improvement (*Table 3*). This was in partial contrast to Hendrix (1986). He reported a weak negative relationship between specific gravity and diameter (CGP = −0.28), but essentially no relationship between specific gravity and height or volume.

Fiber length was highly heritable, with a family heritability of 0.73 (*Table 3*). Family means across plantations ranged from 0.98 mm to 1.14 mm, while within plantation family means ranged from 0.94 mm to 1.17 mm. Coefficients of genetic prediction between fiber length and growth parameters ranged from 0.28 to 0.39. Based on these data, selection for volume growth in a breeding program would not have negative impact on fiber length. However, because the range in fiber length among family means was so small (0.16 mm,or 15 percent of the overall mean), and because other commercial bottomland hardwoods produce longer fibers than green ash (Foster and Thor, 1979; Ezell and Stewart, 1981), it is doubtful that a breeding program to select for longer fibers in green ash would be useful.

Conclusions

Genetic and environmental factors influenced fiber length in green ash. However, it appeared that local genetic variation was more important than geographic variation. No discernible pattern of geographic variation could be identified.

Fiber length was a highly heritable characteristic which was moderately related to growth rate in green ash. It should be possible to select for volume improvement without reducing fiber length. However, selection for fiber length would not be useful, since the range among family means was small.

Specific gravity of green ash was affected by plantation, provenance and family within provenance. A significant plantation × family within provenance interaction existed for specific gravity; however, families with high specific gravity at all test locations could be identified.

Specific gravity was highly heritable and unrelated to growth parameters. Selection of high or low specific gravity families could be made without significant loss of volume gains in a breeding program.

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The Xylem Resin Terpene Composition of Pinus greggii Engelm. and Pinus pringlei Shaw

By Linda A. Lockhart

Oxford Forestry Institute, Department of Plant Sciences,
University of Oxford, South Parks Road,
Oxford OX1 3RB, England

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Summary

Stem-xylem oleoresin was collected from natural stands of one provenance (33 trees) of *Pinus greggii* Engelm., and one provenance (26 trees) of *P. pringlei* Shaw, in Mexico. The samples were analysed for monoterpene and sesquiterpene composition by gas-liquid chromatography using OV1 and CW20M capillary columns. Frequency distributions and mean terpene values and ranges, as percentages of total terpenes present in the samples, for seven major terpenes, were used to identify distinctive terpene profiles in each species. Little intra-specific variation was encountered in *P. greggii*, which typically contained high levels of limonene and β-phellandrene. However, substantial variation was observed in *P. pringlei*. It was possible to allocate *P. pringlei* trees to one of two terpene phenotypes that were characterized by either high α-pinene or high Δ-3-carene. Diagramatic displays of the data by the use of Andrews Curves confirmed the subjective classification of terpene phenotypes for both species and graphically illustrated the levels of intra-specific variation. The results presented are believed to be the first full chemical descriptions of the two species. Comparisons of the *P. greggii* and *P. pringlei* terpene patterns were made with those of the morphologically similar closed-cone pines *P. patula* SCHIEDE and DEPPE and *P. oocarpa* SCHIEDE ex SCHLECHT., respectively. Terpene phenotypes similar to those of *P. greggii* and *P. pringlei* were observed in some provenances of *P. patula* ssp. *tecunumanii* (EGUILUZ and PERRY) STYLES.

Key words: P. greggii, P. pringlei, terpene variation, gas-liquid chromatography, closed-cone pines.

Introduction

Many descriptions of the terpene compositions of Mexican and Central American pine species have been published (*eg* MIROV, 1961; LOYTTYNIEMI *et al*, 1982; COPPEN et *al*, 1988). However, little information is available for *Pinus greggii* ENGELM. and *Pinus pringlei* SHAW.

Both pines, classified by CRITCHFIELD and LITTLE (1966) as members of the subsection Oocarpae, are indigenous to Mexico. *P. greggii* in the east and north-east and *P. pringlei* in southern regions. *P. pringlei* was thought by MARTINEZ (1948) to be closely related to *P. oocarpa* SCHIEDE ex SCHLECHT. MIROV (1961) reported *P. greggii* to be closely related morphologically to, but distinguishable from, *P. patula* SCHIEDE and DEPPE.

MIROV (1961) presented data of the terpene composition of *P. pringlei* based on one sample from Urapan, Michoácan state, Mexico (see *Table 4.*). He also attempted the analysis of a batch of turpentine of *P. greggii*, obtained from the vicinity of Saltillo, Coahuila, Mexico. Results of the partial fractional distillation of *P. greggii* turpentine contained α- and β-pinene and the unfractioned residue was thought to contain L-β-phellandrene together with L-limonene and some sesquiterpenes.

Samples of stem-xylem resin were obtained for the present study from one provenance each of *P. greggii* and *P. pringlei* during the Oxford Forestry Institute's Central American Pine Project. This project focused on the intensive study of the genetic resources of *P. patula* ssp. *tecunumanii* (EGUILUZ and PERRY) STYLES and the species' relationship with *P. patula* and *P. oocarpa* (MCCARTER and BIRKS, 1985; LOCKHART, 1990a; LOCKHART, 1990b).

Materials and Methods

The xylem resin was tapped from living trees of *P. greggii* and *P. pringlei* during January to March 1985.

The resin samples were analysed for monoterpenes and sesquiterpenes by gas-liquid chromatography (GLC) on OV1 and CW20M fused silica capillary columns according to the analytical conditions described by LOCKHART (1985) and LOCKHART (1990b). The separated chemical constituents were identified by comparison with known purified chemical standards, and recorded as percentages of total terpenes.

Results

Seven terpene constituents were identified previously as discriminatory chemicals (BURLEY and GREEN, 1977; LOCKHART, 1990b). The mean percentage values and ranges of these in the *P. greggii* and *P. pringlei* samples are shown in *Table 2*. The frequency distributions of six of the chemicals are presented as histograms of the number of trees in ten percentage class intervals (*Figure 1*). Estragole was not included because of its zero or low values.

1. P. greggii

The major distinguishing terpene patterns for *P. greggii* were low (< 12%) α-pinene and low (< 2%) β-pinene,

Table 1. — Site details.

Species Provenance	State/Department Country	Latitude Longitude	Altitudinal Range (m)	Number of Samples
<u>P. greggii</u> Las Placetas	Nuevo León Mexico	24° 56' N 100° 06' W	2300	33
<u>P. pringlei</u> Sierra de Oaxaca	Oaxaca Mexico	17° 20' N 97° 07' W	2180	26

Table 2. — Discriminatory terpenes — % of total terpenes.

Chemical	P. greggii		P. pringlei	
	Mean %	Range %	Mean %	Range %
α-pinene	7.34	4.94-11.37	39.87	4.27-83.15
ß-pinene	1.42	1.10- 1.80	13.14	0.63-44.17
Δ-3-carene	0.84	0.56- 1.32	23.28	0.00-71.78
limonene	32.42	11.55-49.10	0.49	0.00- 1.28
ß-phellandrene	45.30	31.77-65.08	2.73	0.00-39.60
estragole	0.00	0.00	1.47	0.00- 3.74
longifolene	5.66	0.67-11.90	9.04	0.00-24.06

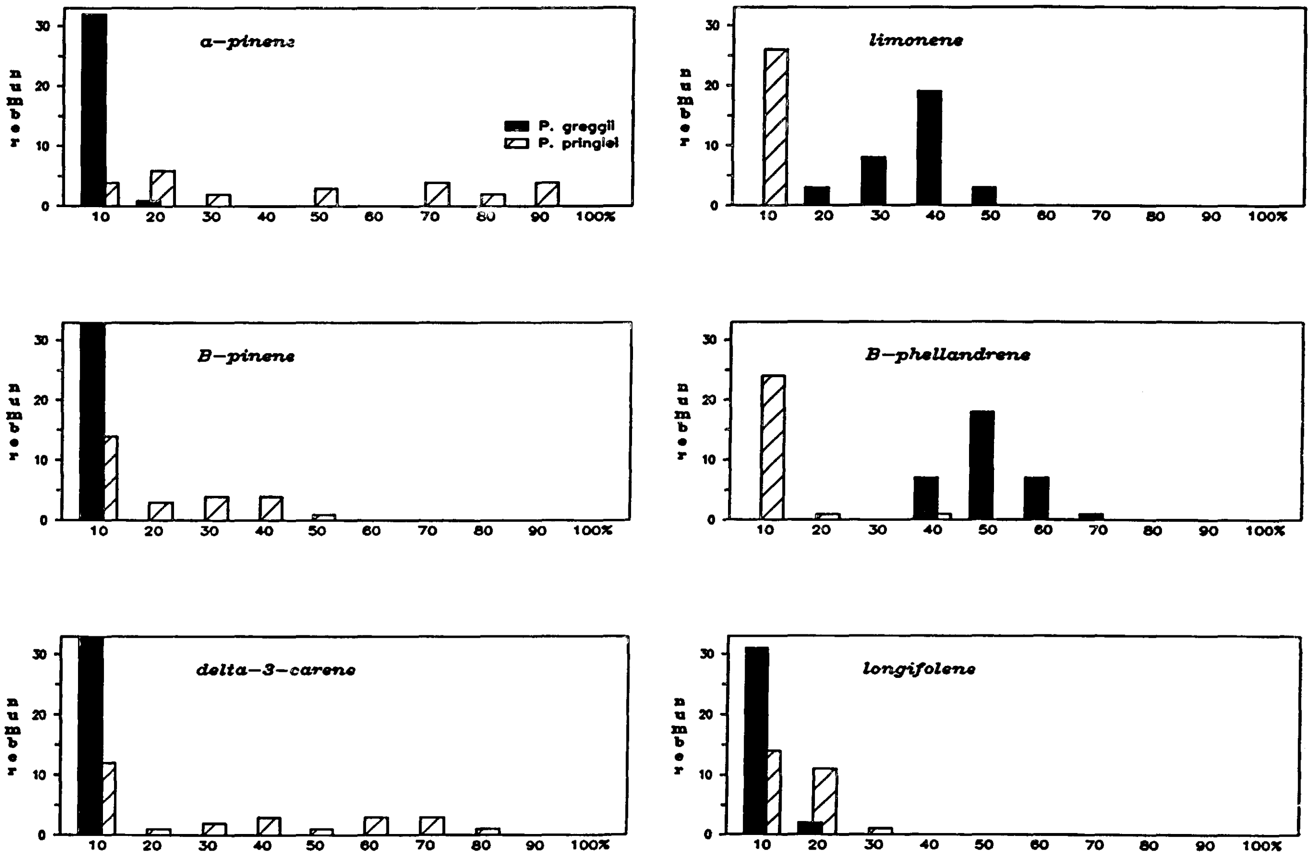

Figure 1. — Frequency distributions of the major terpenes in *P. greggii* (33 trees) and *P. pringlei* (26 trees).

combined with high levels of both limonene (> 12%) and β-phellandrene (> 30%). Estragole was absent from all samples. Narrow ranges of terpene values, particularly for the pinenes, were observed and displayed graphically as histograms of frequency distribution (Figure 1) and as Andrews Curves (*Figure 2*).

Andrews Curves (Andrews, 1972) map each multi-response observation (*ie* the seven terpene variables) as a function f of a single variable t (in these data t = α-pinene). The function f(t) produces curve patterns depending on observed values of p variables plotted over the range $-\pi$ to $+\pi$ on the x axis. Every curve represents the function f(t) of the multi-response observations for a single tree. The shape of the curve allows identification of the predominant resin phenotypes. Within-provenance variation is estimated from the cohesiveness or spread of the curves within the population. Clusters of chemically similar trees are recognisable and outliers are easily spotted.

Andrews Curves supported the initial subjective resin phenotype classifications. Only limited comparison could be made with Mirov's (1961) description of *P. greggii* but in general the quantitative descriptions agreed.

2. *P. pringlei*

Substantial variation in the seven major components was observed in trees of *P. pringlei*. The distinguishing chemicals appeared to be $\triangle$-3-carene and α-pinene.

High levels (> 19%) of $\triangle$-3-carene were found in 46% of trees. The remaining 54% of trees contained high amounts of α-pinene (> 42% total terpenes). Noticeable amounts (> 10%) of β-pinene were often found in association with both phenotypes; 58% of $\triangle$-3-carene trees and 36% of α-pinene trees. Confusing frequency distributions emerged for α-pinene and $\triangle$-3-carene (*Figure 1*) and more realistic statistics were obtained by presenting the data according to terpene phenotypes (*Table 3*).

The variation was demonstrated further by Andrews Curves (*Figure 2*), in which α-pinene phenotypes were represented by curves in the upper regions of the y axis (f= +20 to +60). The $\triangle$-3-carene phenotypes were typically illustrated by single domed peaks, which originated and terminated at low values on the y axis (f = —30 to —80).

Comparisons with the data of Mirov (1961) show a number of discrepencies paticularly in the levels of α-pinene, β-pinene and $\triangle$-3-carene (*Table 4*). Mirov's data, however, were from the analysis of one batch (presumably one tree) of *P. pringlei* resin. The data presented here were derived from 26 individual tree samples and have identified within-provenance variation in terpene composition. In addition, Mirov's sample was collected in Michoácan state, Mexico — more than 350 km north-west of the Sierra de Oaxaca provenance of the OFI collection. Between-provenance clinal variation in terpene composition, associated with altitude, has been identified in other pines of Mexico and Central America (Lockhart, 1990b) and may account for the discrepencies observed in terpene composition between the sets of *P. pringlei* data.

Conclusions

The data presented here are believed to be the fullest descriptions available (in terms of tree numbers) of the terpene compositions of *P. greggii* and *P. pringlei* in their

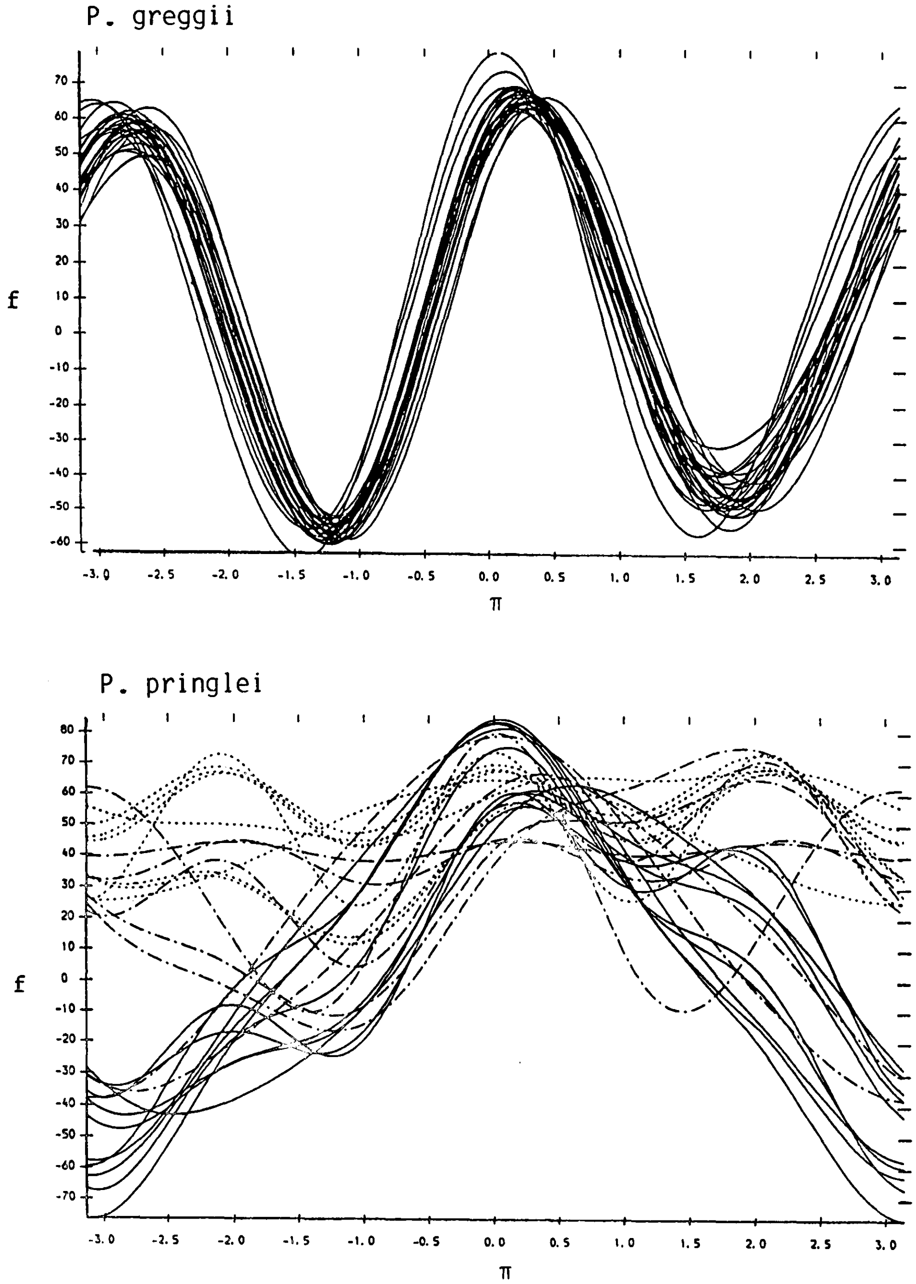

Figure 2. — Andrews Curves.

natural occurrences. In fact, that of *P. greggii* is the first complete description known.

The terpene profiles derived from these data reinforce the conventional taxonomic distinction between *P. greggii* and *P. patula*. The two species differ primarily in their limonene and β-phellandrene contents although the presence of relativeley high levels of β-phellandrene suggests a common origin of the genes responsible for the synthesis of this terpene.

The terpene profile of *P. greggii* more closely resembles those of the Guatemalan and Mexican provenances of another closed cone pine, *P. patula* ssp. *tecunumanii*1).

The *P. pringlei* resin samples may be allocated to two distinctly different terpene phenotypes. The α-pinene phenotypes resemble provenances of *P. oocarpa* in Mexico and Central America described by Lockhart (1990b). Similarities in the levels and ranges of certain chemicals, *eg* α-pinene, $\triangle$-3-carene and longifolene are clearly evident. However, the amounts of β-pinene present in *P. pringlei* are atypical of most *P. oocarpa* trees.

Both qualitative and quantitative similarities between *P. pringlei* and *P. patula* ssp. *tecunumanii* terpenes are apparent. The level of variation (ranges of values) and the consistent occurrence of $\triangle$-3-carene is reminiscent of the patterns found by Lockhart (1990b) for provenances of *P. patula* ssp. *tecunumanii* in parts of Honduras and Nicaragua.

The natural distributions of *P. pringlei* and *P. greggii* overlap with those of *P. oocarpa* and *P. patula*, respectively. This, combined with the terpene variation evident in *P. patula* ssp. *tecunumanii*, and its chemical similarities with the two species reported here, suggests that this complex group may be inter-related.

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1) Although the taxonomic status of *P. patula* ssp. *tecunumanii* has been established by Styles (1985) and confirmed on morphological grounds by McCarter and Birks (1985), the chemical evidence has not been able to substantiate the designation as a subspecies of *P. patula* (Lockhart, 1990b).

Table 3. — *P. pringlei* terpene phenotypes.

Chemical	α-pinene phenotype		Δ-3-carene phenotype	
	Mean %	Range %	Mean %	Range %
α-pinene	62.64	42.97-83.15	13.35	4.27-28.55
ß-pinene	12.07	0.63-44.17	16.76	0.88-38.34
Δ-3-carene	0.06	0.00- 0.81	48.73	27.16-64.69
longifolene	9.18	0.00-24.06	8.87	2.37-19.56

Table 4. — Mirov's (1961) *P. pringlei* data.

Chemical	Mean %
α-pinene	73
ß-pinene	2
Δ-3-carene	11
terpinolene	1
methyl chavicol	2.5
longifolene	6

Representative data covering the entire natural ranges of *P. greggii* and *P. pringlei* are now required to determine the extent of inter- and intra-provenance variation. Full comparisons could then be made with other closed cone pines already studied in depth.

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Variation in Susceptibility of Pinus muricata and Pinus radiata to Two Species of Aphidoidae

By J. A. Simpson1) and P. K. Ades2)

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Summary

In two provenance trials in north-eastern New South Wales, Australia, it was found that the closely related species *Pinus radiata* and *P. muricata* differed markedly in relative susceptibility to two species of aphid.

P. radiata was more susceptible than *P. muricata* to the woolly aphid, *Pineus pini*. A putative intervarietal hybrid, *P. radiata* var. *binata x P. radiata* var. *radiata*, was the most susceptible, *P. radiata* var. *radiata* was less susceptible and *P. muricata* the least susceptible. There were also differences in susceptibility between five local seedlots of *P. radiata* var. *radiata* from New South Wales plantations. The four seed orchard lots were less susceptible than a seedlot collected from unimproved plantations. This is possibly due to an indirect response to selection for growth rate in plantations where *Pineus pini* has been present for many years.

In contrast, *Pinus muricata* was more susceptible to the needle aphid, *Eulachnus thunbergii*, than was *Pinus radiata*. There appears to be clinal variation in the natural populations of *P. muricata*, with the northern provenances being the most susceptible and the southernmost provenance sampled, Monterey, being no more susceptible than *P. radiata*.

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1) Wood Technology and Forest Research Division, Forestry Commission of New South Wales, P. O. Box 100, Beecroft, NSW 2119, Australia

2) School of Agriculture and Forestry, University of Melbourne, Parkville, Vic. 3052, Australia