

# The influence of felling age and site altitude on pulping properties of *Pinus patula* and *Pinus elliottii*

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**P**LANTATIONS OF *PINUS PATULA* Schiede & Deppe and *Pinus elliottii* Engelm. are grown in the Usutu Forest, Swaziland, for manufacture of unbleached kraft pulp. The crop cycle consists of short rotations (16–20 years) without thinning, and the forest is the sole source of mill furnish. *P. patula* and *P. elliottii* currently represent 66% and 26% of the planted area and together provide more than 95% of mill furnish. *P. elliottii* is grown mostly at lower altitudes where it will outyield *P. patula* and on-sites at any altitude with shallow soils or a high risk of wildfires.

Wood properties are generally recognized as having a major influence on the pulping process and characteristics of unbleached kraft pulps. This study was undertaken to determine the degree of variation that exists within current mill furnish from the Usutu Forest. Laboratory pulping results are presented for nine samples each of *P. patula* and *P. elliottii* grown in the forest across a representative range of altitudes and felling ages.

## MATERIALS AND METHODS

The material for the laboratory pulping tests was taken from adjacent *P. patula* and *P. elliottii* stands aged between 23 and 26 years and located at low, middle, and high altitudes in the forest. In each stand, 20 trees were selected at random. Each tree was sampled to provide an 18–20 mm thick disc cut at the middle of each third of the height of the tree

at its current age, when it was 18 years old, and when it was 11 years old (i.e., nine discs per tree). These discs were airfreighted to the Oxford Forestry Institute, England, for laboratory determinations. Details of sampled sites and stands are given in **Table I**. Further information on the methods of field sampling is described elsewhere (1).

At the Oxford Forestry Institute, the appropriate number of outer growth rings, formed after the desired sample age, were removed from the sample discs to represent 11- and 18-year-old trees. The advantage of sampling these “trees within trees” was to remove the uncontrollable variation that would have been contributed by genetics and environment had separate stands been sampled for each altitude/age combination.

Each species/age/altitude combination was represented by three discs, cut from each of 20 trees (i.e., 60 discs per sample), which were chipped in a mechanical guillotine-type laboratory chipper, mixed, and subsampled for laboratory pulping. Pulping was done by the kraft (sulfate) process in a stationary digester with forced circulation of the liquor. A constant set of cooking conditions was used on all samples: 17.5% active alkali, 25% sulfidity, 1 h to reach temperature and 4 h at temperature (170°C). This was aimed at achieving a kappa number in the range 35 to 40. Each digestion was duplicated and, in a few cases where results obtained were unexpected, a second

## ABSTRACT

Kraft pulping and pulp strength characteristics were determined for samples of *Pinus patula* and *Pinus elliottii* grown across a range of altitudes from 790 to 1460 m a.s.l. and representing felling ages of 11–25 years. Intrinsic species differences, felling age, and site altitude all had a significant influence on pulping characteristics. Pulp yield characteristics differed between the two species but not site altitude or felling age. Pulp strength variation was related to felling age and the influence of altitude on the intrinsic characteristics of the two species.

## Application:

A classification based on species, felling age and site altitude could facilitate blending of timber deliveries to the pulp mill to achieve greater consistency in pulp strength characteristics.

pair of digestions was made (samples EH, PH, and PL at 11 years and PH at 25 years).

Pulp was evaluated by beating in a PFI mill and forming handsheets on a semiautomatic British standard sheet machine. The Canadian Standard Freeness (CSF) of each pulp suspension was determined. After conditioning pulp sheets in an atmosphere of 23°C and 50% relative humidity, strength properties were determined using appropriate ISO and British standards. Tear, burst, tensile, and tensile energy absorption (T.E.A.) indices and double folds were determined. Handsheets were tested for each sample without beating and for four or five samples beaten in the range 1000 to 9000 revolutions in the PFI mill. Values were interpolated from the derived beating curves at 500 CSF and used for comparison of strength properties of the prepared pulps.

Sample code	Species	Age class	Age felled	Site altitude
PH	<i>P. patula</i>	1964	25 yr	1460 m
PM	<i>P. patula</i>	1966	23 yr	1230 m
PL	<i>P. patula</i>	1963	26 yr	790 m
EH	<i>P. elliotii</i>	1952	37 yr	1460 m
EM	<i>P. elliotii</i>	1965	24 yr	1230 m
EL	<i>P. elliotii</i>	1964	25 yr	790 m

### I. Details of sites and stands sampled

	Mean	<i>P. patula</i> s.d.	Range	Mean	<i>P. elliotii</i> s.d.	Range	t-test value	Laboratory error
Tear index	13.1	1.2	11.2-14.5	12.0	2.4	8.9-16.3	-1.17	±0.42
Burst index	6.22	0.21	5.73-6.50	6.13	0.37	5.52-6.64	-0.57	±0.10
Tensile index	93.2	3.4	87.6-97.7	91.9	4.5	86.0-98.8	-0.69	±1.73
T.E.A. index	1583	109	1410-1725	1730	217	1440-2075	1.82	±73
Beating revs.	5425	237	5040-5725	5110	626	3930-6110	-1.42	±687
Double folds	1339	123	1139-1550	1166	208	775-1375	-2.14*	±30
Total yield	46.4	1.4	45.6-49.8	43.4	1.3	40.8-46.2	4.76***	±0.41
Screened yield	43.8	1.1	41.0-44.5	42.5	1.2	39.6-43.6	-2.56*	±0.68
Kappa No.	34.4	2.6	31.4-39.4	31.7	4.9	26.1-38.3	-1.49	±1.44
Alkali consumed	74.4	2.9	69.3-77.2	74.1	1.8	70.2-75.6	-0.24	±1.97

\* = Statistically significant at 5% level of probability  
 \*\* = Statistically significant at 1% level of probability  
 \*\*\* = Statistically significant at 0.1% level of probability

II. Mean and range for pulp properties of all *P. patula* and *P. elliotii* samples at 500 CSF. Significant differences between means for two species are compared by t-test. Standard error for laboratory determinations calculated from variance estimates for laboratory duplicates (Table 3).

Source of variation	df	Tear index	Burst index	Tensile index	T.E.A. index	Beating revs.	Double folds	Total yield	Screen yield	Kappa no.	Alkali consumed
Species	1	8.604	0.0738	21.938	154711	153533	228006	80.4011	17.7803	68.063	3.3611
Altitude	2	15.213	0.1476	19.312	112269	1555302	29209	1.2411	7.7633	101.467	13.8436
Age	2	26.133	0.2173	29.655	201478	1988781	74272	7.0811	1.2858	11.094	7.0836
Sp. x Alt.	2	12.018	0.9862	123.41	120803	2236031	305465	11.5544	0.4678	58.141	50.6729
Sp. x Age	2	1.86	0.0048	9.187	5411	572970	8977	1.0178	6.2353	14.183	1.9619
Alt. x Age	4	0.108	0.0142	11.884	12944	178430	23001	0.7944	0.7742	8.85	5.2482
Sp. x Alt. x Age	4	0.564	0.0885	14.971	6828	272109	15998	0.8861	2.4928	7.411	14.459
Laboratory duplicates	18	0.175	0.0099	2.985	5367	472275	17017	0.1667	0.4597	2.084	3.8906
Total	35										

III. Mean square estimates of variance attributed to species, altitude, felling age and their interactions and the laboratory duplicates. Note that no estimate of error variance can be obtained.

Wood chemistry was determined on the high altitude *P. patula* and low altitude *P. elliotii*, these being

representative of the largest part of the mill furnish. The main wood constituents were determined on sam-

ples ground to pass a 425 mm sieve using the appropriate TAPPI Test Methods.

	Tear index	Burst index	Tensile index	T.E.A. index	Beating revs.	Double folds	Total yield	Screen yield	Kappa no.	Alkali consumed
Age (both species)	0.66***	-0.35	-0.30	-0.62**	0.58**	-0.27	0.35	0.05	-0.04	0.21
Altitude (both species)	-0.47*	0.29	0.16	0.35	0.08	0.17	-0.10	-0.27	-0.27	-0.11
Age ( <i>patula</i> only)	0.88***	-0.51	-0.59	-0.91***	0.80**	-0.33	0.49	-0.53	0.36	0.20
Altitude ( <i>patula</i> only)	-0.04	-0.71*	-0.65*	-0.18	0.39	-0.84**	0.61	-0.20	0.36	-0.63
Age ( <i>elliottii</i> only)	0.64	-0.28	-0.10	-0.62	0.63	-0.30	0.58	0.62	-0.26	0.25
Altitude ( <i>elliottii</i> only)	0.75*	0.89***	0.77**	0.70*	0.02	0.82**	0.77**	-0.44	-0.64	0.76*

\* = Statistically significant at 5% level of probability  
 \*\* = Statistically significant at 1% level of probability  
 \*\*\* = Statistically significant at 0.1% level of probability

#### IV. Linear correlation coefficients for stand altitude and age with pulping properties determined across and within species

### RESULTS

#### Statistical analysis

The use of a bulk sample of 20 trees of each species at each site and the technique of "tree within tree" sampling to obtain the three felling ages was intended to minimize unwanted genetic and environmental variation. The normal rotation age of commercial plantations was less than the sample age required for the study. Consequently, adjacent stands about 25 years old of each species were rare, and effectively precluded any replication of the sample sites at the three altitudes. Hence, no statistical estimate of uncontrolled variation could be derived by analysis of variance with which to evaluate the significance of the species, site altitude, felling age effects and their interactions on pulping properties. The overall means for each species were compared using a simple t-test, as shown in Table II. Estimates of variance attributed to the main effects and interactions of species, site altitude, felling age and the duplicate laboratory cooks were determined, as listed in Table III. The reproducibility of the laboratory determinations was good, with low standard errors which were mostly small relative to the absolute range in values (Table II). Across all properties, the effects of species, age, altitude and the interaction between species and altitude were the source of the

Species	<i>P. patula</i>			<i>P. elliottii</i>		
Site altitude	1460 m a.s.l.			790 m a.s.l.		
Felling age (yr)	11	18	25	11	18	25
Cold water soluble*	1.6	1.9	0.6	2.5	2.3	1.4
Hot water soluble*	3.0	2.8	2.2	4.7	3.7	3.1
1% NaOH soluble*	12.5	11.7	12.7	15.8	14.3	11.5
Ethanol-Benzene*	2.0	2.1	1.5	6.6	4.7	2.9
Lignin**	28.3	27.8	27.8	29.3	30.4	28.2
Holocellulose**	63.5	72.5	63.7	72.5	63.3	62.6
Alpha-cellulose**	41.3	42.7	42.6	42.4	41.1	40.9

\* = percent unextracted bone dry wood  
 \*\* = percent Ethanol-Benzene extracted bone dry wood

#### V. Chemical analysis of high altitude *P. patula* and low altitude *P. elliottii* wood samples

largest estimates of variance. Simple linear correlations were determined for altitude and age, with each pulping property for the data from the two species combined and for each species separately, as outlined in Table IV.

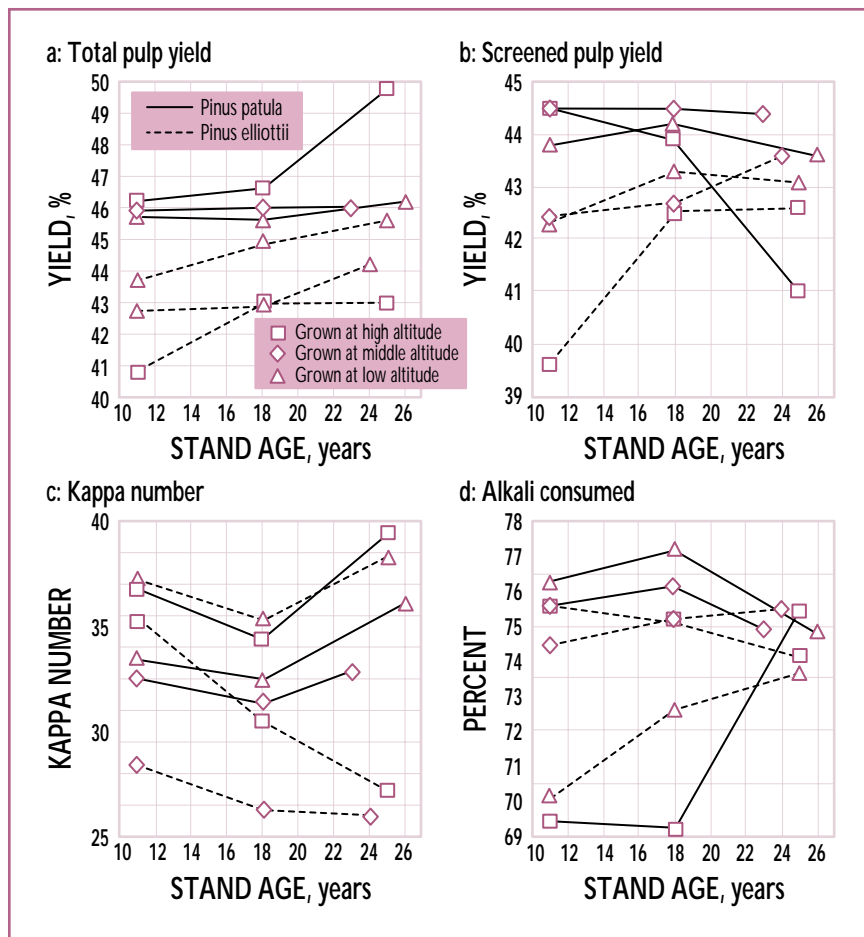
#### Pulp yield characteristics

Pulp yield and associated characteristics are presented in Fig. 1. Both the total and, to a lesser degree, screened pulp yield of *P. patula* was significantly greater than for *P. elliottii* (Table II). There was a significant correlation between altitude and total yield of *P. elliottii* (Table IV), which increased from 42.3% at the highest altitude to 44.7% at the lowest altitude site. This effect was accompanied by trends in kappa and

alkali consumed which, although not statistically significant, suggest this could partly arise from differences in degree of cook and delignification. However, the relationship between yield and kappa (Fig. 2) for the two species indicates other intrinsic differences may be involved. The influence of felling age on pulp yield was not significant (Table IV).

#### Pulp strength characteristics

The various pulp strength properties measured are presented in Fig. 3. The largest estimates of variance for these properties were associated with age, altitude and the interaction of species with altitude (Table III). Except in the case of double folds, where the overall mean value for *P. elliottii* was significantly less than *P.*



1. Pulp yield, kappa, and alkali consumed for *P. patula* and *P. elliottii* grown at high, middle, and low altitude in relation to felling age

*patula*, mean pulp strength properties did not differ significantly between the two species (Table II). Simple intrinsic species differences did not contribute the major source of variation in pulp strength properties.

Felling age was significantly correlated with tear, T.E.A. and double folds, with a very close relationship

within the *P. patula* data. Tear increased and T.E.A. decreased with felling age. Beating revolutions to obtain 500 CSF was significantly correlated with felling age, increasing from an average 4867 revs. for 11-year-old samples to 5558 revs. for the average of the oldest samples.

Significant correlations were found between site altitude and pulp strength but were distinctly different for the two species. For tear and T.E.A. indices, there were significant correlations with altitude for the *P. elliottii* samples but not the *P. patula* samples. Greatest tear and least T.E.A. occurred in the lowest altitude *P. elliottii* samples. For burst, tensile and double folds, both the *P. patula*

and *P. elliottii* data were significantly correlated with altitude, but the trends were reversed in the two species, such that there were no significant correlations in the combined data set. For *P. patula*, burst, tensile and double folds decreased with increasing altitude, but for *P. elliottii* they increased with altitude. In absolute terms, and due to the influence of site altitude, the range in burst, tensile and double folds was greater for the *P. elliottii* than *P. patula* samples (Fig. 3).

#### Wood chemistry

The main wood constituents of the high altitude *P. patula* and low altitude *P. elliottii* are presented in Table V. There is a trend for extractives to decrease with increasing tree age and to be generally higher in *P. elliottii* than in *P. patula*. The lignin content of *P. patula* is also lower than that of *P. elliottii*.

#### DISCUSSION

Many studies have demonstrated the role of wood chemistry, density, and fiber characteristics in determining pulp properties. The influence of species, site altitude and felling age on variation in pulping characteristics must act through their influence on these wood properties. Indeed, the choice of these factors for study was founded on their known general importance in this respect. Another important reason for their selection was that they are variables which could be managed by silviculture practice, harvesting and timber delivery scheduling.

The results of the study demonstrate that intrinsic species differences, felling age and site altitude can all have a significant influence on the variation in pulping characteristics of mill furnish derived from the Usutu Forest.

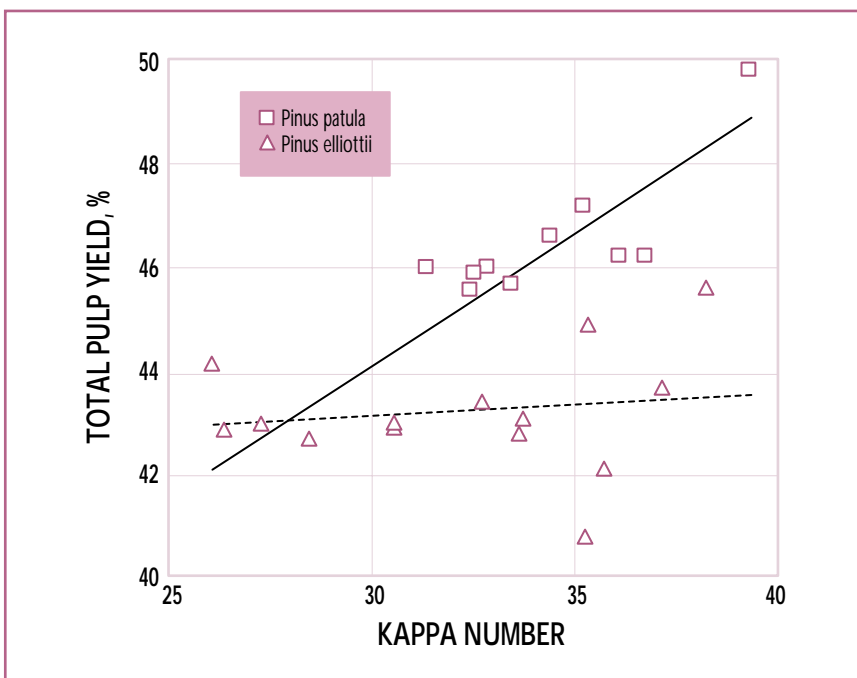
The pulp yield variation was found to be related primarily to intrinsic differences between the two species. *P. patula* had a 2–3%

#### KEYWORDS

Age, altitude, characteristics, evaluation, felling, kraft pulping, *Pinus elliottii*, *Pinus patula*, pulp properties, sites, Swaziland, trees.

higher pulp yield than *P.elliottii*. The magnitude of this effect is that to produce 1.0 ton bone dry screened pulp, one would need 5.3 tons *P.patula* chips or 5.5 tons *P.elliottii* chips (at 57% moisture content). The wood chemistry data shows *P.patula* has a lower lignin and extractive content than *P.elliottii*, confirming other data from South Africa (2) and Malawi (3) for these species, and this chemical difference is the likely reason for the superior pulp yield of *P.patula*.

Pulp strength variation was related to felling age and to the influence of altitude on the intrinsic characteristics of the two species. The effect of site altitude was most marked with *P.elliottii* influencing tear, burst, tensile, T.E.A. and double fold strength. The altitude effect on *P.patula* was confined to burst, tensile and double folds, but with the effects opposed to that with *P.elliottii*. Within the normal age range of felling in the Usutu Forest, the largest source of variation would be associated with site altitude. For typical 18-year-old fellings, the extreme range in pulp strength properties for timber from management units at high and low altitude in the forest would be 8.9–14.5 mN m<sup>2</sup> g<sup>-1</sup> for tear index, 6.6–5.7 kPa m<sup>2</sup> g<sup>-1</sup> for burst index, 99–86 Nm g<sup>-1</sup> for tensile index and 1880–1440 mJ g<sup>-1</sup> for T.E.A. index. These extremes would both be associated with plantings of *P.elliottii*. Such variation can practically be managed by scheduling harvesting and deliveries of pulpwood of the two species from different altitude sites to achieve a consistent blend at the woodyard. A similar range is encountered between slabwood, toplogs and thinnings of *P.radiata*, which represent extremes in the mill furnish supplied to pulp mills in New Zealand (4), as was encountered with the 18 samples tested in the present study. The impact of blending sources of *P.patula* and *P.*



2. The relationship between total pulp yield and kappa for all samples of *P. patula* and *P. elliottii*

*elliottii* at Usutu could be expected to be comparable to that achieved by the practice of controlling the blend of sawmill residues and plantation thinnings in pulp mills that utilize both these sources of furnish.

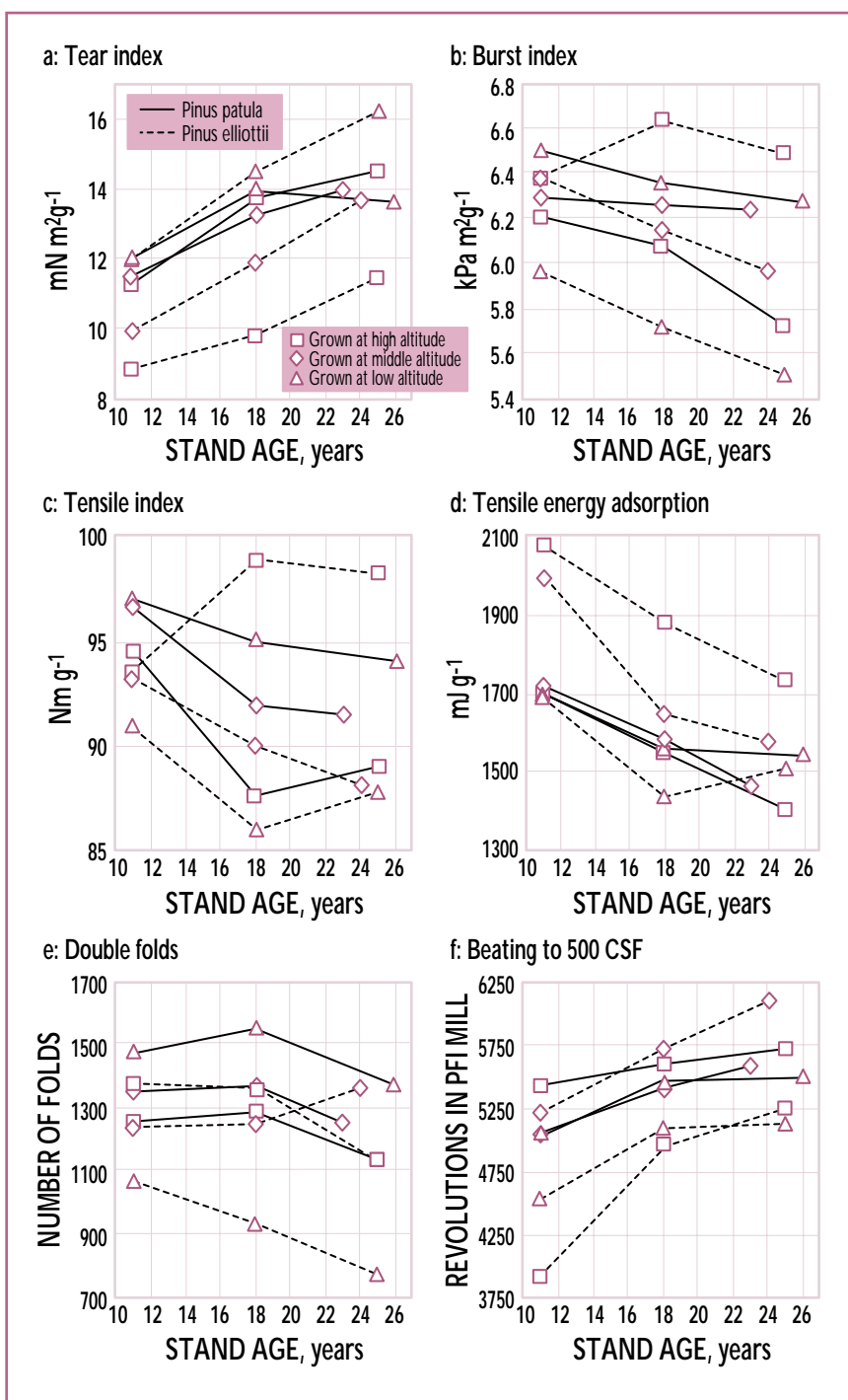
When considering the effect of site altitude, it is important to note that, with the exception of low altitude, *P.patula*, which was growing very much “off-site,” the height growth of all stands indicated that they were of high site quality (unpublished data). In the hard pines group, which includes both *P.patula* and *P.elliottii*, growth rates related to site quality do not cause major changes in wood density (5). Site altitude, through its influence on temperatures and length of growing season, is the site variable most likely to influence wood density properties and hence pulping characteristics. Wood density has been shown to decline with site altitude for *P.elliottii* and the closely related *P.caribaea* grown in South Africa and Zimbabwe (6–9) but not for *P.pat-*

*ula* (10). The wide variation of pulp strength properties of *P.elliottii* associated with altitude is consistent with the trends found for wood density and its general effect on these properties. This effect, and the opposed trends in burst, tensile and double folds with site altitude for the two species, require further study to identify the controlling mechanisms.

## CONCLUSIONS

Several conclusions can be drawn concerning the variation in pulp properties of *P.patula* and *P.elliottii* grown across the range of site altitudes and felling ages existent in the Usutu Forest.

1. *P.patula* had a 2–3% higher pulp yield, at equivalent kappa, than *P.elliottii*.
2. Tear increased and T.E.A. decreased as felling age increased.
3. Pulp strength variation was related to felling age and the influence of altitude on the intrinsic characteristics of the two species.



3. Pulp strength properties measured at 500 CSF for *P. patula* and *P. elliottii* grown at high, middle, and low altitude in relation to felling age

4. Burst, tensile and double folds were significantly influenced by site altitude, although these effects were opposed for the two species; they increased in *P. elliottii*

but decreased in *P. patula* at higher altitudes. For *P. elliottii*, but not *P. patula*, tear decreased and T.E.A. increased at higher site altitude.

5. In absolute terms, greatest variation occurred in *P. elliottii*, being generally more sensitive to site altitude than *P. patula*.

These results suggest that the classification of mill furnish, based on species, felling age and site altitude, would facilitate blending of pulpwood to provide greater consistency in pulp strength characteristics. **TJ**

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