.65	4.0	9.6	39.80	383.95	2.4	3.3
		to	1.70	7.52	13.38	8.5	15.5	206.22	1189.95	3.0	4.8
	HE	from	0.42	3.36	7.22	3.3	7.2	22.18	241.06	1.8	2.8
		to	1.21	6.55	12.34	7.5	14.7	150.55	1054.44	3.6	5.0



(a)



(b)

Figure 1. – Advantage (gain) in eight-year volume from using seed of *P. tecunumanii* provenances over *P. patula* (a) at Stapleford and Cashel and over *P. oocarpa* (b) at Gungunyana and Maswera (Provenance codes are shown in *Table 1*).

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ranked provenances for two-year height at most of the sites but ended among the poorest provenances at age eight years. For eight-year volume, the most productive provenances were Juquila and Guajiquiro at Stapleford, Yucul and Las Victorias at Cashel, San Francisco and Yucul at Gungunyana and Villa Santa and San Francisco at Maswera. The mean annual increments of the most productive provenances at the different sites translated to 26.1 $m^3ha^{-1}yr^{-1}$ (1760 m a.s.l.); 17.3 $m^3ha^{-1}yr^{-1}$ (1450 m a.s.l.); 24.9 $m^3ha^{-1}yr^{-1}$ (1050 m a.s.l.) and 11.1 $m^3ha^{-1}yr^{-1}$ (780 m a.s.l.)

The HE *P. tecunumanii* had its highest eight-year mean individual tree volume of 1729.2 dm^3 at Stapleford while the LE *P. tecunumanii* had its highest mean volume of 1756.4 dm^3 at Gungunyana. The stem straightness rating of the HE *P. tecunumanii* was consistently better than that of the LE *P. tecunumanii* at most of the sites. HE *P. tecunumanii* provenances with consistently superior stem straightness rating included Juquila, San Jeronimo and Las Piedrecitas, while Yucul had superior stem straightness rating among the LE *P. tecunumanii* provenances.

Figure 1 shows the advantage to be gained in eight-year volume from using seed from each of the 16 *P. tecunumanii* provenances over *P. patula*, the currently planted species at Stapleford and Cashel, and over *P. oocarpa* at Gungunyana and Maswera. Commercially deploying seed of any of the 16 *P. tecunumanii* provenances instead of *P. patula* would be a disadvantage at the present moment as this will result in negative gains ranging from –40% for Mt Pine Ridge to –6% for Juquila at Stapleford (*Fig. 1a*). At Cashel however, some provenances were significantly superior to *P. patula* and their planting in place of *P. patula* would result in gains

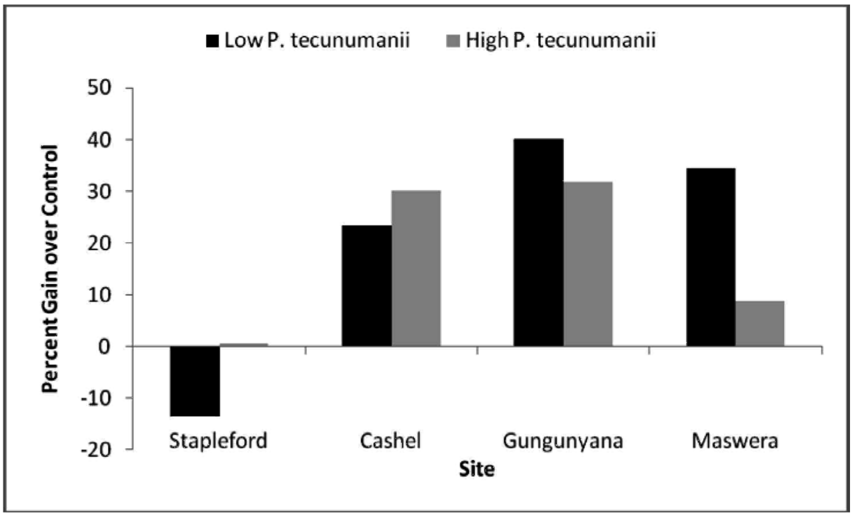

Figure 2. – Advantage (gain) in 8-year volume from using seed from the best 10 families of high and low elevation *P. tecunumanii* over *P. patula* (at Stapleford and Cashel) and over *P. oocarpa* (at Gungunyana and Maswera).

Table 10. – ANOVA F-values for two-, five- and eight-year height, diameter, volume and stem straightness (hgt2, hgt5, hgt8, dbh5, dbh8, vol5, vol8, str5 and str8) across sites.

Source	DF	Trait								
		hgt2	hgt5	dbh5	vol5	str5	hgt8	dbh8	vol8	str8
Site S	3	274.6^{***}	502.9^{***}	1316.4^{***}	1017.2^{***}	210.8^{***}	316.2^{***}	726.7^{***}	524.9^{***}	65.9^{***}
Block-within-site B(S)	16									
P. tecunumanii type A	1	124.5^{***}	77.96^{***}	55.91^{***}	25.55^{***}	0.12^{ns}	57.04^{***}	28.02^{***}	15.90^{***}	6.20^{*}
Site**P. tecunumanii* type S*A	3	14.33^{***}	57.00^{***}	32.98^{***}	31.92^{***}	50.13^{***}	49.14^{***}	37.74^{***}	36.78^{***}	53.72^{***}
B(S)*A	16									
Provenance P(A)	14	11.87^{***}	7.52^{***}	7.49^{***}	6.08^{***}	5.01^{***}	8.07^{***}	4.83^{***}	5.03^{***}	5.93^{***}
LE *P. tecunumanii* provenance	7	14.47^{***}	8.19^{***}	8.54^{***}	8.12^{***}	4.32^{***}	8.45^{***}	5.73^{***}	7.53^{***}	5.62^{***}
HE *P. tecunumanii* provenance	7	9.62^{***}	8.48^{***}	6.85^{***}	4.27^{***}	5.45^{***}	7.86^{***}	4.26^{***}	3.27^{**}	6.17^{***}
S*P(A)	42	6.58^{***}	9.36^{***}	7.02^{***}	7.42^{***}	6.38^{***}	7.35^{***}	5.09^{***}	5.43^{***}	5.14^{***}
S*LE *P. tecunumanii*	21	6.83^{***}	9.81^{***}	7.25^{***}	8.76^{***}	5.21^{***}	6.06^{***}	4.55^{***}	4.24^{***}	4.04^{***}
S*HE *P. tecunumanii*	21	5.64^{***}	9.06^{***}	6.87^{***}	6.18^{***}	7.01^{***}	8.11^{***}	5.36^{***}	6.30^{***}	5.66^{***}
B(S)*P(A)	224									
Family(PA)	144	5.21^{***}	3.53^{***}	3.71^{***}	2.86^{***}	2.36^{***}	2.98^{***}	3.53^{***}	3.05^{***}	2.38^{***}
Family-within-LE *P. tecunumanii*) F(P)	72	4.28^{***}	2.33^{***}	2.68^{***}	2.47^{***}	1.87^{***}	1.97^{***}	2.67^{***}	2.43^{***}	2.36^{***}
Family-within-HE *P. tecunumanii*) F(P)	72	6.62^{***}	4.96^{***}	4.86^{***}	3.33^{***}	2.83^{***}	4.07^{***}	4.46^{***}	3.77^{***}	2.39^{***}
S*F(PA)	432	1.65^{***}	1.55^{***}	1.65^{***}	1.52^{***}	1.57^{***}	1.65^{***}	1.75^{***}	1.53^{***}	1.53^{***}
Site*F(LE *P. tecunumanii*)	216	1.56^{***}	1.14^{ns}	1.25^{**}	1.35^{**}	1.10^{ns}	1.19^{*}	1.12^{ns}	1.19^{*}	1.13^{ns}
Site*F(HE *P. tecunumanii*)	216	1.80^{***}	2.03^{***}	2.11^{***}	1.72^{**}	2.04^{***}	2.14^{***}	2.42^{***}	1.94^{***}	1.87^{***}
Error	1152									

ns, *, *** and **** = not significant at 5, significant at 5, 1% and 0.1% respectively.

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as high as 16%. The planting of any of the 16 *P. tecunumanii* provenances at Gungunyana and Maswera instead of *P. oocarpa*, the appropriate control for the lower, warmer and drier sites would result in eight-year volume gains ranging from –18% to 31% at Gungunyana and from –48% to 16% at Maswera respectively (*Fig. 1b*). At these two sites, most of the negative gains were associated with HE *P. tecunumanii* provenances.

The seed of *P. tecunumanii* was collected and tested as family seedlots, and therefore permitted the estimation of potential gains that would result from using seed of selected families instead of bulk seed of provenances. Planting seed from the top 10 ranked families from the HE *P. tecunumanii* gave yield advantage in eight-year volume of 1% and 22% over *P. patula* at Stapleford and Cashel, and 33% and 10% over *P. oocarpa* at Gungunyana and Maswera respectively (*Fig. 2*). The planting of seed from the top 10 families of the LE *P. tecunumanii* gave gains in eight-year volume of respectively –13% and 23% over *P. patula* at Stapleford and Cashel, and 40% and 34% over *P. oocarpa* at Gungunyana and Maswera (*Fig. 2*).

The combined analysis of all the data across sites revealed significant effects ($P < 0.001$) of site, elevation *P. tecunumanii* type, provenance and family and their associated interactions for all the traits (*Table 10*). The interaction between site and *P. tecunumanii* type was mostly a change in rank between sites, with the HE *P. tecunumanii* being superior to the LE *P. tecunumanii* at higher altitude sites and vice versa at lower altitude sites. Families of the HE *P. tecunumanii* were more interactive with sites compared to families of the LE *P. tecunumanii* (*Table 10*).

Discussion and Conclusions

The study revealed substantial differences between the LE and HE *P. tecunumanii* in adaptation, growth and stem quality and the differences depended on age of growth and also on site. The differences between the two types of *P. tecunumanii* were very large and possibly exaggerated at lower and drier altitudes where the LE *P. tecunumanii* was significantly superior in growth and adaptation and this was attributed to maladaptation of some of the provenances of the HE *P. tecunumanii* such as Las Piedrecitas that occurs in a cloud forest environment at 2200 m in natural stands and may be drought sensitive. In well watered environments the LE *P. tecunumanii* had a higher early height growth which however did not persist beyond the fifth year of growth. Although there are not many well designed studies comparing the performance of the LE and HE *P. tecunumanii* together, the study by HODGE and DVORAK (1999) of the two population groups based on some contiguous trials gave a pointer. In one such test in Colombia, established at 1750 m a.s.l., the HE *P. tecunumanii* had an average volume of 2518 dm^3 compared to 2282 dm^3 for the LE *P. tecunumanii* at eight years (HODGE and DVORAK, 1999). These figures when contrasted with results of this study of eight-year volume of 1729.2 dm^3 and 1588.6 dm^3 for the HE and LE *P. tecunumanii* respectively at Stapleford, which although lower, largely confirm that the HE *P. tecunumanii* is more productive than the LE *P. tecunumanii* at high altitudes. In the present study, at medium altitude (1450 m a.s.l.), the LE and HE *P. tecunumanii* were comparable in productivity (1155.1 versus 1174.5 dm^3) respectively, which is also consistent with the results from South Africa at a comparable altitude (HODGE and DVORAK, 1999). At lower altitudes, the results of the present study showed that the LE *P. tecunumanii* is superior in growth to the HE *P. tecunumanii* and is largely consistent with the results of HODGE and DVORAK (1999), who reported that the LE *P. tecunumanii* was superior to the HE *P. tecunumanii*. The fact that, the LE *P. tecunumanii* outperformed the HE *P. tecunumanii* at lower altitudes, and vice versa, implies that a need probably exists, to deploy seed of their provenances in the same pattern in afforestation programmes to optimise yields.

In this study, the Mt Pine Ridge provenance was found to be significantly different from the other LE *P. tecunumanii* provenances. The provenance showed exceptional height growth at two years, where it was ranked among the top but its growth rate subsequently declined with increasing age, to be ranked lowest for both growth and stem straightness at age five and eight years. ZAMUDIO (1992) studied rank changes in *P. tecunumanii*, and observed that most family rank changes in growth occur in the first 3 years of growth. Such early fast growth could be exploited in situations where weeds are a serious problem and seed sources that quickly escape or suppress weed growth will reduce the frequency of weeding. In the case of Mt Pine Ridge provenance, its advantage of early fast growth could be far outweighed by its relatively poor growth beyond the post establishment phase as well as its poor stem form which would result in reduced plantation productivity. The poor stem straightness rating exhibited by the Mt Pine Ridge provenance in these tests is consistent with the observations made by DVORAK (1986), who proposed to separate Belize sources from the other LE *P. tecunumanii* because of the preponderance of poor stem form in the natural stands.

The Mexican provenances comprising Juquila and Las Piedrecitas, which are also isolated from the other HE *P. tecunumanii* populations were also found to be significantly different in growth and stem straightness from the other HE sources. At low altitude sites (Gungunyana and Maswera), the observed differences could have been exaggerated as a result of maladaptation of these (Juquila and Las Piedrecitas) provenances which originate from cooler and well watered environments while the differences at the higher altitude (Stapleford) could have been a result of the exceptionally high growth rate of Juquila, which is now regarded as not *P. tecunumanii* (DVORAK and RAYMOND, 1991; HODGE and DVORAK, 1999; DVORAK, 2008). The Juquila provenance has been shown to contain markers that align it with *Pinus herrerae* or closely related *P. pringlei* and was recently described as *P. herrerae* (DVORAK *et al.,* 2000b; DVORAK *et al.,* 2007). Some of the largest trees with imposing stem form and fine branching in these tests were from this provenance.

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Las Piedrecitas was only average in volume production in the present study and was also found to be a poor provenance in tests in Brazil (MOURA and DVORAK, 1998).

Although no individual provenance of *P. tecunumanii* was superior to the currently grown second generation bred *P. patula* at high altitude, some families of these *P. tecunumanii* provenances, particularly those from the HE *P. tecunumanii* were marginally superior by about 0.6 percent at high altitude and by up to 21 percent at medium altitude (1450 m a.s.l.), the lower limit of tolerance for economic production of *P. patula* in Zimbabwe. *P. tecunumanii* provenances and families have been tested against *P. patula* in a number of trials and results have been variable (MORRIS, 1988; DVORAK and SHAW, 1992). The variable results may be a result of different ages of the tests and appropriateness of the controls. This is consistent with the present results in which *P. patula* was outperformed by a number of *P. tecunumanii* provenances at age two years in its recommended altitudinal range (above 1760 m a.s.l.) but the latter was outperformed from age five years. Also, in some of the studies cited, *P. patula* may have been inappropriately used as a control species in for example, warm low altitudes where its performance is known to be poor. Caution is required in the interpretation of the comparisons between *P. tecunumanii* and *P. patula* or *P. oocarpa* as the seed of these controls were all improved seed. First generation bred *P. patula*, for example, is known to have a volume yield advantage over unimproved material of more than 17.5 percent (BARNES, 1977) realised from the intense breeding and selection, while second generation bred seed is believed to have an improvement in volume of up to 30 percent. If these improvements were discounted the current conclusions could probably be altered.

In the lower warmer and drier sites, the use of seed from *P. tecunumanii* provenances such as Yucul and San Francisco or seed from selected superior families in afforestation instead of *P. oocarpa* could substantially increase timber yields. The superiority of some provenances of *P. tecunumanii* over *P. oocarpa* has in the past been demonstrated in Zimbabwe (CROCKFORD *et al.,* 1988; NYOKA and BARNES, 1995); in Brazil (MURILLO and DVORAK, 1988; MOURA *et al.,* 1991 cited by MOURA and DVORAK, 1998); in South Africa (DVORAK and SHAW, 1992) and in Kenya (WRIGHT *et al.,* 1992). Overall, some of the most productive provenances such as San Jerónimo, Villa Santa, Yucul, Guajiquiro and Juquila (although now regarded *Pinus herrerae*) identified in this study have shown superiority in other studies (DVORAK and SHAW, 1992; WRIGHT and OSORIO, 1992; NYOKA and BARNES, 1995; MOURA and DVORAK, 1998; HODGE and DVORAK, 1999).

In this study, genotype-environment interaction was found to be present and significant at three levels namely elevation *P. tecunumanii* type, provenance and at family level. The LE *P. tecunumanii* was found to be more productive in lower altitude environments while the HE *P. tecunumanii* was found to be more productive in high altitudes. This study revealed that site*family interaction is present and probably of practical importance in the HE sources but is less apparent in the LE sources. Significant site*provenance and site*family interactions have also been reported in *P. tecunumanii* (DVORAK *et al.,* 1989; DVORAK and ROSS, 1994; CROCKFORD *et al.,* 1990; HODGE and DVORAK, 1999). DVORAK and SHAW (1992) found moderate site*family interaction and very little site*provenance interaction.

The most productive provenances by environment were identified as Juquila and Guajiquiro (1760 m a.s.l.), Yucul and Las Victorias (1450 m a.s.l.), San Francisco and Yucul (1050 m a.s.l) and Villa Santa and San Francisco (780 m a.s.l.). The eight-year timber yield potential of the LE *P. tecunumanii* at lower altitude (1050 m a.s.l.) was found to be similar to that of the HE *P. tecunumanii* at higher altitude (1760 m a.s.l). The 2^{nd} generation bred clonal seed of *P. patula* was found to be superior to all the provenances of *P. tecunumanii* although the most productive families of the latter were comparable in growth. A number of provenances of *P. tecunumanii* were also shown to be significantly superior to first generation bred clonal seed source of *P. oocarpa* in the medium and lower altitude sites, presenting opportunities for immediate deployment of seed of *P. tecunumanii* in these environments. Furthermore, the LE *P. tecunumanii* has been shown to be highly resistant to pitch canker compared to the HE or the widely planted *P. patula* (DVORAK *et al.,* 2009), again presenting opportunities for its immediate deployment in areas that are affected by the disease. There is however, no immediate yield advantage of using *P. tecunumanii* seed in high altitude environments currently planted to *P. patula*, unless the intention is for species diversity or replacing the highly invasive *P. patula*. Considering that some of the families of *P. tecunumanii* were comparable in growth to second generation bred *P. patula*, breeding and selection could also hasten the planting of *P. tecunumanii* in the higher altitudes in the near future. The real advantage of using *P. tecunumanii* versus *P. patula* will not be realized until the *P. tecunumanii* is taken through one more generation of breeding.

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