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Original article

Variation of pulpwood quality with provenances and site in *Eucalyptus globulus*

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Abstract – Differences in basic wood density, fibre morphology, chemical composition and pulp yield were studied among 4 provenances of *Eucalyptus globulus* planted in trials at three sites. Sampling was carried out at the age of 9 years. Provenances and site were not found to have a significant effect on wood density. Fibre length increased radially from pith to bark, with a pattern similar for all provenances. Provenance and site were significant sources of variation for fibre length, cell wall thickness and lumen diameter. At the worst growth quality site, fibres were shorter, with thicker cell walls and smaller lumen diameter. In relation to chemical composition, only extractives showed within tree variation and significant provenance and sites effects. Pulp yield ranged from 56.9 to 60.9% at Kappa numbers from 13.2 to 17.5, with provenance a highly significant influencing factor.

***Eucalyptus globulus* / wood density / fibre biometry / chemical composition / pulp yield / provenance variation / site variation**

Résumé – Influence de la provenance et du site dans la qualité papetière du bois de *Eucalyptus globulus*. La densité du bois, morphologie des fibres, composition chimique et rendement en pâte ont été analysés sur rondelles à 1,30 m de hauteur de 5 arbres de 4 provenances de *Eucalyptus globulus* de 9 ans en trois régions différentes. La provenance et le site n'ont pas influencé significativement la densité du bois. La longueur des fibres augmente radialement du cœur à la périphérie, avec une variation similaire pour toutes les provenances. La provenance et le local ont été des facteurs significatifs de la variation de la longueur des fibres, de l' épaisseur de la paroi et du diamètre du lumen des fibres. Dans le site à plus faible croissance, les fibres étaient plus courtes, avec une paroi plus épaisse et un diamètre du lumen plus petit. Du point de vue chimique, les composés extractibles sont influencés significativement par la provenance et site. Le rendement en pâte (56,9 % à 69,9 % avec indices Kappa entre 13,2 et 17,5) a été significativement influencé par la provenance. La difference de rendement en pâte entre provenances, en moyenne pour les trois sites, a été de 5,0 %.

***Eucalyptus globulus* / densité du bois / fibre morphologie / composition chimique / rendement en pâte / provenance variation / site variation**

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1. INTRODUCTION

Eucalyptus globulus Labill. was introduced in Portugal in the middle of the 19th century as an ornamental. During the last 50 years the area planted with this species has constantly increased and is today the fourth most planted tree species in Portugal. The first afforestations used imported seed lots of unknown origin. Later on, and until the 1970's the plantations were established with seed collected mainly in only one area (Ovar, in the north of Portugal). This narrow genetic base and the danger of severe inbreeding became a concern when afforestation increased to provide in the growing needs of the pulp industry.

In this context a set of provenance trials were established in 1985 in order to estimate the geographic variation in the Portuguese population and to compare it with provenances from the natural range and exotic areas [1].

Many studies on the genetics of wood properties suggest that there are considerable heritable differences between provenances for most wood properties [31]. The growing knowledge of the impact of raw-material properties on pulp quality has led to research on wood quality parameters and to their integration as selection traits in the improvement programmes.

A few studies on wood and growth traits in eucalypt species have been published. Clarke et al. [4] examined a variety of wood characteristics including the average density, fibre length and chemical composition of 3 provenances from 9 eucalypt species established in a trial in South Africa. They found significant differences in density and fibre length between the species and provenances, and also significant differences in chemical composition between species. Varghese et al. [26] found highly significant differences in density between 10 provenances of *E. grandis*. McKimm and Ilic [10] found no significant variation in fibre length between 5 *E. nitens* provenances.

Turner et al. [24] examined pulps produced from *E. globulus* trees taken from different sites in Tasmania and found significant differences in pulp quality. Matheson et al. [9] studied 7 year old provenances of *E. obliqua* from 22 different sites in Tasmania and found significant differences between provenances and sites for the pulp yield. More recently, Beadle et al. [2] found similar results when comparing the pulp yield of 2 provenances of *E. globulus* and *E. nitens* growing at 4 different sites in Tasmania. They found significant differences between provenances and sites for the same species.

This paper reports on the raw material quality of 4 provenances of *Eucalyptus globulus* trees at three sites at the age of 9 years.

2. MATERIALS AND METHODS

Study material was obtained from provenance trials of *Eucalyptus globulus* Labill. consisting of 37 provenances established at 6 sites. These sites were chosen to represent the eucalypt area of expansion in Portugal. Sampling took place at 9 years of age. The experimental design used at each site was randomized complete block with 7 blocks and 5 plants per experimental plot. The plantations were established following the practices usually applied in eucalypt plantations in Portugal, i.e. 3 m × 3 m spacing. Further details are given in Almeida et al. [1].

Sampling was carried out in one block in three of the sites (Furadouro, Vale de and Núcleo Barrosas) by taking discs at breast height (b.h.) from 5 trees of 4 provenances, which were selected based on their above average growth. All provenances were of the subspecies *globulus* with the following seed origin: 1 from Bogalheira (Portugal); 10 from Pepper Hill (Tasmania); 12 from Swansea (Tasmania); 23 from Geeveston (Tasmania). The location, climatic data and soil characteristics of the three sites are given in *table I*. The characterization of the origin of the four provenances used for this study is given in *table II*.

The three locations have different quality site indices for eucalypt growth: the average total volume in the trials at 9 years of age was calculated as 122.6, 123.3 and 65.6 $m^3\ ha^{-1}$ in Furadouro, Núcleo Barrosas and Vale de Galinha respectively, using tree d.b.h. and total height and an eucalypt volume equation [23]. The four provenances selected showed different growth and the average total volumes at the three sites were 135.6, 128.1, 112.0 and 182.1 $m^3\ ha^{-1}$ for provenances 1, 10, 12 and 23, respectively. The average total volume for the four provenances was 172.8, 140.6 and 100.3 $m^3\ ha^{-1}$ in Furadouro, Núcleo Barrosas and Vale de Galinha respectively.

Wood density was determined on a tree disc as basic density, using oven-dry weight and green saturated volume determined by the water immersion method.

For fibre length measurement, sampling was carried out along the radius from pith to bark at 10%, 30%, 50%, 70% and 90% of the total radius. To separate the fibres the samples were macerated using a 1:1 glacial acetic acid: hydrogen peroxide solution at 40 ºC during 6 h. At

Table I. Characterization of the three sites of the *Eucalyptus globulus* provenance trials used for this study.

	Furadouro	Núcleo Barrosas	Vale de Galinha
Latitude	39º 20' N	41º 18' N	40º 29' N
Longitude	9º 13' W	8º 17' W	8º 20' W
Altitude, m	50	520	550
Mean annual rainfall, mm	607	1709	1263
Maximum mean temperature, ºC	19.5	18.6	18.3
Minimum mean temperature, ºC	11.1	7.4	7.4
Soils	Eutric cambisols on sandstone	Humic cambisols on schists	Humic cambisols on schists

Table II. Characterization of the origin of the four provenances of the *Eucalyptus globulus* used for this study.

Prov. nº	Subsp.	Origin	Site	Latitude/longitude	Altitude (m)
1	*globulus*	Portugal	Bogalheira	39º 10' N – 9º 04' W	90
10	*globulus*	Tasmania	Pepper Hill	41º 40' S – 147º 55' E	500
12	*globulus*	Tasmania	Swansea	42º 08' S – 148º 02' E	100
23	*globulus*	Tasmania	Geevston	43º 10' S – 146º 55' E	100

each point 40 fibres were measured using a Leitz ASM 68K semi-automated image analysis system. Preliminary testing showed that with this sampling intensity, the error was below 5% at a 95% confidence level [8].

A weighted mean fibre length for each tree (at b.h.) was calculated, as described by Miranda et al. [11].

The cross-sectional dimensions of fibres were determined on the samples taken at the 90% relative radial position. Twenty unbroken fibres were selected at random and measured at mid-length. The total diameter and the lumen diameter were measured and the cell wall thickness calculated as half of their difference.

The chemical composition was determined on 40–60 mesh woodmeal following standard procedures for wood analysis. Total extractives were determined in a Soxhlet apparatus using a sequence of dichloromethane, ethanol and water. Klason lignin and acid soluble lignin were determined following the relevant Tappi test methods [20, 21]. The polysaccharides were calculated based on glucose and xylose after total hydrolysis and separation and quantification by HPLC.

Kraft pulping was performed in 100 ml rotating stainless steel reaction vessels, immersed in a temperature controlled oil bath. Each charge consisted of 10 g of oven-dry wood chips measuring approximately $2 \times 0.2 \times 0.2$ cm^3 in size. The conditions were as follows: liquor-to-wood ratio 4.5:1, 15% active alkali, 30% sulphidity, pulping temperature 170 ºC, pulping time 2 h. Pulp yields were calculated based on the oven-dry weight of wood chips charged to the reactor and the Kappa number was determined following Tappi standards [20].

An analysis of variance was performed using the Scientific Statistical software SigmaStat© for Windows Version 2.0, from Jandel Corporation. The effect of site and provenance on the measured parameters was calculated with the following ANOVA model:

$$Y_{ijk} = \mu + \alpha_I + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{(ij)k}$$

where Y_{ijk} is the individual tree measurement taken on the j^{th} provenance (fixed effect) on k^{th} replication in i^{th} site (fixed effect); μ is the overall mean; α_I is the effect of the i^{th} site; β_j is the effect of the j^{th} provenance; $(\alpha\beta)_{ij}$ is the effect of interaction of j^{th} provenance and i^{th} site, and $\varepsilon_{(ij)k}$ is the experimental error associated to observation Y_{ijk}.

3. RESULTS

3.1. Wood basic density

Site, provenance and provenance within site density means are given in *table III*. These densities are within the range reported for 10–14 year old trees [25].

Table III. Wood basic density (kg m^{-3}) of 4 *Eucalyptus globulus* provenances at the age of 9 years at three sites. The standard deviations are given in parentheses.

Provenance	Furadouro	Núcleo Barrosas	Vale de Galinha	Provenance Means
1	572	537	527	545 (24)
10	560	522	504	529 (29)
12	527	541	531	533 (11)
23	529	550	518	533 (16)
Site means	547	538	520	

Across sites the wood density of the 4 provenances varied very little, with only 1.6 kg m^{-3} difference between the lowest and highest values (respectively prov. 10 and prov. 1).

Within each site the between provenance variability was low, with coefficients of variation of the mean under 5% in all cases. Site and provenance were not statistically significant effects for wood density variation.

At the age of 7 years a previous study on the growth characteristics and wood density had already shown that there were no significant differences on wood density in these 4 provenances [12, 13].

3.2. Fibre morphology

The mean values for site, provenance and provenance within site for fibre length, wall thickness and lumen diameter are given in *table IV*. These values are within the range of variation found in earlier studies [7, 8, 22, 30]. The analysis of variance showed that site had a highly significant effect on fibre length ($P < 0.001$). In Núcleo Barrosas and Vale de Galinha, wood fibres were about 8.5% shorter than in Furadouro.

Within each site, the between provenance variation in fibre length was significant ($P = 0.013$). However the

Table IV. Fibre dimensions of 4 *Eucalyptus globulus* provenances at three sites at the age of 9 years. The standard deviations are given in parentheses.

	Prov.	Furadouro	Núcleo Barrosas	Vale Galinha	Mean
Fibre	**1**	0.955 (0.040)	0.923 (0.097)	0.881 (0.028)	0.919 (0.037)
length	**10**	0.952 (0.063)	0.831 (0.086)	0.880 (0.018)	0.888 (0.061)
(mm)	**12**	1.007 (0.064)	0.919 (0.048)	0.932 (0.044)	0.953 (0.048)
	23	1.036 (0.034)	0.904 (0.068)	0.934 (0.049)	0.958 (0.069)
	mean	0.988 (0.041)	0.894 (0.043)	0.907 (0.030)	0.930 (0.033)
Fibre	**1**	5.842 (0.548)	5.464 (0.305)	6.309 (0.216)	5.872 (0.423)
wall thickness	**10**	6.452 (0.333)	5.514 (0.541)	5.896 (0.271)	5.954 (0.472)
(μm)	**12**	5.356 (0.500)	5.432 (0.451)	6.778 (0.729)	5.855 (0.800)
	23	6.845 (0.598)	6.430 (0.623)	6.460 (0.348)	6.578 (0.231)
	mean	6.124 (0.658)	5.710 (0.481)	6.361 (0.366)	6.065 (0.345)
Lumen	**1**	8.149 (1.442)	9.509 (2.307)	7.088 (1.227)	8.249 (1.214)
width	**10**	9.384 (1.120)	10.772 (1.109)	9.667 (1.449)	9.940 (0.733)
(μm)	**12**	9.212 (1.739)	10.848 (1.084)	8.233 (1.154)	9.431 (1.321)
	23	9.936 (2.635)	9.459 (1.402)	9.133 (2.059)	9.509 (0.404)
	mean	9.170 (0.748)	10.147 (0.767)	8.530 (1.129)	9.282 (0.724)

differences between provenances were relatively small with coefficients of variation of the mean below 8%. This between provenance variability in *E. globulus* is similar to the range found in 10 provenances of *E. grandis* [26] and in 5 provenances of *E. nitens* [10]. It is also similar to the between tree variation found in plantations using mixed seed lots, where coefficients of variations of the mean fibre length in different sites ranged from 4 to 7% [8].

No significant effect of provenance and site on mean fibre length could be detected in the same trials at the age of 7 years [11].

The fibre length variation along the wood radius is shown in *figure 1* for all the provenances at the three sites. Fibre length was characterised by an increase from pith to bark. The increase was more rapid in the inner part of the tree, i.e. between 10 and 30% of the wood radius there was a mean fibre length increase of 10–20% while it was only 5% between the 70 and 90% radial positions. This pattern of variation was found in all provenances and at all sites. This type of radial variation in fibre length has been also reported for 14 years old [8] and 18 year old *E. globulus* trees [16]. In *E. grandis*, an increase from 0.81 mm at 3 years to 1.15 mm at 9 years was reported [3].

The mean values for fibre wall thickness and lumen diameter are within the range of variation reported for the species, i.e. 2.1–6.0 µm wall thickness and 7.3–12.0 µm lumen width at 10–18 years of age [7, 22].

Site had a highly significant effect on wall thickness ($P < 0.001$) and lumen diameter ($P = 0.004$). At the site with the slowest growth (Vale de Galinha) the fibres had thicker walls and a smaller lumen diameters. Provenance also had a highly significant effect on wall thickness ($P < 0.001$) and lumen diameter ($P = 0.036$). It is known that the fibre morphology influences paper properties e.g. bulk and surface properties, and therefore raw material from different provenances or sites may be used to obtain papers with different properties.

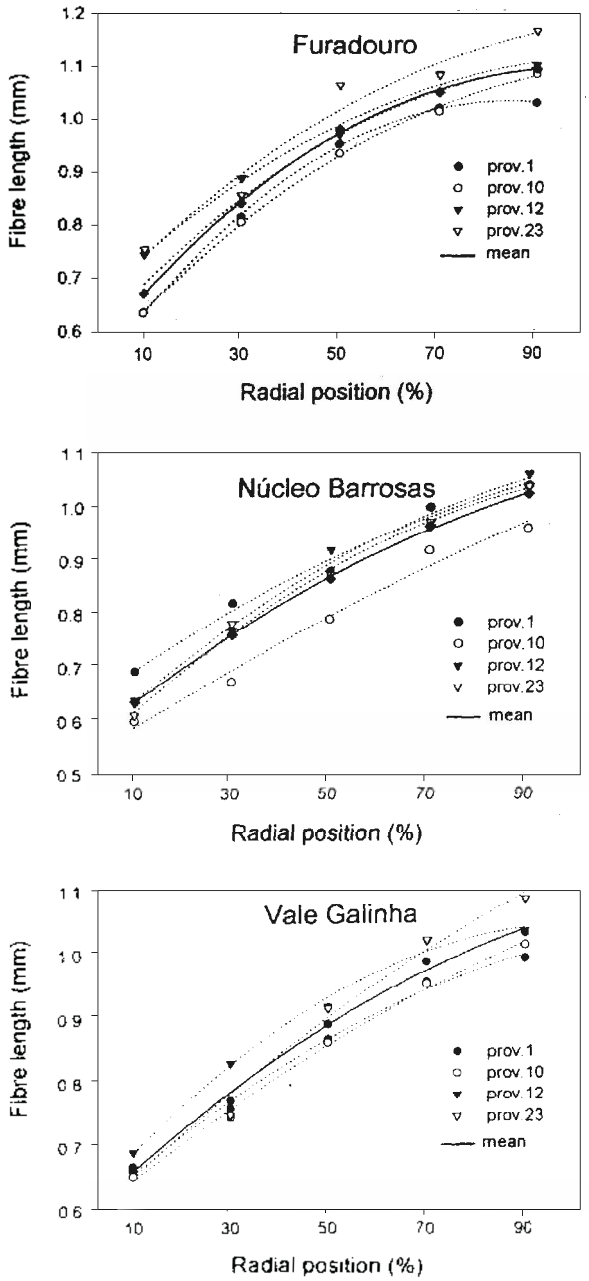

Figure 1. Radial variation in fibre length at different sites in Portugal.

3.3. Chemical composition

The chemical composition of the wood produced by the 4 provenances of *Eucalyptus globulus* is presented in *table V* for each site.

The mean chemical composition was the following (in % of oven-dry wood): extractives 3.7%, lignin 26.1%, glucan 49.8% and xylan 14.4%. These results do not differ substantially from the chemical composition of eucalypt wood at the normal harvesting age of 10–13 years for pulpwood production [5, 14, 15, 17, 27]. Rodrigues et al. [19], studying all 37 provenances in this trial, showed that lignin contents ranged from 23 to 34%.

Table V. Chemical composition of 4 *Eucalyptus globulus* provenances at three sites at the age of 9 years. The standard deviations are given in parentheses.

Site/Properties	**Provenance**				
Furadouro	**1**	**10**	**12**	**23**	**Mean**
Extractives					
dichloromethane	0.2 (0.1)	0.2 (0.1)	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)
ethanol	2.0 (0.4)	1.6 (0.4)	1.1 (0.3)	1.6 (0.8)	1.6 (0.4)
water	1.7 (0.2)	1.3 (0.2)	1.4 (0.3)	1.2 (0.2)	1.4 (0.2)
total	3.9 (0.6)	3.1 (0.5)	2.8 (0.5)	3.0 (1.0)	3.2 (0.5)
Lignin					
Klason	21.5 (1.0)	19.6 (1.0)	20.9 (1.5)	20.4 (1.8)	20.6 (0.8)
soluble	5.5 (1.1)	4.5 (0.2)	4.8 (0.4)	4.6 (0.4)	4.9 (0.5)
total	27.0 (1.7)	24.2 (1.2)	25.7 (1.9)	25.2 (2.3)	25.5 (1.2)
Carbohydrates					
glucan	49.5 (4.0)	52.6 (1.1)	47.3 (2.7)	53.4 (3.4)	50.7 (2.8)
xylan	14.8 (2.2)	13.9 (1.0)	14.3 (1.1)	13.9 (1.7)	14.1 (1.6)
total	63.5 (2.7)	66.5 (1.5)	61.5 (2.3)	67.3 (2.5)	64.7 (2.7)
Núcleo Barrosas	**1**	**10**	**12**	**23**	**Mean**
Extractives					
dichloromethane	0.4 (0.1)	0.5 (0.1)	0.5 (0.1)	0.3 (0.02)	0.4 (0.1)
ethanol	2.1 (0.4)	2.5 (0.4)	2.2 (0.5)	2.3 (0.6)	2.0 (0.2)
water	1.1 (0.3)	1.4 (0.2)	1.2 (0.1)	2.2 (0.2)	1.5 (0.5)
total	3.6 (0.8)	4.4 (0.6)	3.9 (0,6)	4.8 (0.6)	4.2 (0.5)
Lignin					
Klason	20.9 (1.8)	20.7 (2.1)	21.8 (1.1)	20.8 (0.6)	21.1 (0.5)
soluble	4.8 (0.4)	4.7 (0.5)	5.0 (0.3)	4.7 (0.2)	4.8 (0.1)
total		(2.5)	26.8 (1.4)	25.5 (0.8)	25.9 (0.6)
Carbohydrates	25.7 (2.2)				
glucan	50.0 (4.7)	52.4 (5.1)	48.9 (3.1)	51.3 (2.1)	50.7 (1.5)
xylan	14.7 (2.8)	12.1 (1.8)	15.9 (1.4)	13.6 (0.9)	14.1 (1.6)
total	64.7 (2.7)	64.5 (3.3)	64.8 (1.8)	64.9 (1.8)	64.7 (1.2)
Vale Galinha	**1**	**10**	**12**	**23**	**Mean**
Extractives					
dichloromethane	0.5 (0.1)	0.6 (0.2)	0.3 (0.1)	0.6 (0.3)	0.5 (0.1)
ethanol	2.5 (0.3)	1.2 (0.3)	1.6 (0.3)	1.4 (0.8)	1.7 (0.6)
water	1.0 (0.03)	1.2 (0.3)	1.1 (0.2)	1.0 (0.1)	1.1 (0.1)
total	4.0 (0.4)	4.2 (1.3)	3.0 (0.8)	3.0 (0.8)	3.6 (0.6)
Lignin					
Klason	22.4 (1.3)	22.7 (0.6)	21.5 (1.1)	20.6 (1.0)	21.8 (0.9)
soluble	5.1 (0.3)	5.2 (0.2)	5.0 (0.3)	4.8 (1.0)	5.0 (0.2)
total	27.5 (1.5)	27.9 (0.8)	26.5 (1.4)	25.4 (1.2)	26.8 (1.1)
Carbohydrates					
glucan	46.7 (4.5)	46.2 (4.1)	48.2 (3.0)	50.6 (2.5)	47.9 (2.0)
xylan	14.3 (2.0)	16.0 (0.9)	14.6 (1.5)	14.4 (0.9)	14.8 (0.8)
total	61.0 (3.1)	62.2 (3.5)	62.8 (2.8)	65.0 (1.8)	62.8 (1.7)

The within provenance variation was small for lignin, glucan and xylan and moderate for extractives (coefficient of variation of the mean ≈ 25%). The differences in chemical composition between provenances were statistically non-significant for all components except for extractives (extractives $P < 0.001$, lignin $P = 0.152$, glucan $P = 0.026$). This variability is similar to the between-tree variation found previously in commercial plantations, where coefficients of variation within a site for 10 trees were around 5% of the mean with only extractives showing higher variation [17]. Clarke et al. [4], studying 3 provenances of 9 eucalypt species, found statistically

Table VI. Pulp yield and Kappa nº of 4 *Eucalyptus globulus* provenances at three sites. The standard deviations are given in parentheses.

Provenance	Furadouro		Núcleo Barrosas		Vale de Galinha	
	Pulp yield %	Kappa nº	Pulp yield %	Kappa nº	Pulp yield %	Kappa nº
1	55.6 (4.0)	17.5 (0.9)	57.1 (0.3)	16.2 (0.1)	56.9 (1.4)	16.4 (1.0)
10	58.5 (0.6)	15.8 (0.6)	57.0 (0.4)	18.4 (0.6)	57.9 (1.2)	14.4 (0.2)
12	58.9 (0.8)	15.3 (0.9)	57.4 (1.4)	17.5 (1.0)	58.3 (0.8)	14.7 (0.1)
23	60.9 (0.3)	15.4 (1.1)	58.7 (0.4)	15.8 (0.8)	59.3 (1.3)	13.2 (1.0)

significant differences between species ($P < 0.001$) for cellulose, pentosans, lignin and extractives and between provenances for each species for cellulose ($P < 0.001$) and pentosans ($P < 0.01$).

3.4. Pulp yield

Table VI shows the average pulp yield and Kappa number for the 4 provenances at the three sites.

The pulp yields obtained are within the range reported for *E. globulus* at the same age. A pulp yield of 52% was reported for 8–12-year-old trees [25], pulp yield of 51.3 and 57.3% at K18 for 8.5-year-old clonal material [6] and pulp yield of 48.0 and 54.4% for 6 and 10-year-old trees respectively [28].

Both provenance and site had a highly significant effect on pulp yield ($P < 0.001$), but their interaction was non-significant ($P = 0.872$). Most published data are in accordance with these results. Turner et al. [24] compared the pulp yields of *E. globulus* trees growing at different sites in Tasmania. He found a strong site effect as the trees from a west coast provenance produced an average pulp yield of 56% compared to only 40% of trees of an east cost provenance. Matheson et al. [9], in a study on the geographic variation of *E. obliqua* in 22 localities throughout the natural range of the species, found significant differences between provenances for pulp yield ($P < 0.05$).

Williams et al. [29] also compared characteristics on 8-year-old trees form two provenances of each of *E. globulus* and *E. nitens*, growing in intensively managed plantations at four sites with different altitudes in Tasmania. They found significant differences between sites and provenances for kraft pulp yields ranging from 53.8 to 57.6% for *E. globulus*, and from 52.2 to 48.7% for *E. nitens*. However, Raymond et al. [18] studying 3 provenances of *E. regnans* from widely separated regions of its natural distribution, found the pulp yields to vary within a small range (1.4%). No significant difference between provenances could be detected ($P = 0.075$).

3.5. Selection by quality parameters

The provenance variation characteristics as well as the significance of provenance and site effects are given in *table VII*. In addition to the conclusions discussed below, attention should be given to the fact that the number of provenances, sites and trees tested, even if quite extensive when considering wood quality evaluation, was rather small in comparison to the usual requirements in genetics.

It is known that genetic and site factors affect tree growth and this has been confirmed in this study as across sites provenance volume growth ranged from 112 to 182 m^3 h^{-1} at 9 years of age. This corresponds to a variation of 62% in relation to the lowest value. Growth

Table VII. Coefficients of variation and the significance of the provenance and site effects on various growth and wood properties of 9-year-old *Eucalyptus globulus.*

	Across site provenance variation (%)	Provenance Effect *P*	Site Effect *P*
Volume growth	62.0	0.006	0.022
Wood basic density	3.0	0.775	0.109
Fibre length	7.9	0.013	< 0.001
Fibre cell wall thickness	12.3	< 0.001	< 0.001
Fibre lumen width	20.5	0.036	0.004
Extractives	21.8	< 0.001	0.086
Lignin	5.1	0.956	0.152
Polysaccharides	4.3	0.026	0.022
Pulp yield	5.0	< 0.001	< 0.001

Table VIII. Across site pulp yield production for the different *E. globulus* provenances at 9 years of age.

Provenance	Volume	Wood density	Pulp yield	Pulp production	
	m^3 ha^{-1}	kg m^{-3}	%	kg m^{-3}	t ha^{-1}
1	135.6	545	56.5	307.9	41.75
10	128.1	529	57.8	305.8	39.17
12	112.0	533	58.2	310.2	34.74
23	182.1	533	59.6	317.7	57.85

should therefore be an important selection criterion for maximising production.

Wood properties are also important. For instance, wood density and pulp yield affect production per unit area, fibre characteristics affect pulp and paper quality and extractives and lignin content affect process efficiency. However, the variation in most of the wood properties studied was considerably lower than that of volume growth range (*table VII*). Only lumen diameter and extractives content showed a higher provenance variation.

However, the differences in volume growth and wood properties are useful when selecting production material taking into account potential production per unit area (e.g. tons pulp per ha) and pulp mill capacity (e.g. tons of pulp per m^3 wood). In the case studied here, the calculation of the potential pulp production per ha (by using growth, density and pulp yield factors) increased the range of variation between provenances, even if slightly (*table VIII*). For instance the ratio between provenance 23 and provenance 12 was 1.62 in relation to volume growth and 1.66 in relation to pulp production per ha.

4. CONCLUSIONS

Within site and within provenance variation was low for all the properties studied with the exception of extractives. However, provenance and site were significant sources of variation for fibre morphology, extractives content and pulp yield.

In addition to growth, tree selection including wood quality factors may increase pulp yield (e.g. density and pulp yield) and influence pulp quality (e.g. fibre morphology) or mill operation (e.g. lignin).

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