WINDBREAK-GROWN *CASUARINA* AND *EUCALYPTUS* TREES FOR UNBLEACHED KRAFT PULP[1]

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ABSTRACT

A laboratory-scale evaluation was conducted of juvenile windbreak-grown *Casuarina* and *Eucalyptus* trees for kraft pulp production. Test results of unscreened pulp yields, pulp chemical analyses, and handsheet physical properties indicated that windbreak-grown materials are suitable for unbleached kraft pulp. *Casuarina* gave the best pulp yield and had higher tear strength than *Eucalyptus*, but both species were superior to kraft pulps from agricultural raw materials such as rice straw and *Thymelia*, which are currently used in Egypt. For both species, the best kraft pulping schedule tested was a 4:1 liquor-to-wood ratio with 20% active alkali with additional conditions constant. Scanning electron micrographs of handsheets helped explain the observed differences in physical properties between the two species. Mixing of *Casuarina* and *Eucalyptus* raw material prior to pulping shows promise for unbleached kraft pulp production.

Keywords: Pulp properties, unbleached pulp, juvenile wood, handsheets, scanning electron microscopy, fiber morphology.

A fiber shortage in Egypt has forced that nation's economy to depend almost totally on imported wood and fiber products. During the last two decades many new windbreaks, shelterbelts, and small woodlots have been planted with rapidly growing hardwoods to aid in the growth of agricultural crops. If windbreak-grown trees could be used for pulp production, windbreaks and shelterbelts would have added economic value.

Recent demands by pulp mills for locally grown woody raw material have created a serious need for more information on pulping characteristics of the locally available species. This information is also needed for tree improvement programs of such species as *Casuarina* and *Eucalyptus* for planting in woodlots, windbreaks, and shelterbelts.

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Preliminary studies on the pulping of Egyptian windbreak-grown *Eucalyptus* trees have indicated that they are suitable for pulp production. For example, properties of unbleached handsheets from these *Eucalyptus* pulps were superior to that of handsheets from bagasse and rice straw, which are currently the main raw material source for writing and printing papers in Egypt (Aly 1976; Ahmed et al. 1978; Kandeel et al. 1978).

The purpose of the present study was to evaluate the potential of windbreak-grown *Casuarina* and *Eucalyptus* trees as a raw material source for unbleached kraft pulp.

The specific objectives of the study were to:

a. evaluate a range of kraft pulping conditions for juvenile *Casuarina glauca* and *Eucalyptus camaldulensis* trees grown in windbreaks;
b. determine the pulp yields, pulp chemical properties, and physical properties of handsheets of both species using TAPPI standard methods and scanning electron microscopy (SEM).

MATERIALS AND METHODS

Four sample trees of 15-year-old *Casuarina glauca* and of 4-year-old *Eucalyptus camaldulensis* were selected from windbreak plantations at the Faculty of Agriculture Experiment Station at Abis, Egypt. The *Casuarina* trees averaged 16 m in height and 20 cm dbh, and the *Eucalyptus* were 9 m tall and 12 cm dbh. After debarking, the whole trees (aboveground) were sawn into 30 × 3 × 3 mm nominal dimensions in preparation for pulping.

Pulping

Prior to pulping, the *Eucalyptus* chips were extracted with hot water for 4 h at 80 C (Bowman and Nelson 1965; Kherallah 1975), because of their high extractive content (Nelson et al. 1970); the *Casuarina* chips were not pre-extracted.

Chips (MC % = 9–15) were pulped in a laboratory-scale autoclave digestor by a conventional kraft process as in previous investigations (Aly 1976; Kandeel et al. 1978). Five different pulping schedules were studied for each species (Tables 1 and 2); each one varied according to the liquor-to-wood ratio and active alkali percent ($NaOH + Na_2S$ expressed as Na_2O), but the time to cooking temperature (90 min) and time at maximum temperature (120 min at 165 C) were held constant for each cook. Five replications of each species were pulped separately by each of the schedules. Five mixed batches in a 1:1 proportion of *Casuarina* and *Eucalyptus* were also pulped with a 4:1 liquor : wood ratio, and 20% active alkali at the above time and temperature.

After pulping, the pulp slurries were washed and standard pulp determinations were made for unscreened yield, alpha-cellulose content, hemicellulose content, permanganate number, and ash content (TAPPI 1950; 1958).

Pulp and paper testing

Wet pulps were gently disintegrated, filtered, and readjusted to 6% consistency. Pulps from all cooks were then beaten for 20 min in a Jokro mill[2] at 150 rpm.

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[2] Mention of trade names does constitute an endorsement of the products by the USDA, Forest Service.

TABLE 1. *Kraft pulping conditions and yields, pulp chemical analysis, and physical properties of unbleached handsheets of 15-yr-old windbreak-grown* Casuarina glauca *trees.*

	Pulp conditions			Pulp chemical analysis				Handsheet properties[e]		
Cook[a] code	Liquor : wood ratio	Active[b] alkali % (NaOH + Na_2S)	Unbleached[c] pulp yield %	Lignin[d] %	Alpha-cellulose[d] %	Hemi-cellulose[d] %	Ash[d] %	Tensile breaking length (km)	Burst[f] factor	Tear[g] factor
1	2:1	20.0	49	6	83	11	<1	7.9	55	100
2	4:1	15.0	55	17	73	8	1	7.4	46	97
3	4:1	17.5	54	14	80	9	<1	8.9	56	94
4	4:1	20.0	56	12	79	7	2	8.9	58	100
5	6:1	20.0	53	8	80	10	2	7.4	53	90

[a] Cooking time—90 min to max. temp. (165 C) and 120 min at max. temp. Each value is average of five separate cooks. Coefficient of variation = 7–11%.

[b] Based on oven-dry (OD) weight of chips and 30% sulfidity. Expressed as Na_2O.

[c] (OD pulp/OD wood) × 100.

[d] Based on OD pulp weight.

[e] Beating time = 20 min in Jokro mill at 150 rpm.

[f] Multiply by 0.098 to obtain burst index. SI units = $kPa \cdot m^2 g^{-1}$.

[g] Multiply by 0.098 to obtain tear index. SI units = $mN \cdot m^2 g^{-1}$.

Beaten pulp samples were disintegrated again and placed in a plate mixer until a Schopper Riegler Freeness (S.R.F.) of ca. 500 ml was reached.

Standard handsheets (ca. 60 $g \cdot m^{-2}$) were made for each cook. After conditioning, the unbleached handsheets were tested for tensile, tear, and burst strength in accordance with standard methods used by the Institute of Paper Chemistry (Institute of Paper Chemistry 1951). All paper testing was carried out in the National Paper Company Laboratories in Alexandria, Egypt.

Scanning electron microscopy (SEM)

The SEM investigation of the handsheets was done at the Forestry Sciences Laboratory, USDA Forest Service, Rhinelander, Wisconsin, USA, with the ISI-60 SEM. Samples (1 cm^2) were selected from the central portion of a handsheet from the "best" cooking schedule of each species. For surface viewing the handsheet sample was mounted on the stub with the dull side up. For edge or cross-sectional viewing, the handsheet sample was cut to ca. 5 × 8 mm and then submerged in liquid N_2 for 1 min. The sample was cut on a liquid N_2-cooled brass plate with a new scalpel blade, and mounted with edge view toward the beam between two graphite rods. After mounting, all samples were coated with ca. 25 nm of gold for viewing at 10 kV.

RESULTS AND DISCUSSION

Pulp yields and chemistry

Casuarina.—Unscreened pulp yields for the 15-yr-old *Casuarina* raw material ranged from 49 to 56% for the five cooking schedules studied (Table 1). The highest yield of the schedules was 56% with a 4:1 liquor : wood ratio at 20% active alkali (AA). Similar unbleached pulp yields for *Casuarina* were reported by Maheswari et al. (1979). Both the higher and lower liquor : wood ratios gave lower pulp yields. Changing the AA from 15 to 20% at the 4:1 liquor : wood ratio decreased the lignin percent of the pulp, but the resultant pulp yields were not

TABLE 2. *Kraft pulping conditions and yields, pulp chemical analysis, and physical properties of unbleached handsheets of 4-yr-old windbreak-grown* Eucalyptus camaldulensis *trees.*

	Pulp conditions			Pulp chemical analysis				Handsheet properties[e]		
Cook[a] code	Liquor : wood ratio	Active[b] alkali % (NaOH + Na_2S)	Unbleached[c] pulp yield %	Lignin[d] %	Alpha-cellulose[d] %	Hemi-cellulose[d] %	Ash[d] %	Tensile breaking length (km)	Burst[f] factor	Tear[g] factor
1	2:1	19.9	49	4	78	15	1	7.8	65	74
2	4:1	14.5	48	6	80	14	<1	8.0	69	82
3	4:1	19.0	49	5	81	14	<1	8.9	64	72
4	4:1	20.0	49	4	81	14	<1	9.0	69	80
5	6:1	18.0	49	5	78	15	1	7.7	64	72

[a] Cooking time—90 min to max. temp. (165 C) and 120 min at max. temp. Each value is an average of five separate cooks.
[b] Based on oven-dry (OD) weight of chips and 30% sulfidity. Expressed as Na_2O.
[c] (OD pulp/OD wood) × 100.
[d] Based on OD pulp weight.
[e] Beating time = 20 min in Jokro mill at 150 rpm.
[f] Multiply by 0.098 to obtain burst index. SI units = $kPa \cdot m^2g^{-1}$.
[g] Multiply by 0.098 to obtain tear index. SI units = $mN \cdot m^2g^{-1}$.

significantly different. At the 4:1 liquor : wood ratio, alpha-cellulose percent increased with AA up to 17.5%, and then stayed the same.

Eucalyptus.—Unscreened pulp yields of the 4-yr-old *Eucalyptus* had a narrow range (48–49%) for our five cooking schedules (Table 2) and compare favorably with the most common cooking conditions used in other countries (FAO 1975; Maheswari et al. 1979; Foelkel and Zvinakevicius 1980). A liquor : wood ratio of 4:1 at 14.5, 19.0, and 20.0% AA gave similar alpha-cellulose contents. However, the 14.5% AA level unexplainably had a higher lignin percent than the other schedules. Apparently, once a critical AA is reached, changes in AA are more important than changes in liquor : wood ratio in processing of juvenile *Eucalyptus* wood (MacDonald and Franklin 1969).

Comparisons.—For all cooking schedules, the *Casuarina* pulps were higher in lignin and lower in hemicellulose than the *Eucalyptus*. Alpha-cellulose contents were similar for both species, but pulp yields were higher for *Casuarina* than for the *Eucalyptus* in this study. This result indicates that the differences in species could be age-related specific gravity differences because the *Casuarina* was 11 years older; however, Kandeel et al. (1978) found similar pulp yields for 12-yr-old windbreak-grown *Eucalyptus* as we did for 4-yr-old trees (Table 3). This observation suggests to us that the higher pulp yields of the *Casuarina* may be attributed to the higher inherent specific gravity of that species.

As expected, the yield of the mixed pulp was intermediate (54%) to the two single-species pulps. We believe raw material mixing of windbreak-grown species shows promise. It should also be noted that the *Casuarina, Eucalyptus,* and mixed tree species pulp all had higher pulp yields than rice straw, which is currently one of Egypt's main raw material sources for pulp (Table 3).

Handsheet properties

Casuarina.—Pulping conditions of the five schedules studied also affected the resultant handsheet physical properties such as tensile-breaking length, burst factor, and tear factor (Table 1). Handsheet properties for the 2:1 and 6:1

TABLE 3. *Comparison of the physical properties of unbleached handsheets from* Casuarina, Eucalyptus, *and agricultural material kraft pulps.*

Handsheet property	*Eucalyptus* (Eu) Pulp[a]	*Eucalyptus* (Eu) Pulp[c]	*Casuarina* (Ca)[c] pulp	Mixed[c] pulp (Eu + Ca)	Rice[b] straw	*Thymelia*[b] *hirsuta*
Tensile breaking length (km)	9.9	9.0	8.9	9.0	6.3	6.4
Burst factor[d]	76	69	58	60	42	45
Tear factor[e]	110	80	100	76	47	48
Yield %	48	49	56	54	45	—

[a] From Kandeel et al. 1978 (12-yr-old trees).

[b] From Abou-Salem (1966) and El-Tarboulsi and Abou-Salem (1967).

[c] Current investigation—liquor : wood ratio = 4:1, active alkali = 20%.

[d] Multiply by 0.098 to obtain burst index. SI units = $kPa \cdot m^2 \cdot g^{-1}$.

[e] Multiply by 0.098 to obtain tear index. SI units = $mN \cdot m^2 \cdot g^{-1}$.

liquor : wood ratios as well as the 4:1 liquor : wood ratio at 15 AA were significantly different than for the other two 4:1 cooks. For example, tensile-breaking lengths were marginal to low from a commercial viewpoint for all cooks except the 4:1 liquor : wood ratio at 17.5 and 20 AA. The 4:1 liquor : wood ratio at 15% AA had lower handsheet properties than all the other cooks. This outcome is probably due to the higher lignin content and lower alpha and hemicellulose contents of that pulp (Table 1). Therefore, our results indicate that pulping *Casuarina* at 4:1 liquor : wood ratio at 20% AA gives acceptable handsheet properties. This conclusion is similar to that reported by Guha et al. (1970) for *Casuarina equisetifolia*. In general, the 6:1 liquor : wood ratio cook had the lowest overall strength values for all the handsheet physical properties studied.

Eucalyptus.—Changing the pulping conditions also affected the handsheet properties in *Eucalyptus*. As found in the *Casuarina* pulps, the 2:1 and 6:1 liquor : wood ratios in all cases had lower handsheet properties than the 4:1 liquor : wood ratio. For example, the tensile-breaking lengths of the 2:1 and 6:1 were 7.8 and 7.7 km, respectively; both of these values are marginally acceptable for most paper products. All cooks had burst factors similar to other pulping studies (FAO 1975) and appear to be suitable for commercial use. On the other hand, all cooks had tear factors that were marginally low in terms of suitability for commercial use. The best pulping schedule with respect to all handsheet properties was the 4:1 liquor : wood ratio at 20% AA just as with the *Casuarina*. However, this active alkali percent is higher than the percentages often used for juvenile hardwoods (Barker 1974), and from an economic standpoint may be higher than practical (MacDonald and Franklin 1969).

Comparisons.—In general, the *Casuarina* pulps produced handsheets with higher strength properties than the *Eucalyptus* (Tables 1, 2, and 3). These results are in contrast to those of Maheswari et al. (1979), although the absolute values of our strength properties are much higher than theirs. Moreover, handsheets from mixed pulps had intermediate strength values between the single species handsheets, except for tear factor. It should be noted that all wood pulps in this study produced handsheets with strength properties superior to agricultural raw material such as rice straw and *Thymelia* (Abou-Salem 1966; El-Tarboulsi and Abou-Salem 1967). In addition, they were similar to strength properties of handsheets from other juvenile hardwoods (Barker 1974; Parham et al. 1977). Although the *Casuarina* and *Eucalyptus* handsheets had similar breaking lengths, *Casuarina* was notably higher in tear strength and lower in burst strength than the *Eucalyptus*. Tear strength is a particularly important paper property used to evaluate the pulping potential of juvenile hardwood species. Tear strength in hardwoods is closely related to fiber lengths and interfiber bonding (Britt 1970). Unfortunately, juvenile hardwoods characteristically have short fiber lengths that directly affect their tear strength. However, note that tear strength of handsheets made from older *Eucalyptus* trees by Kandeel et al. (1978) was much higher than those from this study (Table 3), presumably because of the longer fiber length and thicker cell walls of the 12-yr-old *Eucalyptus* trees (Tewfick 1975). But the *Eucalyptus* did have a slightly higher burst strength than the *Casuarina*. This difference is probably due to the higher individual fiber strength of *Eucalyptus*.

Clearly, handsheets from 4-yr-old *Eucalyptus* had inferior overall strength properties when compared to the 15-yr-old *Casuarina* trees in this study, and to the 12-yr-old *Eucalyptus* reported by Kandeel et al. (1978). Possibly these differences are related to the pre-extraction of *Eucalyptus* wood was well as age and species differences.

Our results suggest that mixing of the woody raw materials should be considered where possible to take advantage of some of the best attributes of both species. We also believe that the possibility of mixing woody raw material and agricultural materials should be explored.

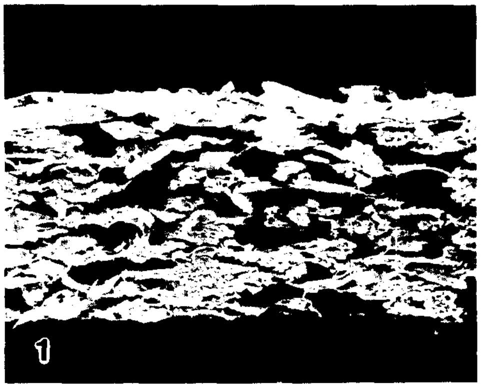
Scanning electron microscopy

The SEM examination of the handsheet cross sections and surfaces revealed morphological differences between the two species that are useful in explaining some of the observed physical properties of the handsheets. Cross-sectional and surface views of the *Casuarina* handsheets showed a thick and porous sheet made up of stiff and nonfibrillated fibers (Figs. 1 and 2). These fibers also appeared to be long and narrow (Fig. 2).

By comparison, the cross sections of the *Eucalyptus* handsheets at the same magnification as the *Casuarina* showed that the *Eucalyptus* sheets were more compact with a thinner caliper (Fig. 3). Surface views showed flatter and more ribbonlike fibers than the *Casuarina* handsheets. (Fig. 4).

Further comparisons revealed other differences between the species. For example, the *Casuarina* handsheet surface views showed numerous vessel aggregates (Figs. 5 and 6) that no doubt contributed to the large void spaces seen in cross sections in Fig. 1. These aggregates no doubt increase bulk and decrease interfiber bonding within the handsheet. Also *Casuarina glauca* is characterized by large vessels with angular rows of intervessel pits (Fig. 6) and by chambered rhomboid-shaped crystals in the rays (Fig. 7) (Metcalfe and Chalk 1950; El-Osta et al. 1981); both can influence final handsheet properties by decreasing interfiber bonding. The large vessels may also tend to "pick" from paper surfaces. We also observed numerous dirt and grit deposits in the *Casuarina* handsheets (Fig. 8). However, dirt and grit will probably always be present in windbreak-grown raw material.

To some extent the pre-extraction employed in this experiment may have influenced the observed handsheet morphology. For example, pre-extraction of the



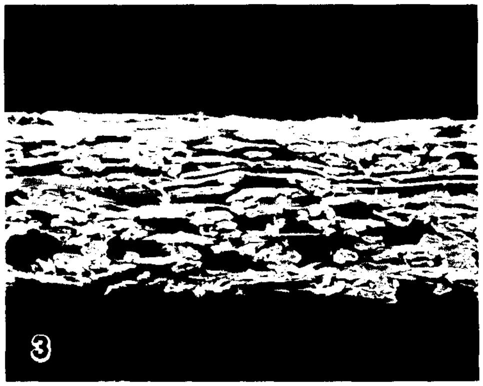


FIG. 1. Cross-sectional view of unbleached *Casuarina* handsheet. Beating time = 20 min. Note the thick and porous sheet. SEM (320×).

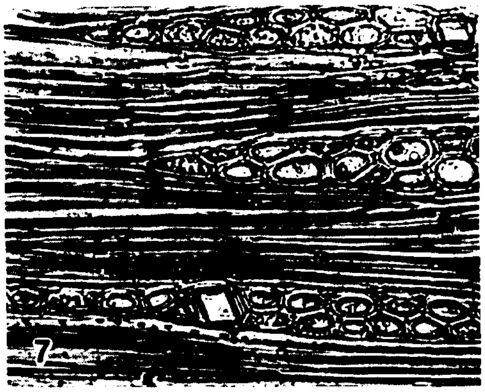
FIG. 2. Surface view of unbleached *Casuarina* handsheet in Fig. 1. Note stiffness and lack of collapse of the long and narrow fibers. SEM (100×).

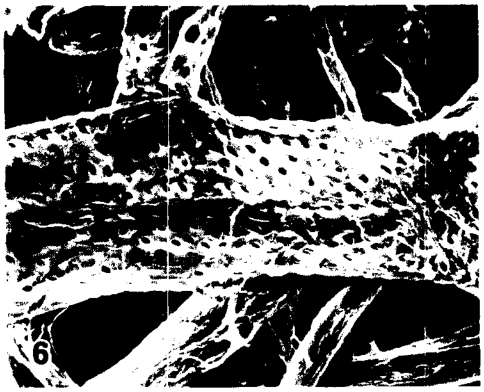
FIG. 3. Cross-sectional view of unbleached *Eucalyptus* handsheet. Beating time = 20 min. Note compactness and thin caliper of the sheet when compared to Fig. 1. SEM (320×).

FIG. 4. Surface view of unbleached *Eucalyptus* handsheet showing fiber collapse and fibrillation. SEM (100×).

Eucalyptus raw material no doubt removed some hemicelluloses and possibly some dirt and grit as well. Moreover, extraction may have resulted in more fibrillation and a more compact sheet.

The collapse and fibrillation of fibers evident in the *Eucalyptus* handsheets appear to be related to their physical properties (Figs. 3 and 4). For example, the acceptable burst factor and tensile-breaking length are probably related to the favorable degree of interfiber bonding between fibers (Table 2). On the other hand, the lack of sufficient fiber length and the presence of thin cell walls no doubt resulted in the marginal to low tear strength values (Britt 1970). Likewise, the morphology of the *Casuarina* handsheets also appears to be related to these physical properties. For example, the long fiber length and thick cell walls probably explain *Casuarina*'s above average tear strength and acceptable breaking length (Table 1). However, the lack of fibrillation and collapse was probably





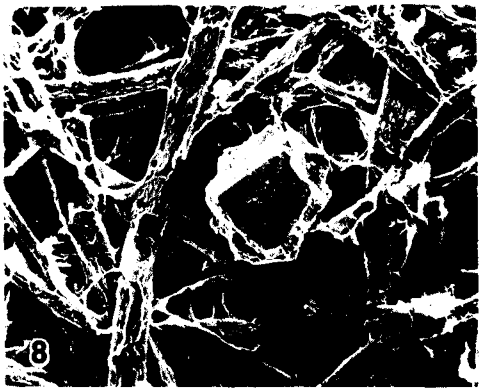


FIG. 5. Large vessel aggregates as seen on surface view of *Casuarina* handsheet. SEM (330×).

FIG. 6. Intervessel pitting on *Casuarina* handsheet surface. SEM (825×).

FIG. 7. Light photomicrograph of rhomboid-shaped chambered crystal in a ray of *Casuarina glauca* wood. Light microscopy. (200×).

FIG. 8. Surface view of grit deposit in unbleached *Casuarina* handsheet. SEM (470×).

responsible for the low burst strength observed. This result is no doubt largely due to the low level of interfiber bonding.

SUMMARY AND CONCLUSIONS

1. Results of laboratory experiments on unscreened pulp yield, pulp chemical analysis, and handsheet properties of windbreak-grown *Casuarina* and *Eucalyptus* trees suggest that these raw materials are suitable for production of unbleached kraft pulp.
2. Windbreak-grown *Casuarina* and *Eucalyptus* trees appear to be a superior raw material for use in kraft pulping when compared to agricultural raw materials currently being used in Egypt such as rice straw and *Thymelia*.
3. The best kraft pulping schedule studied from a pulp and paper quality standpoint for the windbreak-grown species appears to be a 4:1 liquor-to-wood ratio with a 20% active alkali concentration.
4. Mixing of *Casuarina* and *Eucalyptus* raw materials before pulping shows promise as a furnish for unbleached kraft pulp. The possibility of mixing

windbreak-grown woody raw materials with the agricultural materials should also be explored.

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