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Summaries

SUMMARY

Three samples of *Pinus caribaea* var. *hondurensis* and four of *Pinus oocarpa* grown in Zimbabwe over an altitudinal range of 700 m to 1 300 m were examined to determine their suitability for the production of papermaking pulps.

Details of growing conditions, climate and rate of growth are reported.

The wood density of *P. caribaea* decreased with increased altitude of the growing site: altitude had no effect on the wood density of the samples of *P. oocarpa*.

Both species were pulped by the sulphate process, *P. caribaea* yielding 45% and *P. oocarpa* 46% of pulp with a kappa number of 40. There was little difference in tensile and bursting strengths of pulps from any of the samples. *P. caribaea* grown at low altitudes had the highest tearing strength and with this species tearing strength decreased with increasing altitude of the growing site. *P. oocarpa* yielded pulp with a tearing strength similar to that of *P. caribaea* from the middle altitude and altitude had no influence on pulp quality of this species.

All samples were pulped by the Refiner Mechanical and Thermal Refiner Mechanical processes and yielded pulps suitable for use in newsprint.

RÉSUMÉ

Trois échantillons de *Pinus caribaea,* variété *hondurensis,* et quatre échantillons de *Pinus oocarpa,* tous deux cultivés au Zimbaboué à une altitude allant de 700 m à 1 300 m, ont été examinés afin d'établir s'ils conviennent à la production de pâte à papier.

Tous les détails relatifs aux conditions de culture, de climat, ainsi qu'au taux de croissance figurent dans ce rapport.

La densité de bois du *P. caribaea* diminue lorsque le site de culture est situé à haute altitude; en revanche, un examen des échantillons de *P. oocarpa* a montré que l'altitude n'avait aucun effet sur la densité de bois de ce dernier.

Les deux espèces ont été réduites en pâte par le procédé au sulphate, le *P. caribaea* donnant un taux de pâte de 45% et le *P. oocarpa* de 46% avec un indice kappa de 40. Peu de différence a été constatée entre les résistances à l'éclatement et à la tension de la cellulose de chacun des échantillons. Cultivé à basse altitude, le *P. caribaea* a la résistance au déchirement la plus élevée; en outre, avec cette espèce, la résistance au déchirement diminue lorsque le site de culture se trouve à plus haute altitude. Le *P. oocarpa* a donné une pâte ayant une résistance au déchirement semblable à celle du *P. caribaea* cultivé à moyenne altitude, celle-ci n'ayant d'ailleurs aucune influence sur la qualité de la cellulose obtenue avec les échantillons utilisés.

Tous les échantillons ont été réduits en pâte par les procédés mécaniques de raffineur et de raffineur thermique, et ont produit des pâtes appropriées à la fabrication de papier journal.

RESUMEN

Se llevó a cabo et examen de tres muestras de *Pinus caribaea* var. *hondurensis* y de cuatro de *Pinus oocarpa,* cultivadas en Zimbabwe a altitudes de entre 700 y 1 300 m, para determinar su adecuabilidad para la producción de pastas papeleras.

En este informe presentamos detalles sobre sus condiciones de cultivo, clima e índice de crecimiento.

La densidad de la madera de la especie *P. caribaea* fue reduciéndose con el aumento de la altitud de cultivo. La altitud no ejerció impacto alguno sobre la densidad de la madera, en las muestras de *P. oocarpa.*

Ambas especies fueron reducidas a pasta en conformidad con el proceso de reducción al bisulfito. La especie *P. caribaea* proporcionó un rendimiento del 45% y la *P. oocarpa* del 46% de pasta, con un número kappa de 40. Apenas si se encontró en las muestras diferencia alguna entre la resistencia a la tracción y al reventón de las pastas. La *P. caribaea* cultivada a baja altitud obtuvo la mayor resistencia al rasgado, habiéndose observado en esta especie una reducción de la resistencia al rasgado con el aumento de la altitud de cultivo. La especie *P. oocarpa* proporcionó pasta con una resistencia al rasgado similar a la de la *P. caribaea* de altitud media, sin que la altitud ejerciera influencia alguna sobre la calidad de la pasta en esta especie.

Todas las muestras fueron reducidas a pasta siguiendo los procesos de refinado mecánico y de refinado termomecánico, habiéndose obtenido rendimientos apropiados para su empleo en papel de periódico.

Pulping Characteristics of *Pinus caribaea* var. *hondurensis* and *Pinus oocarpa* Grown in Zimbabwe

INTRODUCTION

Pinus caribaea var. *hondurensis* was introduced to Zimbabwe in 1954, and *P. oocarpa* in 1957. Neither species has been established as a commercial crop, but experimental plots of both species have been established on a wide range of sites. In their native, Central American, habitats, *P. caribaea* grows in an altitudinal range from sea level to 850 m (Barrett and Golfari, 1962), whilst *P. oocarpa* is widely distributed with an altitudinal range of 900 m to 2 400 m (Mirov, 1967). In this investigation, where the pulping characteristics of samples of the two species growing on adjacent plots were determined, it was possible to assess the difference between the species and the effect of altitude on them.

SITES AND GROWING CONDITIONS

Both species are growing on three sites. The following information was provided by the Zimbabwe Forestry Commission.

Chiwengwa

This site is at 700 m, with a mean annual rainfall of 1 500 mm. Climatic data are given in Table 1. The site description is: Dolerite/granite contact.

Soil Texture: at least 1 m of sandy clay loam. Colour: using the Munsell soil colour chart, the surface when dry is red-brown (2.5 YR 4/4) and when moist dark red brown (2.5 YR 3/4) and at 0.9 m dark red (10 YR 3/6) when dry and moist. Free draining; rather dry (August). pH: 5.4 at surface and 0.9 m.

Natural Vegetation Bamboo (*Oxytenanthera*), *Brachystegia, Uapaca, Hyparrhenia* grass.

Other Relevant Information: Slope 5°, east aspect. Mole rats present. Frosty.

Muchakata

This site is at 1 050 m with a mean annual rainfall of 1 520 mm. Climatic data are given in Table 2. The site description is: Granite/dolerite contact.

Soil Texture: 1 m or more sandy clay but slightly obstructed by quartz gravel at 0.75 m and 0.9 m depth. Colour: surface, dry, red brown (2.5 YR 4/4), moist, dark red (10 R 3/6); at 0.9 m moist, weak red (10 R 4/4). pH: 4.6 at surface to 5.1 at 0.9 m.

Natural Vegetation Dense *Uapaca*, open patches with *Hyparrhenia* grass.

Other Relevant Information Nearly level, slightly exposed. A focal point for *Armillaria mellea.*

Mukandi

This site is at 1 325 m and has a mean annual rainfall of 1 760 mm. Climatic data are given in Table 3. The site description is: Granite.

Soil Texture: sandy loam at surface to loamy sand at 0.9 m; obstructed by rock at 0.9 m depth. Colour: surface, dry, grey brown (10 YR 5/2), moist, very dark grey (10 YR 3/1); at 0.9 m, moist yellowish red (5 YR 4/8). pH: 4.2 at surface to 4.1 at 0.9 m.

Natural Vegetation *Bridelia, Hypericum, Ficus, Philippia, Albizia, Cussonia,* herbs and grasses.

Other Relevant Information Slope 18°; north west aspect; moderate exposure; occasional violent winds. Small amount of surface rock.

SAMPLING

A sample of 15-year old trees of each species was taken from each site, and a sample of 10-year old trees of *P. oocarpa* was taken at the Chiwengwa site.

The three samples of *P. caribaea* were all from the Mountain Pine Ridge provenance, in Belize. Three of the four *P. oocarpa* samples were from a half-sib family of a South African breeding population (Clone 0.10). The 10-year old *P. oocarpa* sample came from a mix of half-sib families of five South African clones, including 0.10, in a clone bank in Zimbabwe.

Each sample was taken by selecting ten trees at random from within the site. The length of the bole to 25 cm girth over-bark of each tree selected was measured; sampling points were marked at 10%, 30%, 50% and 70% of this length and four 20 mm thick discs were cut from each point. The over-bark girth of these discs was measured and they were air dried and sent to the Overseas Development Natural Resources Institute (ODNRI) for examination.

TREE DIMENSIONS

The height and breast height diameter of the trees are recorded in Table 4.

Trees grown at Chiwengwa, the site at lowest altitude, were the tallest and their height decreased with increasing altitude. It was not possible to draw a conclusion as to the effect of altitude on girth of trees since the differences in girth were so large that there was no significant difference between mean values. However, it is a reasonable inference that wood production from both species is greatest at the lowest altitude.

At each altitude the average height of trees of *P. oocarpa* was greater than that of trees of *P. caribaea*, although only in one case (Muchakata site) was the difference significant at the 5% level. The differences in girth showed no consistent pattern and were not statistically significant. Allowing for the fact that the bark content of *P. oocarpa* was lower than that of *P. caribaea* it is probable that *P. oocarpa* produces a greater weight of wood.

EXPERIMENTAL PROCEDURES, RESULTS AND DISCUSSION

The experimental methods are fully described in the Appendix. Wood density and chemical composition were determined by standard methods published by TAPPI. Pulp was evaluated by beating in a PFI mill, forming sheets on a British Standard sheet machine, and testing after conditioning at 23±1°C and 50±2% relative humidity, using the appropriate International and British Standards.

Bark Content

The bark content, calculated from the dimensions of discs, is recorded in Table 4. The three samples of *P. caribaea* included about 30% bark by volume, the three 15-year old samples of *P. oocarpa* about 24%. There was no difference between the bark content of either species attributable to site, but the difference between the species was significant.

The 10-year old sample of *P. oocarpa* had the lowest bark content of these samples, 20%.

Apparent Wood Density

Wood density was determined using one disc from each sampling point and the value calculated as oven-dry weight/green volume. The mean value for each sample and the range for individual trees within the sample are recorded in Table 5. There was no difference in density between the two samples of *P. caribaea* grown at Chiwengwa and Muchakata, but that of the sample grown at Mukandi, the site at highest elevation, was significantly lower. Barnes *et al.* (1977) reported that the conditions at Mukandi (high rainfall, relatively high mean temperature and small winter water deficit) were favourable to the continuous growth *P. caribaea*. The low density of the wood, and the wide, thin-walled fibres found in the pulp from *P. caribaea* grown at Mukandi would be the result of continuous growth.

There was no significant difference in density between the three 15-year old samples of *P. oocarpa*, but the density of the 10-year old sample was significantly lower.

The density of temperate pines commonly used in the pulping industry is between 310 and 560 kg m^{-3} (Rydholm, 1965); the values for all of these samples were within that range.

The density of the wood at the top of the tree was lower than that at the bottom for more than 90% of the trees examined. This difference could have practical importance if multiple utilisation of trees is proposed; for example, if the bottom is used for timber production and the top for pulpwood.

Fibre Dimensions

The dimensions of fibres (tracheids) were determined using a well-cooked pulp from each sample. The fibre length, width and wall thickness were determined by direct measurement of the magnified image; the fibre length was also determined by fractionation. The results are recorded in Table 6. The samples of *P. caribaea* yielded pulps with fibres over 3 mm long, around 40 μm wide and with walls around 4.5 μm thick. The only significant difference was in width, where the samples from Chiwengwa and Muchakata yielded pulps with fibres 38.6 and 39.3 μm wide, whilst that from the higher altitude site, Mukandi, yielded pulps with fibres 45.5 μm wide. The greater width taken with the same wall thickness, would account for the lower density of the latter sample. There was no significant difference between the fibre dimensions of the pulps yielded by the three 15-year old samples of *P. oocarpa:* length around 3 mm, width around 38 μm, wall thickness 4.4 μm. The 10 year old sample of *P. oocarpa* yielded pulps with about the same fibre length and width but thinner walls; younger samples normally have shorter fibres. The only difference between the two species was that the fibres in pulps from *P. caribaea* were a little longer than those in pulps from *P. oocarpa* but the difference was small and unlikely to be of practical significance.

The fibre dimensions indicate that pulps from all these samples would have fibres that were a little longer and more coarse than those in most pulps from temperate pines.

Chemical Analysis

The chemical components which significantly affect the pulping characteristics of wood were determined and the results are recorded in Table 7.

There were no significant differences between the samples with regard to lignin (26.6 to 28.4%), holo-cellulose (60.2 to 62.3%) and alpha-cellulose (41.0 to 42.8%) contents. The resin content, as measured by the amount of wood soluble in ethanol-benzene, was higher for *P. caribaea* (1.4 to 2.6%) than for *P. oocarpa* (1.4 to 1.6%). The values obtained indicated that all the samples would be suitable for pulping by the sulphate process and that all samples could be pulped using the same conditions.

Chemical Pulping and Pulp Evaluation

Chemical pulping trials were made by the sulphate (or kraft) process. Each sample was pulped using three different levels of chemical charge: the least severe conditions were those expected to yield, from a suitable wood, an unbleached pulp for use in wrapping paper; the most severe were those expected to yield a bleachable grade of pulp. The pulps were evaluated by beating in a PFI mill, forming sheets on a British Standard sheet machine and testing them after conditioning in a standard atmosphere of 23±1°C and 50±2% relative humidity. Details of digestion conditions and a summary of pulp characteristics are given for *P. caribaea* in Table 8 and for *P. oocarpa* in Table 9. Most digestions were duplicated and, in these cases, the values reported are the average for two digestions.

The three samples of *P. caribaea* yielded over 45% of pulp with a kappa number around 40 when pulped using 16% active alkali, and 42% with a kappa number around 25 using 20% active alkali. There was a tendency for the total yield to be lower and the screenings to be higher for samples from the higher altitude sites. For the tensile and bursting strengths there was little difference between pulps obtained from woods on the three sites and all were satisfactory, but there was a marked difference in the tearing strength. The tearing strengths of pulps from wood grown on the highest site, Mukandi, were 30% lower than those from the lowest site, Chiwengwa.

The three 15-year old samples of *P. oocarpa* yielded about 46% of pulp with a kappa number of about 40 when pulped using 16% active alkali, and nearly 42% with a kappa number around 25 using 20% active alkali. The major strength characteristics were similar for the pulps from all samples. The yield of pulp from the 10-year old sample of *P. oocarpa* was not significantly different from that of the 15-year old sample from the same site. The pulp from the younger sample had higher tensile and bursting strengths and a lower tearing strength than that from the older sample: the difference in tearing strength (about 12%) is the characteristic most likely to be of practical importance.

Both the *P. caribaea* and the 15-year old *P. oocarpa*, when digested by the same sulphate conditions, yielded similar quantities of pulp with similar kappa numbers. The only major differences between pulps from the two species was that the tearing strength of pulps from *P. caribaea* decreased as the altitude of the site increased. All of the pulps from *P. oocarpa* samples had strength characteristics similar to those of the *P. caribaea* grown on the middle altitude site, Muchakata.

Bleaching and Bleached Pulp Evaluation

One pulp from each sample with a kappa number about 25, was bleached using a four-stage sequence of chlorine, sodium hydroxide, sodium hypochlorite, and chlorine dioxide. The quantity of chlorine used in the first stage was determined by the kappa number of the pulp: the quantity of chemical used in the subsequent stages was the same for all pulps. Details of bleaching conditions and bleached pulp evaluation are given in Table 10.

About 5% of the unbleached pulp was lost in the bleaching process: consequently the yield of bleached pulp on dry wood was about 40%. All of the pulps had an ISO brightness of around 84. This was considered a good value, as the four stage process is relatively simple and no attempt was made to determine optimum bleaching conditions. The use of more complex systems, with more stages and with optimum conditions should produce a brighter pulp. There was no significant difference between the strength characteristics of the bleached pulps and those of the unbleached pulps from which they were made. Consequently, the conclusions drawn for the relationship between samples using unbleached pulp characteristics are equally applicable to bleached pulps.

Use of Chemical Pulps

A number of wood species used in industrial pulping have been pulped in this laboratory to provide comparative data for use in assessing the potential value of samples under investigation. Selected values from these digestions are reported in Table 11.

All of the samples under examination could be pulped using the same pulping conditions as are necessary for *Pinus* spp. used in industry. The yield and kappa number of the pulps obtained from the present samples and from wood species used in industry were similar. The tensile and bursting strengths were also similar, but, except for the sample of *P. caribaea* grown at Chiwengwa, the tearing strengths were low.

Sulphate (kraft) pulps from *Pinus* spp. are most often used for sack kraft and wrapping papers. Criteria used for determining suitability of pulps for inclusion in these grades are: Sack kraft — tensile index over 60 $N\ m\ g^{-1}$, tear index over 14 $mN\ m^2\ g^{-1}$; Wrapping paper — tensile index over 45 $N\ m\ g^{-1}$, tear index over 12.5 $mN\ m^2\ g^{-1}$. All of the samples yielded pulps that would meet the requirement for tensile strength. The sample of *P. caribaea* grown at Chiwengwa yielded pulps which with a drainability of 500 CSF had a tearing strength suitable for wrapping paper and with a drainability value of 600 CSF for sack kraft. The sample of *P. caribaea* grown at Muchakata and all the 15-year old samples of *P. oocarpa* yielded pulps which, at a drainability value of 600 CSF, had a tearing strength suitable for wrapping paper. In practice these results mean that none of these samples could be used to produce pulp suitable for high quality sacks and that wrapping paper could be produced only when using very free (high drainability value) pulps. A 15-year old sample of *P. oocarpa* yielded pulps with a tearing strength 20% higher than pulps from a 10-year old sample grown on the same site. Consequently, it is recommended that trees older than 15 years are examined to determine whether pulps with higher tearing strengths can be obtained.

Mechanical Pulping and Pulp Evaluation

All of the samples were pulped by the Refiner Mechanical (RMP) and the Thermal Refiner Mechanical (TRMP) methods. Refiner Mechanical Pulp is produced by the mechanical action of a disc refiner at atmospheric pressure without any pre-treatment of chips. Thermal Refiner Mechanical Pulp is produced when chips are pre-steamed at temperatures over 100°C followed by disc refining at atmospheric pressure.

Details of the characteristics of a representative selection of the Refiner Mechanical pulps (RMP) from *P. caribaea* are given in Table 12 and from *P. oocarpa* in Table 13. Increasing the degree of refining caused a reduction in drainability, decrease in the proportion of coarse fibres and increase in the proportion of fine fibres, increase in tensile and burst indices, opacity and scattering coefficient and decrease in tear index. The samples of *P. caribaea* from Muchakata and Mukandi sites yielded stronger pulps than the sample from Chiwenga. The 10-year old sample of *P. oocarpa* yielded pulps with higher tensile and bursting strengths and lower tearing strength than the 15-year old samples: there was little difference between the characteristics of pulps from the three 15-year old samples.

Unbleached pulps from *P. caribaea* had a slightly higher brightness than those from *P. oocarpa*; the tensile and bursting strengths of pulps from the samples of *P. caribaea* grown at Muchakata and Mukandi and all the 15-year old samples of *P. oocarpa* were similar but the tearing strength of the pulps from *P. caribaea* was slightly higher.

Characteristics of a representative sample of thermal refiner mechanical pulps (TRMP) from *P. caribaea* are given in Table 14 and from *P. oocarpa* in Table 15.

When pulped by the TRMP process *P. caribaea* samples exhibited the same trends as when pulped by the RMP process: namely that pulps obtained from samples grown on Muchakata and Mukandi sites were stronger than those obtained from the sample grown at Chiwengwa. In general the TRMP pulps were about 10% stronger than RMP pulps of equal freeness (drainability) from the same samples.

The TRMP pulps obtained from the samples of *P. oocarpa* grown at Muchakata and Mukandi were similar to each other, and stronger than those obtained from the sample of *P. oocarpa* grown at Chiwengwa. This last sample was the only one of the six examined which did not yield a TRMP pulp stronger than its RMP pulp. This result was so unexpected and atypical there must be a suspicion that it was due to the processing of this sample.

It was not possible to measure the energy consumed by refiner runs, but it was obvious from the ease with which chips were disintegrated, and the fact that RMP runs were longer than TRMP runs by a factor of about three, that TRMP pulping requires much less energy in the refining stage.

Comparison with Commercial Pulps

To assess the potential of these samples for mechanical pulping, a comparison was made with data for commercial pulps, which is recorded in Table 16. This comparison shows that all the samples yielded pulps with better strength characteristics than stoneground pulp used in newsprint, but the pulp would need bleaching to a satisfactory brightness.

The RMP and TRMP pulps have similar tensile and bursting strengths and a little lower tearing strengths than commercial samples of these grades made from spruce and Southern pine, but were generally weaker than the same grades made from *P. radiata*. It would be expected that pulps made using commercial equipment would be stronger than those made using laboratory equipment; it is likely that RMP and TRMP pulps from *P. caribaea* and *P. oocarpa* could be used in the same way as pulps from Southern pine and *P. radiata*.

CONCLUSIONS

1. Trees grown at the lowest altitude were the tallest and height decreased with increasing altitude; trees of *P. caribaea* were shorter and had a higher bark content than those of *P. oocarpa*. Consequently, *P. oocarpa* would be expected to produce more wood.

2. The density of wood of *P. caribaea* grown at Mukandi, the site at highest altitude, was significantly less than that of wood from the other two sites. The altitude of the site had no effect on the density of wood of *P. oocarpa*.

3. Chemical analysis indicated that all samples were suitable for pulping by the sulphate process, with no significant difference between the samples in lignin, holo-cellulose and alpha-cellulose contents.

4. *P. caribaea*, pulped by the sulphate process, yielded over 45% of pulp with a kappa number of 40. The tensile and bursting strengths of pulps showed little difference between the three sites, but the tearing strength was highest for pulps obtained from the sample grown at Chiwengwa, the site at lowest altitude, and tearing strength of pulp decreased with increase in the altitude of the site where samples were grown.

5. *P. oocarpa*, pulped by the sulphate process, yielded about 46% of pulp with a kappa number of about 40; there was no significant difference in the strength characteristics of pulps from samples grown at different altitudes.

6. The sample of *P. caribaea* grown at Muchakata, the site at mid-altitude, and all the samples of *P. oocarpa* yielded pulps with similar strength characteristics.

7. Only the sample of *P. caribaea* grown at Chiwengwa, the lowest altitude, yielded pulps with a tearing strength high enough to make them suitable for use as wrapping papers. It is likely that older trees would yield pulp with higher tearing strength.

8. All samples were pulped by the Refiner Mechanical (RMP) and Thermal Refiner Mechanical (TRMP) processes. All of the samples yielded pulps with strength characteristics greater than those of stoneground pulps used for newsprint. They had similar tensile and bursting strengths but slightly lower tearing strength than RMP and TRMP pulps obtained commercially from spruce and Southern pines.

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Table 1

Climatic conditions: Chiwengwa

Month	Temperature, °C				Relative humidity, % 24-hour mean	Rainfall, mm			Rain days	Evaporation mm Mean
	Maximum		Minimum			Mean	Record Highest	Record Lowest		
	Mean	Highest	Mean	Lowest						
July	24.9	31	6.0	−4	79	7.3	46.6	Nil	3	74.4
August	26.8	33	7.2	−2	76	10.4	28.4	Nil	2	94.9
September	30.2	38	9.0	1	67	14.4	103.4	Nil	2	140.7
October	30.4	38	13.6	4	69	53.9	140.0	3.6	6	143.4
November	30.1	39	15.9	6	75	140.0	287.5	12.7	11	131.2
December	29.6	39	17.8	12	82	279.8	712.5	48.8	18	119.8
January	30.1	37	18.4	11	82	346.5	700.4	53.3	20	124.6
February	29.5	36	18.0	11	83	303.2	551.7	123.7	16	102.5
March	29.3	35	16.9	7	83	247.5	690.0	36.6	16	111.6
April	27.7	33	14.3	6	83	54.7	147.6	5.3	8	88.4
May	26.6	34	9.9	2	82	28.2	84.6	Nil	4	76.8
June	24.5	31	6.9	1	81	13.2	40.6	Nil	4	64.0
Year	28.4	39	13.0	−4	79	1,499.1	2,506.8	687.2	110	1,272.0
Number of years	7	7	7	7	7	15	15	15	7	7

Source: Zimbabwe Forestry Commission

Notes: Latitude 18°41′S; longitude 32°55′E; altitude 698 m. At confluence of Nyamukwarara and Chiwengwa rivers; bottom of steep-sided valley. Low minimum temperatures in winter due to cold air drainage; very high diurnal temperature ranges

Table 2

Climatic conditions: Muchakata

Month	Temperature, °C				Relative humidity, % 24-hour mean	Rainfall, mm			Rain days	Evaporation mm Mean
	Maximum		Minimum			Mean	Record Highest	Record Lowest		
	Mean	Highest	Mean	Lowest						
July	21	28	10	4	70	11.7	46.2	Nil	3	88
August	23	30	11	5	66	10.5	25.4	Nil	2	114
September	26	34	13	6	62	19.2	119.2	Nil	2	154
October	26	34	15	9	67	55.3	110.8	14.7	5	155
November	26	35	16	10	76	178.1	284.0	69.3	11	132
December	26	34	17	13	83	328.4	551.6	118.6	16	113
January	26	34	17	12	85	343.4	608.7	84.8	17	117
February	26	30	17	13	84	252.9	534.5	84.6	15	100
March	25	31	16	10	82	216.8	607.4	34.5	13	112
April	24	30	14	10	80	55.3	105.0	14.9	7	93
May	23	31	12	7	75	32.3	117.9	Nil	4	90
June	20	27	10	6	74	12.8	39.6	0.6	3	75
Year	24	35	14	4	75	1,516.7	2,348.8	715.3	98	1 337
Number of years	7	7	7	7	7	7	7	7	7	7

Source: Zimbabwe Forestry Commission

Notes: Latitude 18°42'S; longitude 32°53'E; altitude 1,050 m. Only rainfall is measured at Muchakata: the other values have been estimated using measurements made at Mutepfa and Mukandi

Table 3

Climatic conditions: Mukandi

Month	Temperature, °C				Relative humidity, % 24-hour mean	Rainfall, mm			Rain days	Evaporation mm Mean	Daily sunshine h
	Maximum		Minimum			Mean	Record Highest	Record Lowest			
	Mean	Highest	Mean	Lowest							
July	19.6	27	8.5	2	72	16.1	71.4	Nil	4	80.2	7.3
August	21.4	28	9.6	3	69	29.7	88.6	1.8	4	106.1	8.3
September	24.8	32	11.4	4	65	19.6	121.7	Nil	3	142.5	8.8
October	25.0	32	13.6	7	70	72.1	146.8	20.8	8	142.1	7.4
November	24.6	33	14.9	8	79	184.9	363.7	45.7	14	119.3	6.0
December	24.3	32	16.0	11	85	327.4	785.9	70.5	19	102.9	4.8
January	24.6	32	16.3	10	86	370.5	647.1	69.3	20	107.6	5.5
February	24.0	29	16.0	11	86	329.2	674.9	147.1	18	91.2	5.1
March	24.0	29	15.3	9	85	259.1	638.3	61.1	17	105.2	6.0
April	22.6	29	13.2	8	83	92.0	185.4	9.9	10	85.7	6.2
May	21.6	30	10.8	6	78	40.5	108.8	2.0	7	83.0	7.2
June	19.1	26	8.7	4	77	21.6	61.7	Nil	6	69.3	6.7
Year	23.0	33	12.9	2	78	1,762.7	2,733.7	890.8	130	1,235.5	6.6
Number of years	7	7	7	7	7	15	15	15	15	7	7

Source: Zimbabwe Forestry Commission

Notes: Latitude 18°43′S; longitude 32°51′E; altitude 1,268 m. Flattish area in mountain country; north-easterly aspect; sheltered by higher ridge to east

Table 4

Dimensions of trees in sample

Species	Site	Age years	Height, m		Diameter breast height over bark, cm		Bark, % Mean
			Mean	Range	Mean	Range	
Pinus caribaea	Chiwenga	15	25.9	23.2–28.4	24.1	19.5–28.9	31
Pinus caribaea	Muchakata	15	22.7	20.5–24.2	27.1	21.1–32.1	29
Pinus caribaea	Mukandi	15	20.2	15.0–24.2	26.0	16.5–36.3	31
Pinus oocarpa	Chiwengwa	10	20.8	19.9–23.2	21.6	16.7–27.2	20
Pinus oocarpa	Chiwengwa	15	27.0	23.4–29.3	27.3	19.1–34.1	24
Pinus oocarpa	Muchakata	15	25.4	22.9–29.3	23.2	16.7–28.4	23
Pinus oocarpa	Mukandi	15	22.6	19.4–25.8	24.3	17.9–37.5	25

Table 5

Apparent wood density

Species	Site	Age Years	Density, kg m^{-3}	
			Mean	Range
Pinus caribaea	Chiwengwa	15	424	395–507
Pinus caribaea	Muchakata	15	425	388–486
Pinus caribaea	Mukandi	15	377	322–433
Pinus oocarpa	Chiwengwa	10	360	341–384
Pinus oocarpa	Chiwengwa	15	439	407–463
Pinus oocarpa	Muchakata	15	420	342–473
Pinus oocarpa	Mukandi	15	441	403–475

Table 6

Fibre dimensions by projection and McNett classification of sulphate pulps

Species	Site	Age years	Fibre dimensions by projection				Fibre weight fractions by classification, %								Calculated* fibre length by classification mm
			Length mm		Width µm	Wall thickness µm	Passed aperture, µm: —	1,680	1,190	841	595	420	210	74	
			All fibres	Whole fibres			Retained on aperture, µm: 1,680	1,190	841	595	420	210	74	—	
Pinus caribaea	Chiwengwa	15	2.72 (0.10)	3.41 (0.10)	38.6 (1.2)	4.7 (0.1)	59.6	11.7	9.2	5.0	5.4	4.3	1.6	3.1	3.1
Pinus caribaea	Muchakata	15	2.46 (0.09)	3.06 (0.11)	39.3 (1.2)	4.5 (0.1)	54.7	13.7	10.0	5.9	5.0	4.8	1.6	4.4	3.1
Pinus caribaea	Mukandi	15	2.69 (0.08)	3.34 (0.09)	45.5 (1.3)	4.7 (0.1)	40.0	19.2	14.6	8.6	7.7	4.9	1.7	3.3	2.9
Pinus oocarpa	Chiwengwa	10	2.44 (0.08)	3.10 (0.10)	38.1 (1.1)	3.9 (0.1)	45.2	17.3	14.0	7.7	6.5	5.0	1.6	2.8	3.0
Pinus oocarpa	Chiwengwa	15	2.52 (0.08)	3.03 (0.09)	37.9 (1.0)	4.4 (0.1)	51.0	15.0	10.9	7.5	5.4	4.8	1.5	4.0	3.0
Pinus oocarpa	Muchakata	15	2.49 (0.08)	2.87 (0.09)	38.8 (1.1)	4.5 (0.1)	50.3	15.1	11.1	6.7	6.9	5.0	1.7	3.2	3.0
Pinus oocarpa	Mukandi	15	2.41 (0.08)	2.93 (0.09)	38.7 (1.1)	4.3 (0.1)	47.2	15.9	12.1	7.1	7.9	5.3	1.5	3.0	3.0

Notes: *By difference
Figures in brackets are the standard error of the mean for each determination

Table 7

Chemical analysis

Species	Site	Age years	Cold water solubles	Hot water solubles	1% NaOH solubles	Ethanol-benzene solubles	Total solubles	Lignin	Holo-cellulose	Alpha-cellulose
Pinus caribaea	Chiwengwa	15	2.3	2.7	11.1	1.4	3.5	26.7	62.2	42.2
Pinus caribaea	Muchakata	15	2.8	3.3	11.9	2.6	4.6	26.7	60.9	41.5
Pinus caribaea	Mukandi	15	2.5	2.8	12.7	2.3	3.5	28.4	60.2	41.2
Pinus oocarpa	Chiwengwa	10	2.2	2.5	12.6	1.4	3.3	27.3	61.5	40.7
Pinus oocarpa	Chiwengwa	15	2.2	2.8	13.1	1.5	3.6	26.6	61.8	41.0
Pinus oocarpa	Muchakata	15	2.2	2.6	12.4	1.4	3.1	27.3	62.3	42.0
Pinus oocarpa	Mukandi	15	2.1	2.6	12.5	1.6	3.1	27.2	62.2	42.8

Note: All expressed as percentage oven-dry component on oven-dry unextracted wood
Total solubles = quantity extracted by successive applications of ethanol-benzene, ethanol and hot water

Table 8

Pinus caribaea: sulphate digestion conditions, pulp yield and evaluation

	Drainability CSF	Chiwengwa			Muchakata			Mukandi		
Cook number		114	148	113	155	153	121	126	115	151
Digestion conditions										
Active alkali as Na_2O on oven-dry wood, %		16	18	20	16	18	20	16	18	20
Sulphidity, %		25	25	25	25	25	25	25	25	25
Liquor to oven-dry wood ratio		5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1
Maximum temperature, °C		170	170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1	1	1	1
Time at maximum temperature, h		4	4	4	4	4	4	4	4	4
Chemical consumption										
Active alkali consumed as Na_2O on oven-dry wood, %		14.1	13.3	14.1	13.8	13.8	14.1	12.1	13.4	14.0
Yield of pulp										
Yield of oven-dry digested pulp on oven-dry wood, %		47.2	44.6	42.8	45.8	43.5	41.9	45.8	43.5	41.7
Yield of oven-dry screened pulp on oven-dry wood, %		44.9	44.4	42.8	43.4	42.7	41.7	41.8	42.5	41.4
Yield of oven-dry screenings on oven-dry digested pulp, %		4.7	0.4	0.2	5.1	1.9	0.4	8.8	2.3	0.7
Pulp evaluation										
Kappa number		40.8	27.5	22.8	38.1	29.9	24.8	42.1	33.6	25.4
Beating, revs	500	6,815	6,975	5,940	6,985	6,295	6,510	7,375	6,640	6,580
	300	9,870	9,975	8,845	10,365	9,595	9,570	11,935	10,410	10,460
Apparent density, $g\ cm^{-3}$	500	0.66	0.67	0.68	0.70	0.69	0.70	0.77	0.75	0.76
	300	0.70	0.70	0.70	0.71	0.71	0.72	0.78	0.79	0.80
Tensile index, $N\ m\ g^{-1}$	500	92.8	98.2	89.7	94.5	92.4	88.9	93.9	91.0	87.5
	300	96.3	97.8	91.9	99.5	93.7	92.0	98.6	93.6	94.1
Tensile energy absorption index, $mJ\ g^{-1}$	500	1,580	1,650	1,600	1,700	1,800	1,630	2,170	1,960	1,880
	300	1,860	1,690	1,660	1,790	1,780	1,700	2,250	1,920	2,030

Tear index, mN m^2 g^{-1}	500	13.5	13.9	13.0	11.7	12.0	11.5	10.2	9.18	9.66
	300	12.5	12.6	12.9	10.9	11.5	10.5	8.99	8.56	8.69
Burst index, kPa m^2 g^{-1}	500	6.31	6.25	5.89	6.08	6.09	5.91	6.22	6.01	5.83
	300	6.74	6.41	6.06	6.69	6.37	6.04	6.49	6.42	6.07
Folding endurance, $\log_{10}n$*	500	2.96	3.01	2.93	2.98	2.96	2.89	3.04	3.10	3.06
	300	3.01	3.02	2.96	3.04	2.99	2.96	3.15	3.12	3.08
Air resistance, s	500	6.7	6.7	7.7	7.2	6.2	7.9	16	18	20
	300	70	47	61	46	53	68	110	120	150

Note: *n = number of double folds

Table 9

Pinus oocarpa: sulphate digestion conditions, pulp yield and evaluation

	Drainability CSF	Chiwengwa						Muchakata			Mukandi		
		10 years			15 years			15 years			15 years		
Cook number		127	135	122	131	149	133	146	154	132	125	147	116
Digestion conditions													
Active alkali as Na_2O on oven-dry wood, %		16	18	20	16	18	20	16	18	20	16	18	20
Sulphidity, %		25	25	25	25	25	25	25	25	25	25	25	25
Liquor to oven-dry wood ratio		5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1
Maximum temperature, °C		170	170	170	170	170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1	1	1	1	1	1	1
Time at maximum temperature, h		4	4	4	4	4	4	4	4	4	4	4	4
Chemical consumption													
Active alkali consumed as Na_2O on oven-dry wood, %		13.4	13.3	14.2	12.8	13.9	14.2	13.0	13.2	14.1	13.2	14.0	14.3
Yield of pulp													
Yield of oven-dry digested pulp on oven-dry wood, %		45.9	44.2	42.3	46.3	43.4	41.7	47.2	43.0	41.9	45.9	43.6	41.9
Yield of oven-dry screened pulp on oven-dry wood, %		43.5	43.7	42.1	44.2	42.8	41.6	45.0	42.7	41.8	43.5	42.7	41.7
Yield of oven-dry screenings on oven-dry digested pulp, %		5.2	1.2	0.4	4.4	1.4	0.3	4.6	0.8	0.2	5.3	2.0	0.6
Pulp evaluation													
Kappa number		40.9	31.4	26.1	42.2	30.3	25.2	42.3	30.8	25.6	38.4	30.7	23.4
Beating, revs	500	6,280	6,595	6,260	7,065	6,640	6,080	7,025	6,375	6,580	6,675	6,240	5,835
	300	10,230	10,070	9,440	11,100	9,825	8,870	9,890	9,940	9,455	10,305	9,245	8,725
Apparent density, g cm^{-3}	500	0.75	0.75	0.75	0.71	0.72	0.72	0.71	0.72	0.72	0.71	0.72	0.71
	300	0.78	0.77	0.78	0.74	0.74	0.74	0.73	0.74	0.74	0.73	0.73	0.74
Tensile index, N m g^{-1}	500	105.7	98.6	100.2	95.0	96.6	91.6	93.7	94.0	87.3	93.2	92.6	90.2
	300	109.1	102.5	103.3	98.5	97.6	94.0	95.0	94.8	91.3	99.5	92.9	90.4
Tensile energy absorption index, mJ g^{-1}	500	1,980	2,020	2,090	1,860	1,880	1,670	1,880	1,860	1,610	1,800	1,850	1,720
	300	2,200	2,200	2,080	1,880	1,800	1,790	1,960	1,930	1,740	1,930	1,960	1,750

Tear index, mN m² g⁻¹	500	9.1	10.3	9.0	11.3	10.7	10.3	10.5	10.4	11.2	11.1	11.8	11.1
	300	8.5	9.8	8.7	10.6	10.4	10.0	11.2	10.7	10.3	11.0	10.7	10.8
Burst index, kPa m² g⁻¹	500	7.11	6.81	6.50	6.29	6.15	6.02	6.20	6.14	5.66	6.25	6.07	5.91
	300	7.48	6.95	6.70	6.45	6.28	6.07	6.55	6.34	5.92	6.35	6.13	6.04
Folding endurance, $\log_{10}n$*	500	3.09	3.01	3.03	2.90	2.94	2.97	3.00	3.01	2.96	3.02	2.92	3.01
	300	3.06	3.03	3.06	3.01	2.99	3.01	3.02	3.01	2.99	3.04	2.98	3.04
Air resistance, s	500	16.6	13.1	17.5	7.2	7.1	7.6	6.6	7.5	9.3	7.6	7.4	8.4
	300	156	117	150	62	59	68	57	63	82	65	58	69

Note: *n = number of double folds

Table 10

Pinus caribaea and *Pinus oocarpa:* bleaching conditions, bleached pulp yield and evaluation

	Drainability CSF	Pinus caribaea			Pinus oocarpa			
		Chiwengwa	Muchakata	Mukandi	Chiwengwa		Muchakata	Mukandi
		15 years	15 years	15 years	10 years	15 years	15 years	15 years
Cook number		113	121	151	122	133	132	116
Unbleached pulp*								
Yield of pulp on oven-dry wood, %		42.8	41.7	41.4	42.1	41.6	41.8	41.7
Kappa number		22.8	24.8	25.4	26.1	25.2	25.6	23.4
Bleaching conditions and consumptions								
1 Chlorination for 1 h at 20°C, pulp consistency, 3%								
Chlorine applied as Cl_2 on oven-dry unbleached pulp, %		6.1	6.8	7.0	7.2	6.9	7.0	6.3
Chlorine consumed as Cl_2 on oven-dry unbleached pulp, %		5.2	5.8	6.2	6.2	6.0	6.1	5.6
2 Alkaline extraction for 1 h at 60°C, pulp consistency, 6%								
NaOH on oven-dry unbleached pulp, %		3	3	3	3	3	3	3
3 Hypochlorite for 2 h at 35°C, pulp consistency, 6%								
NaOCl applied as available Cl_2 on oven-dry unbleached pulp, %		1.0	1.0	1.0	1.0	1.0	1.0	1.0
NaOCl consumed as available Cl_2 on oven-dry unbleached pulp, %		0.9	0.9	0.9	0.9	0.9	0.9	0.9
4 Chlorine dioxide for 3 h at 70°C, pulp consistency, 6%								
ClO_2 applied as Cl_2 equivalent on oven-dry unbleached pulp, %		2.6	2.6	2.6	2.6	2.6	2.6	2.6
ClO_2 consumed as Cl_2 equivalent on oven-dry unbleached pulp, %		2.3	2.3	2.3	2.4	2.3	2.3	2.3
Total chlorine applied as Cl_2 on oven-dry unbleached pulp, %		9.7	10.4	10.6	10.8	10.5	10.6	9.9
Total chlorine consumed as Cl_2 on oven-dry unbleached pulp, %		8.4	9.0	9.4	9.4	9.2	9.3	8.8
Yield of pulp								
Yield of oven-dry bleached pulp on oven-dry unbleached pulp, %		95.2	95.1	94.7	94.9	95.0	95.7	95.3
Yield of oven-dry bleached pulp on oven-dry wood, %		40.7	39.7	39.2	40.0	39.5	40.0	39.7

Pulp evaluation								
ISO brightness, unbeaten pulp, %		82.9	84.6	85.8	84.7	83.0	84.0	84.8
Specific scattering coefficient, unbeaten sheets, $cm^2\ g^{-1}$		315	335	365	365	345	355	355
Beating, revs	500	5,940	6,040	5,650	5,910	5,960	6,240	5,330
	300	8,340	9,330	9,400	9,000	8,970	9,090	7,630
Apparent density, $g\ cm^{-3}$	500	0.68	0.70	0.76	0.74	0.72	0.71	0.70
	300	0.70	0.72	0.79	0.77	0.75	0.74	0.73
Tensile index, $Nm\ g^{-1}$	500	88.3	89.7	84.4	96.8	88.1	82.6	83.9
	300	94.5	88.6	89.8	104.7	92.5	90.8	88.3
Tensile energy absorption index, $mJ\ g^{-1}$	500	1,700	1,700	1,870	1,960	1,770	1,630	1,640
	300	1,840	1,690	1,950	2,100	1,890	1,640	1,790
Tear index, $mN\ m^2\ g^{-1}$	500	12.8	11.2	10.1	9.8	11.0	10.6	11.2
	300	12.5	11.4	8.8	9.0	10.6	10.4	10.3
Burst index, $kPa\ m^2\ g^{-1}$	500	5.92	5.85	5.75	6.18	5.85	5.63	5.60
	300	6.29	6.04	6.00	6.39	6.13	5.78	5.80
Folding endurance, $\log_{10}n$†	500	2.88	2.91	2.95	3.01	2.84	2.93	2.93
	300	2.91	2.95	2.95	3.09	2.91	2.89	2.92
Air resistance, s	500	3.9	6.9	20	13.8	5.1	7.5	5.1
	300	41	55	140	110	47	47	48
Opacity, %	500	62.4	62.5	62.8	63.4	62.0	63.0	63.2
	300	61.1	61.2	60.2	61.9	60.9	62.1	61.8
Specific scattering coefficient, $cm^2\ g^{-1}$	500	170	170	175	175	170	170	180
	300	165	165	160	165	160	170	170

Notes: * References to unbleached pulp in this table are to screened unbleached pulp
† n = number of double folds

Table 11

Commercial coniferous pulpwoods: sulphate digestion conditions, pulp yield and evaluation

	Drainability CSF	Douglas fir Western Canada		Southern pines Southern USA		*Pinus sylvestris* England			*Pinus taeda* Southern Africa		*Pinus patula* Southern Africa	
Cook number		MK 46	MK 45	MK 95	MK 94	MK 83	MK 59	MK 24	MK 311	MK 312	MK 309	MK 310
Digestion conditions												
Active alkali as Na_2O on oven-dry wood, %		17.5	20.0	17.5	20.0	15.0	17.5	20.0	17.5	20.0	17.5	20.0
Sulphidity, %		25	25	25	25	25	25	25	25	25	25	25
Liquor to oven-dry wood ratio		5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1	5:1
Maximum temperature, °C		170	170	170	170	170	170	170	170	170	170	170
Time to reach maximum temperature, h		1	1	1	1	1	1	1	1	1	1	1
Time at maximum temperature, h		4	4	4	4	5	4	4	4	4	4	4
Chemical consumption												
Active alkali consumed as Na_2O on oven-dry wood, %		13.8	14.6	12.7	13.5	12.5	13.6	14.0	13.0	13.7	13.6	14.2
Yield of pulp												
Yield of oven-dry digested pulp on oven-dry wood, %		42.1	40.0	45.5	43.7	48.6	47.0	43.8	44.0	41.5	44.1	41.7
Yield of oven-dry screened pulp on oven-dry wood, %		40.5	39.5	43.7	42.9	45.3	46.4	43.8	43.5	41.5	43.7	41.6
Yield of oven-dry screenings on oven-dry digested pulp, %		3.6	1.1	4.0	1.9	6.8	1.2	0.1	1.2	0.2	0.8	0.3
Pulp evaluation												
Kappa number		32.1	27.3	37.1	29.5	48.7	39.3	26.9	30.6	24.7	35.0	27.8
Beating, revs	500	5,290	4,150	6,010	5,290	6,010	5,580	5,290	4,860	4,860	5,000	4,580
	300	8,290	7,150	9,720	9,150	9,720	8,870	8,580	8,010	8,290	8,010	7,720
Apparent density, g cm^{-3}	500	0.62	0.62	0.67	0.65	0.66	0.67	0.68	0.67	0.68	0.65	0.65
	300	0.65	0.65	0.68	0.68	0.69	0.69	0.71	0.69	0.71	0.68	0.68
Tensile index, N m g^{-1}	500	86.5	85.5	83.0	81.5	104	103	101	97.5	93.5	103	96.5
	300	94.5	91.0	94.0	86.5	111	110	107	105	100	108	103
Tear index, mN m^2 g^{-1}	500	18.3	17.5	15.4	14.9	15.1	13.7	13.6	12.3	11.9	13.3	12.6
	300	17.0	15.7	14.3	14.0	14.4	12.7	12.9	11.5	11.0	12.6	11.7

Burst index, kPa m^2 g^{-1}	500	6.05	5.75	5.65	5.55	7.25	7.15	6.70	6.75	6.15	6.85	6.25
	300	6.85	6.40	5.90	5.85	7.75	7.65	7.35	7.15	6.55	7.15	6.85
Folding endurance, $log_{10}n$*	500	3.14	3.07	2.97	2.94	3.14	3.14	3.05	3.05	3.00	3.03	3.00
	300	3.18	3.12	3.01	3.01	3.21	3.21	3.15	3.11	3.03	3.07	3.06
Air resistance, s	500	23	15	11	11	20	20	22	31	27	23	24
	300	120	100	120	110	200	140	200	220	250	220	210

Note: *n = number of double folds

Table 12

Pinus caribaea; Refiner Mechanical Pulp: McNett classification and evaluation of pulp

Site	Drainability CSF	Fibre weight fraction, %					Density g cm⁻³	Tensile index Nm g⁻¹	Tear index mN m² g⁻¹	Burst index kPa m² g⁻¹	ISO brightness %	Opacity %	Specific scattering coefficient cm² g⁻¹
		Passed aperture, µm —	595	297	149	74*							
		Retained on aperture, µm 595	297	149	74	—							
Chiwengwa	232	46.4	14.7	9.6	6.5	22.8	0.34	18.8	4.3	0.75	48.3	96	430
	167	40.0	18.0	10.2	6.4	25.8	0.34	21.8	4.3	0.86	47.1	96	430
	77	28.3	19.1	12.5	9.2	30.8	0.40	27.8	4.1	1.08	47.9	97	490
Muchakata	250	45.7	16.2	9.3	5.5	23.3	0.32	20.3	5.3	0.82	48.5	94	390
	108	35.1	19.8	9.5	7.3	28.3	0.39	27.0	4.3	1.11	47.8	96	420
	69	36.0	16.7	10.8	8.4	28.1	0.38	31.8	5.5	1.34	49.4	96	480
Mukandi	183	41.3	14.9	8.3	6.2	29.3	0.33	22.0	5.3	0.96	47.1	95	420
	157	35.4	19.7	9.6	15.4	19.9	0.37	29.3	6.3	1.35	49.1	96	480
	102	38.5	16.2	9.0	4.9	31.3	0.34	23.4	5.8	1.04	47.5	96	440
	68	32.3	18.1	10.4	5.9	33.2	0.39	32.3	5.5	1.44	49.4	97	500

Note: * By difference

Table 13

Pinus oocarpa; Refiner Mechanical Pulp: McNett classification and evaluation of pulp

Site	Age years	Drainability CSF	Fibre weight fraction, % Passed aperture, μm — Retained on aperture, μm 595	595 297	297 149	149 74	74* —	Density g cm^{-3}	Tensile index Nm g^{-1}	Tear index mN m^2 g^{-1}	Burst index kPa m^2 g^{-1}	ISO brightness %	Opacity %	Specific scattering coefficient cm^2 g^{-1}
Chiwengwa	10	84	33.5	19.8	13.6	8.2	25.0	0.36	31.1	4.5	1.31	49.0	97	470
		54	28.7	15.8	14.9	13.2	27.4	0.41	35.6	4.3	1.54	49.7	98	540
Chiwengwa	15	247	46.1	14.3	7.8	6.0	25.9	0.32	21.2	5.1	0.84	45.4	95	410
		194	38.7	19.9	8.1	6.6	26.7	0.34	24.6	5.4	1.02	46.5	97	440
		92	29.4	18.3	14.3	11.7	26.3	0.36	25.3	4.1	1.01	48.7	96	480
		58	28.6	21.6	11.4	6.8	31.6	0.41	34.1	4.7	1.45	46.8	98	510
Muchakata	15	145	32.8	21.4	14.3	5.5	26.1	0.33	23.0	5.0	0.96	46.7	97	460
		66	24.6	20.3	14.3	7.4	33.4	0.42	34.0	4.8	1.36	45.4	98	510
Mukandi	15	288	48.8	14.5	8.5	4.5	23.7	0.32	21.2	5.8	0.87	45.0	97	420
		128	32.9	20.2	10.8	5.1	31.0	0.38	26.4	5.0	1.01	45.0	97	440
		73	33.8	18.5	8.0	8.3	31.5	0.38	31.3	5.2	1.41	46.3	97	480

Note: * By difference

Table 14

Pinus caribaea; Thermal Refiner Mechanical Pulp: McNett classification and evaluation of pulp

Site	Drainability CSF	Fibre weight fraction, %					Density g cm^{-3}	Tensile index Nm g^{-1}	Tear index mN m^{2} g^{-1}	Burst index kPa m^{2} g^{-1}	ISO brightness %	Opacity %	Specific scattering coefficient cm^{2} g^{-1}
		Passed aperture, μm — / Retained on aperture, μm 595	595 / 297	297 / 149	149 / 74	74* / —							
Chiwengwa	150	40.8	18.2	7.6	7.7	25.8	0.34	23.6	5.1	0.92	43.5	97	420
	95	21.0	27.5	13.3	9.9	28.3	0.39	25.0	3.6	0.98	44.4	98	470
Muchakata	151	43.2	16.8	7.6	6.2	26.3	0.33	24.5	6.0	1.01	43.1	97	410
	92	41.2	16.5	8.2	8.7	25.5	0.36	31.3	6.2	1.42	44.2	97	440
Mukandi	156	43.7	15.3	6.4	5.9	28.8	0.33	22.8	7.4	1.04	41.8	97	420
	99	35.4	18.4	10.3	5.4	30.5	0.39	28.9	6.1	1.28	41.7	98	470

Note: * By difference

Table 15

Pinus oocarpa; Thermal Refiner Mechanical Pulp: McNett classification and evaluation of pulp

Site	Drainability CSF	Fibre weight fraction, %: Passed aperture, µm — / Retained on aperture, µm 595	595 / 297	297 / 149	149 / 74	74* / —	Density g cm^{-3}	Tensile index Nm g^{-1}	Tear index mN m^2 g^{-1}	Burst index kPa m^2 g^{-1}	ISO brightness %	Opacity %	Specific scattering coefficient cm^2 g^{-1}
Chiwengwa	204	46.5	17.1	8.1	4.3	24.0	0.30	21.5	6.1	0.89	41.2	97	380
	120	36.4	20.5	10.3	4.7	28.0	0.35	24.0	4.7	0.97	42.0	98	440
	73	22.3	24.8	16.0	5.5	31.4	0.39	28.0	3.8	1.10	43.3	98	480
Muchakata	137	45.6	15.1	6.9	6.4	25.9	0.32	24.5	6.8	1.10	40.7	98	420
	115	43.5	16.3	9.3	5.3	25.6	0.38	30.8	5.8	1.36	41.7	98	470
	85	36.3	16.9	10.3	5.7	30.8	0.39	36.4	6.2	1.61	42.2	98	450
Mukandi	180	51.7	13.4	6.6	4.6	23.8	0.29	23.1	7.8	1.04	40.7	97	390
	130	45.8	14.8	5.3	7.1	27.0	0.34	29.0	7.3	1.36	41.1	97	410

Note: * By difference

Table 16

Commercial coniferous pulpwoods: McNett classification and evaluation of mechanical pulp

Species	Pulp type	Drainability CSF	Fibre weight fraction, % Passed aperture, µm — Retained on aperture, µm 595	595 297	297 149	149 74	74* —	Density g cm^{-3}	Tensile index Nm g^{-1}	Tear index mN m^2 g^{-1}	Burst index kPa m^2 g^{-1}	ISO brightness %	Opacity %
Spruce†	Commercial refiner groundwood	101	—	—	—	—	—	0.37	31.4	8.4	1.8	60.5	95.0
Spruce‡	Commercial thermomechanical	90	39.5	—	—	—	—	—	32.0	7.9	1.9	—	—
Spruce°	Stone groundwood Newsprint grade	70–100					30–35		30–40	3.4–4.4	1.5–1.8	58–64	
Southern pine†	Commercial refiner groundwood	100	—	—	—	—	—	0.32	25.4	7.2	0.8	50.0	95.5
Southern pine**	Commercial thermomechanical	100	41	16	9	7	27	0.33	32.4	7.3	1.8	56.0	94.0
Southern pine°	Stone groundwood Newsprint grade	45–65					40–45		18–24	2.7–3.4	0.8–1.2	55–60	
Pinus radiata°°	RMP	100	31.5–36				31.5–33.5	0.36	38.0–38.5	8.9–10.2	2.7	60.5–62.5	95.6
Pinus radiata°°	TRMP	100	37.0–40.5				31.5–33.5	0.38	42.0	10.0–11.5	3.0–3.2	57.5–59.5	95.9–96.2

Notes: * By difference
† Britt (1970)
‡ Skinnar and Lindroos (1982)
** Casey (1980)
° Carpenter (1985)
°° Experimental pulps made using commercial sized pilot plant (Carson and Lloyd, 1982)

Appendix

EXPERIMENTAL METHODS

Bark Content

The volumetric value was calculated from the over-bark and under-bark girths of a log.

$$\text{Bark content} = \frac{g_o^2 - g_u^2}{g_o^2}$$

where: g_o = over-bark girth
g_u = under-bark girth

Apparent Wood Density

One disc, approximately 20 mm thick, from each sampling point was used. The green volume was determined by weighing the disc, which had been soaked in water until it was saturated, suspended in water. It was then dried at 105±3°C to constant weight to obtain its oven-dry weight.

Fibre Dimensions

By microscopy. Fibre measurements were made on re-dispersions of pieces of standard sheets made from unbeaten sulphate pulp and they are thus representative of a composite sample. The fibres were mounted in aqueous medium and the length, width and wall thickness of 400 fibres were measured. The lengths of all fibre elements, both whole and broken, the widths of the partially collapsed fibres, and the wall thickness were determined by measurements of the projected image. The magnification was ×45 for length and ×800 for width and wall thickness. Because pulping and processing during sheet making causes the fibres to collapse, the widths are typical of the pulp only. Fibre wall thickness as measured may also differ from that observed on a cross-section of wood.

By classification. The fibre length by classification was determined using a McNett classifier and weighing, after oven drying at 105±3°C, the fibres retained on each screen. In previous work the average length of the fibres on each screen had been determined by measurement of the projected image as above. These values, given in Table A, were used to calculate the weighted average fibre length in the sample.

Table A

Relationship between aperture and fibre length for McNett classifier

Passed aperture, μm	—	1,680	1,190	841*	595	420	210	74
Retained on aperture, μm	1,680	1,190	841	595	420	210	74	—
Assigned length softwoods, mm	3.8	3.2	2.5	2.1	1.7	1.2	0.65	0.3
Assigned length hardwoods, mm	—	—	—	1.15	1.0	0.68	0.68	0.3

Note: *Not used for hardwoods

Chemical Analysis

A portion of the chips prepared for pulping was ground in a knife mill. Chemical analyses were made on groundwood which passed a 425 μm aperture sieve. For some analyses where the presence of fine material interferes with analysis, the groundwood was further sieved and the fines passing a 250 μm aperture sieve discarded. For some analyses an extractive-free sample of groundwood was prepared by successive treatment with ethanol-benzene, ethanol and hot water as described in TAPPI Standard T12. Some or all of the analyses using the standards or methods indicated in Table B were undertaken.

Table B

Standards used in chemical analysis

Analysis	TAPPI Standard or method used	With or without fines	Extractive free
Hot and cold water solubles	T207	Without	No
1% Sodium hydroxide solubles	T212	With	No
Ethanol-benzene solubles	T204	Without	No
Total solubles*	T12	Without	No
Ash	T211	With	No
Silica (acid insoluble ash)	T244	With	No
Acid insoluble lignin	T222	With	Yes
Pentosans	T223	Without	Yes
Holo-cellulose	Wise *et al.* (1946)	Without	Yes
Alpha-cellulose	T203†	Without	Yes‡

Notes: * Soluble material obtained on extraction with successive ethanol-benzene, ethanol and hot water
†Modified for gravimetric determination
‡Uses material obtained in holo-cellulose determination

Pulping Methods

The sample used for pulping was prepared by taking the same number of approximately 20 mm thick discs from all logs representing the sample. The discs were split along the grain with a mechanical guillotine to give a chip size of approximately 20×20×6 mm. This damages the fibres less than commercial chipping. If necessary the chips were air dried until the moisture content was less than 12% and then mixed to give a representative sample. In the kraft (sulphate) process the active chemicals are sodium hydroxide and sodium sulphide. The active alkali and sulphidity are defined as:

$$\text{Active alkali} = NaOH + Na_2S \text{ expressed as } Na_2O$$

$$\text{Sulphidity} = \frac{Na_2S \times 100}{NaOH + Na_2S} \text{ all expressed as } Na_2O$$

The quantities of chemicals required for digestions at different percentages of active alkali on oven-dry wood, were calculated from the above relationships. A sulphidity of 25% was used in all digestions. Experience in ODNRI and published work show there to be generally little variation in pulp quality with changes in sulphidity between 20 and 30%. Digestions were made in a stainless steel pressure vessel with forced circulation and an electric heat exchanger. The cooked chips were washed free of superficial black liquor and broken up in a propeller type disintegrator to simulate the disintegration occurring during blowing in a commercial digester; the pulp was screened using a plate with 0.15 mm wide slits to remove shive and collected on a 106 μm aperture sieve.

The screened pulp was dried in a stream of air to about 10% moisture. The total weight of air-dry screened pulp and the moisture content of an aliquot were determined for calculating the yield of oven-dry pulp. The shive was also collected, dried and weighed. The chemical consumption was determined by titrating with standard hydrochloric acid (i) an ashed aliquot of the black liquor to determine total alkali; and (ii) an aliquot of the black liquor from which the reaction products of digestion had been removed by precipitation with barium chloride to determine the residual active alkali.

Refiner Mechanical (RMP) and Thermal Refiner Mechanical (TRMP) pulps were both produced using a Sprout Waldam 12 inch laboratory refiner with a 60 horse power electric motor and using plate pattern D2A 505. To produce RMP the chips were purged of air by application of a vacuum and impregnated with water to give a moisture content of approximately 40%. These chips were passed through the refiner at a plate clearance of 0.75 mm with a flow of hot water (about 80°C) sufficient to make the pulp consistency between the plates approximately 4%. This coarse fibre was then given a second pass with the plate clearance varied between 0.25 mm and 0.05 mm to yield a series of pulps with different degrees of drainability. The pulp consistency between the plates was approximately 4%.

TRMP pulp was produced by placing chips in a batch digester, raising the temperature to 135°C and maintaining this temperature for 15 minutes. The chips were then refined, without cooling, with the clearance between the plates of 0.75 mm and at a feed rate which resulted in a pulp consistency of approximately 10% between the plates. The second pass was made in the same way as for RMP.

Unbleached Pulp Evaluation

Experience at ODNRI has shown that air-dried pulp can be stored for long periods with little change in strength characteristics. These were lower, however, than the values for a similar unbeaten slush pulp but little difference was found between the values for the two pulps when beaten. The kappa number, a measure of residual lignin in the pulp, was determined by TAPPI method T236. Physical characteristics of the pulp were determined by preparing sheets with an oven-dry grammage of 60 g m^{-2} and testing, after conditioning, according to current ISO and British Standards (see Table C).

The following non-standard tests were also carried out:

Drainage time. This was determined on the standard sheet machine during normal sheetmaking operations. It is the time in seconds for water at 20°C to flow from the pulp suspension through the wire from a height 350 mm above the wire until the formed sheet is no longer immersed.

Stretch (at rupture) and tensile energy absorption index. Determined on the same test pieces and at the same time as tensile index using a semi-automatic horizontal instrument with a constant rate of elongation.

Bleaching and Bleached Pulp Evaluation

Bleaching trials were made by a four-stage method involving successive applications of chlorine, sodium hydroxide, sodium hypochlorite and chlorine dioxide (CEHD). This is the simplest sequence currently used to obtain a fully bleached sulphate pulp. The quantity of chlorine added was estimated from the kappa number using data, previously obtained, on the relationship between kappa number and chlorine demand. The bleached pulp evaluation was carried out as described under Unbleached Pulp Evaluation, with the following additional tests:

Specific scattering coefficient. Calculated according to the method of Giertz (1950).

Table C

Standards used in the preparation and evaluation of pulp

	ISO Standard	British Standard	Option or variation
Sheet forming	5269		A British Standard sheet machine modified for semi-automatic operation was used to prepare 60 g m^{-2} sheets on oven-dry basis
Conditioning	187	3431	Temperature 23.0±1.0°C; Relative humidity 50±2%
Testing	5220	6095	
Beating	5264/2	6094: Part 2	Pulp weight 30.0 g (oven-dry basis). Pre-beating disintegration 30,000 rev. Post-beating disintegration 3,000 rev. Differential peripheral speed 2 m s^{-1}
Drainability	5267/2		
Grammage	536	3432	Determined on oven-dry basis
Thickness and apparent density	438	3983: Part 1	Face pressure 100 kPa. Measurement positions located as in *TAPPI*, 1970, **53**, 2325
Tensile index	1924	4415	Test length 90 mm; test width 15 mm
Tear index	1974	4468	A single tear instrument was used
Burst index	2758	3137	A pneumatic instrument was used
Folding endurance	5626	4419	A Kohler-Molin instrument was used
Air resistance	3687	5926	
ISO brightness	2469	4432: Part 1	
	2470	4432: Part 2	
For bleached pulps only			
ISO brightness	2469	4432: Part 1	
	3688	4332: Part 4	
Opacity	2469	4432: Part 1	
		4432: Part 3	

ISO brightness of unbeaten pulp. Special sheets are made as prescribed in BS4432: Part 4. The brightness of these sheets is determined within 4 hours of their making. It should be noted that in tables for bleached pulp giving values for ISO brightness for a range of beating points, there is given a beating point of 0 rev. Although this is for unbeaten pulp, it is a value for a normal 60 g m^{-2} grammage sheet. It should not be confused with the test given for ISO brightness of unbeaten pulp and titled as such in tables for bleaching conditions and bleached pulps evaluation.

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