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Full Length Research Paper

Effect of differential irrigation on physical and histochemical properties of kenaf (*Hibiscus cannabinus* L.) grown in the field in Eastern Nigeria

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The effect of moisture stress on the physical and histochemical properties of three certified improved varieties of Kenaf (*Hibiscus cannabinus* L.) relevant to pulp and paper production were investigated. The test plants were grown in the field on a deep sandy-loam soil in the Botanical Garden of Abia State University, Uturu. Three watering regimes representing well-watered control, moderate stress and severe water stress were imposed on the plants. Each irrigation regime was replicated three times in a split plot design with watering treatments as the main plots and the varieties as the sub-plots. Water deficit did not adversely affect the fibre dimensional properties as well as the fibre derived values. Analysis of histochemical properties of Kenaf indicated that water deficit enhanced these properties in the stressed plants when compared with well-watered plants. Thus suggesting that water stress enhances the quality of pulp and paper produced from Kenaf.

Key words: *Hibiscus cannabinus*, kenaf, histochemical, pulp, paper, water deficit.

INTRODUCTION

Kenaf a member of Malvaceae family is an annual crop plant with the potential to supply fibre for the production of paper pulp used for paper production (Clark et al., 1962; Muchow, 1981). As a non-woody plant, its stem contains two distinct fibre types- the bast or the outer bark fibres (comparable to softwood fibres), and the inner core of short woody fibres (comparable to hardwood fibres), both of them may be utilized in pulp production (Francois et al., 1992).

The use of Kenaf to source the paper industry makes ecological sense by preventing desert encroachment through forest conservation, while the use of wood-based fibres degrades the natural forests, destroys wildlife habitats and pollutes the environment. Plantations of *Gmelina*, Pines and Eucalyptus established are unable to satisfy the demands of the existing mills. In addition, the rotation period of some of these pulpwood trees are as many as 8 years. Reliance of paper mills on imported pulp has resulted in a shortfall in paper supply in the country (Idem and Adeoti, 1988).

The paper manufactured from Kenaf pulp has excellent ink-retention characteristics and its high tensile strength is ideal for high- speed presses (Robinson, 1988). Kenaf papers are also as sturdy as wood-pulp paper but are generally brighter, require less ink and have less ink rub-off (Sellers et al., 1993). The smaller amount of lignin and comparable amount of cellulose in Kenaf are also advantageous because of the need for fewer chemicals to remove the lignin and to release the fibres during pulping process.

Kenaf production has been commercialized to source paper and pulp industries in USA, Europe, India and Australia. Also Kenaf paper mills have been established in most countries of the world including America while others are still in planning.

Although water deficit is known to retard every aspect of plant growth including yield (Hsaio, 1973; Enukwesi et al., 1986), water stress is not always injurious, because it has been reported to improve the quality of plant products sometimes (Kramer, 1983).

Ogbonnaya et al. (1992; 1997) studied the effect of water stress on *Gmelina arborea* and on Kenaf (*Hibiscus cannabinus*) and found that although water deficit reduced the volume of wood produced, the quality of pulp and paper produced were not significantly affected. Due to

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scanty information on effect of drought on Kenaf grown in the field, this study was carried out to determine the effect as well as level of water deficit that will enhance the quality of pulp without adversely affecting yield.

MATERIALS AND METHODS

Seed collection

Certified seeds of Kenaf (*H. cannabinus L.)* were collected from the Agricultural Research Service of the United States of America Department of Agriculture (ARS-USDA). Three cultivars namely: Tainung #2, SF 459 and Everglades 41 were used for the study. These varieties were chosen on the basis of their high yield in terms of bast-core ratio, and disease resistance.

Study area and cultural conditions

This experiment was conducted at the Abia State University, Uturu Botanical Garden (Latitude 7^{o} 6 North and Longitude 6^{o} 0 East) on a deep sandy loam soil. The characteristics of the soil were analysed using the method of Page et al. (1982).

The field was cleared of bush, ploughed and made beds of 4 x 4 m. 5 kenaf seeds per hole were planted at a soil depth of 3 cm in a spacing distance of 20 cm between plants and 50 cm between rows to give a total of 160 plants / plot (equivalent to 100,000 plants / ha). The seeds germinated within 2 - 4 days after planting given a germination rate of 90% for Tainung #2, 50% for SF 459 and 30% for Everglades 41. The resulting seedlings were later thinned down at two-leaf stage to one plant per stand, to obtain plants with uniform growth vigour and density.

In order to ensure optimum crop yield, all plots received 320 g of NPK fertilizer (12: 12: 17) equivalent to 200 kg / ha aimed at removing nutrient deficiency as a limiting factor. Plots were kept weed free by hand hoeing. The test plants were checked of insect pests by application of dimethylcyclopropanecarboxylate insecticide (decis EC 12) following instruction on the label. The experiment lasted for a period of five months.

Irrigation treatment application

The experimental field was uniformly irrigated to field capacity by watering and allowed to drain before seeding. The seedlings were subjected to uniform irrigation at weekly intervals from sowing to 21 days after sowing. This was to ensure uniform seedling establishment before the imposition of the treatments.

Water deficit treatments were imposed on the test plants three weeks after germination when they had attained four -leaf stage. Standard rain-gauge was mounted in the field in order to measure the quantity of water added to the plants through rainfall. The test plants were irrigated manually using watering can of known capacity and the required volume applied to each of the treatments as worked out. The amount of water added to the plants through rainfall was determined by the mounted rain-gauge. The experimental plots were subjected to three levels of irrigation regimes as follows:

Control (L1): The plants received a total of 650 mm of irrigation during the growth period to serve as the control. Under this regime, the crop plants received 20.3 mm of irrigation twice weekly throughout the experimental period.

The quantity of water (litre) applied was obtained from the relationship:

$$1 \text{ mm of irrigation / rainfall} = 1 \text{ litre / m}^2.$$

This implies that an area of 1 m^2 will receive a volume of 1 litre of water.

Mild water deficit (L2): The plants receive 14.1 mm of irrigation twice a week giving rise to a sum total of 450 mm of irrigation for the four-month period.

Severe water deficit (L3): The plants under this regime were mostly stressed by subjecting them to 7.8 mm of irrigation two times a week, which amounted to a total of 250 mm of irrigation for the four-month duration.

Experimental design and statistical analysis

The experiment was based on a split plot design. Three irrigation regimes constituted the main plots and the three kenaf varieties as the sub-plots. The watering treatments were replicated three times to give a total of 27 experimental units. The experimental layout size was 660 m^2 consisting of three rows, each with a total of nine experimental plots / units of 4 x 4 m. The biometric and productive determinations were performed on a minimal area of 4 m^2 in the inner part of each plot. The entire layout was surrounded with a row of border plants to protect the plants against external influences. Data obtained were subjected to analysis of variance and means separated using the Duncan Multiple Range Test.

Fibre dimensions and their derives values

Fibre dimensions

Stem samples for the fibre studies were obtained from the second internode counting from the base. These samples were immediately fixed with FAA preservate until when they were needed for maceration. Small slices or slivers for maceration obtained from the bark and from the central wood core were macerated with 10 min (Ogbonnaya, 1990). Macerated materials were washed and stained with 1:1 aqueous safranin- glycerol solution (Okoegwale and Gill, 1988). Fibre samples were teased on slides and viewed under a calibrated microscope for the determination of the following fibre dimensions. A total of five fibres were measured for each sample and mean values calculated for fibre length (fl), fibre diameter (fd), fibre lumen diameter (fld) and fibre wall thickness (fwt).

Derived values: From these above measurements, the following derived values were calculated: Coefficient of suppleness (CS) or flexibility coefficient as fld/fd (Petri, 1952), slenderness ratio (SR) as fl/fd (Rydholm, 1967) and runkel ratio (RR) as 2 x fwt/fld, (Okereke, 1962).

RESULTS

Fibre dimensions and the derived values

Fibre dimensions

The effects of water deficit on the fibre dimensional properties of three kenaf varieties are shown in Tables 1-7. The wood and bark fibre length of the three kenaf varieties were not adversely affected by water deficit. The optimum values of wood fibre elongation were obtained at the 12^{th} week of growth while that of bark were recor-ded by the 10^{th} week of growth (Table 1). The wood fibre

Table 1. Effect of Watering Regime on Fibre Length of core and Fibre Length of bark of three Kenaf cultivars – Tainung #2 (VI), SF 459 (V2), and Everglades 41 (V3) grown in the field

Fibre length/Age (Weeks)	Variety/Fibre type	Watering Regime			
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	Mean
Fibre Length (mm) at 8th week	**Tainung #2 (V1)**				
	Core	0.62	0.67	0.55	0.61a
	Bark	2.4	2.8	2.6	2.6 b
	SF 459 (V2)				
	Core	0.66	0.52	0.57	0.58 a
	Bark	2.5	2.6	2.2	2.4 b
	Everglades 41 (V3)				
	Core	0.66	0.63	0.57	0.62 a
	Bark	2.6	2.4	2.4	2.5 b
Fibre Length (mm) at 10th week	**Tainung #2 (V1)**				
	Core	0.58	0.70	0.57	0.62 a
	Bark	3.0	3.0	2.9	3.0 b
	SF 459 (V2)				
	Core	0.60	0.61	0.62	0.61 a
	Bark	2.7	3.0	2.9	2.9 b
	Everglades 41 (V3)				
	Core	0.59	0.62	0.54	0.58 a
	Bark	2.8	2.7	2.9	2.8 b
Fibre Length (mm) at 12th Week	**Tainung #2 (V1)**				
	Core	0.72	0.62	0.61	0.65 a
	Bark	2.9	2.6	2.8	2.8 b
	SF 459 (V2)				
	Core	0.64	0.59	0.57	0.60 a
	Bark	2.6	2.5	2.4	2.5 b
	Everglades 41(V3)				
	Core	0.58	0.71	0.58	0.62 a
	Bark	2.8	2.8	2.4	2.7 b

length ranged from 0.54 mm for the stressed plants to 0.72 mm for the control. Similarly, bark fibre length was in the range of 2.2 for the stressed plants to 3.1 mm for the well watered control. Analysis of variance at the end of the growth period revealed that there were no significant differences ($P \leq 0.05$) among the fibre length of the wood as well as that of the bark caused by the variety effects and different levels of watering regimes. However, differences between the wood and the bark fibre lengths were significant

The fibre diameter of wood and bark increased with maturity. Water stress affected the fibre diameter of the three kenaf varieties (Table 2).

Moderate stress enhanced the fibre diameter of wood core above that of the control in Tainung #2 (VI) varieties where as in Everglades 41 (V3) and SF 459 (V2) varieties, this property was enhanced by the adequately watered control. Similarly, the fibre diameter of the bark was enhanced by the moderate stress more than those of the control at the 12th week of growth

Similar to the fibre diameter of wood and bark, the fibre lumen diameter (fld) of wood and bark increased with age. Water deficit reduced this fibre dimensional property drastically. Optimum values of fibre lumen diameter were obtained at the 12th week of growth for both wood core and bast for the control of S F 459 (V2) and Everglades 41(V3) but that of Tainung #2 (VI), (Table 3) they were enhanced by moderate stress. The wood core fibre diameter ranged from 0.022 mm for the stressed plants to 0.042 mm for the control. The bark fibre diameter was in the range of 0.008 for the severely stressed to 0.023 mm for well-watered control

In contrast with fibre lumen diameter of wood and bark fibre wall thickness (fwt) decreased with age in both the wood and bark. This fibre dimensional property was not adversely affected by water stress. The wall thickness of wood core of the control began to increase after the 10th week of growth in Tainung # 2 (V1) and SF 459 (V2). The fibre wall thickness of the bark was enhanced by the severe stress (Table 4).

Table 2. Effect of watering regime of Fibre Diameter of wood core and bark of three kenaf cultivals-Tainung #2 (V1) SF 459 (V2) and Everglades 41 (V3) grown in the field.

Fibre Lumen Diameter (mm) Age (Weeks)	Variety/Fibre type	Watering Regime			
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	Mean
Fibre Diameter (mm) at 8th week	Tainung #2 (V1)				
	Core	0.039	0.037	0.035	0.037 a
	Bark	0.025	0.025	0.028	0.026 b
	SF 459 (V2)				
	Core	0.038	0.035	0.034	0.036 a
	Bark	0.03	0.026	0.024	0.027 b
	Everglades 41 (V3)				
	Core	0.041	0.039	0.04	0.04 a
	Bark	0.034	0.031	0.031	0.032 b
Fibre Diameter (mm) at 10th week	Tainung #2 (V1)				
	Core	0.045	0.041	0.04	0.042 a
	Bark	0.027	0.029	0.025	0.027 b
	SF 459 (V2)				
	Core	0.043	0.040	0.04	0.041 a
	Bark	0.028	0.029	0.030	0.029 b
	Everglades 41 (V3)				
	Core	0.042	0.049	0.038	0.043 a
	Bark	0.028	0.033	0.029	0.030 b
Fibre Diameter (mm) at 12th Week	Tainung #2 (V1)				
	Core	0.042	0.049	0.038	0.043 a
	Bark	0.028	0.033	0.029	0.030 b
	SF 459 (V2)				
	Core	0.051	0.043	0.041	0.045 a
	Bark	0.029	0.029	0.030	0.029 b
	Everglades 41(V3)				
	Core	0.052	0.042	0.047	0.047 a
	Bark	0.032	0.033	0.029	0.031 b

Statistical analysis revealed that the differences between the wall thickness of wood as well as those of the bark were not significant At the termination of the experiment, water deficit had significantly reduced fibre wall thickness of the wood, while those of the bark were not drastically retarded when compared with those of the control.

The derived fibre values

The wood slenderness ratio decreased with maturity and began to increase after the 10th week of growth in Tainung #2 (VI) variety at the adequately watered control and the severely stress. Conversely, the moderate stress enhanced the wood core slenderness ratio after the 10th week of growth when compared with the well-watered control and the severely stressed. The bark slenderness ratio showed initial increase and later began to decrease after the 10th week of growth except for Tainung #2 (VI) variety in which it decreased with maturity (Table 5). Water deficit had no adverse effect on the wood and bark slenderness ratio at the end of the growth period

The differences between the wood slenderness ratios were not significant. Similarly, the effects of variety and watering treatment on the bark slenderness ratio were not significant. However, the differences between the wood and bark slenderness ratios were significant (P 0.05) at the end of the experiment.

Wood and bark runkel ratio (RR) decreased with maturity. Water stress had no significant effect on the values of the runkel ratio of the stressed plants when compared with those of the well-watered control. The runkel ratio of the wood core was improved in the stressed plants (Table 6), with the exception of SF 459 (V2) variety.

Tainung #2 (VI) and Everglades 41(V3) varieties were enhanced by the severely stressed plants after the 10th week of growth.

Table 3. Effect of watering Regime on lumen Diameter of core and bark of three kenaf cultivars – Tainung #2 (V1), SF 459 (V2) and Everglades 41 (V3) grown in the field

Fibre Lumen Diameter (mm)	Variety/Fibre type	Watering Regime			Mean
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	
Fibre lumen diameter (mm) at 8th week	Tainung #2 (V1)				
	Core	0.025	0.023	0.022	0.023 a
	Bark	0.01	0.015	0.012	0.012 b
	SF 459 (V2)				
	Core	0.025	0.026	0.022	0.024 a
	Bark	0.013	0.014	0.008	0.012 b
	Everglades 41 (V3)				
	Core	0.023	0.025	0.025	0.024 a
	Bark	0.014	0.015	0.014	0.014 b
Lumen Diameter (mm) @ 10th week	Tainung #2 (V1)				
	Core	0.031	0.029	0.030	0.030 a
	Bark	0.023	0.019	0.019	0.020 b
	SF 459 (V2)				
	Core	0.035	0.031	0.030	0.032 a
	Bark	0.017	0.017	0.015	0.016 b
	Everglades 41 (V3)				
	Core	0.033	0.029	0.032	0.031 a
	Bark	0.016	0.017	0.019	0.017 b
Lumen diameter (mm) @ 12th week	Tainung #2 (V1)				
	Core	0.028	0.039	0.028	0.032 a
	Bark	0.018	0.022	0.016	0.019 b
	SF 459 (V2)				
	Core	0.038	0.033	0.031	0.034 a
	Bark	0.018	0.018	0.018	0.018 b
	Everglades 41(V3)				
	Core	0.042	0.032	0.037	0.037 a
	Bark	0.018	0.021	0.016	0.019 b

Different from what was observed in the runkel ratio, the core and bast coefficient of suppleness (CS) or flexibility coefficient increased with age. These fibres dimensional properties were not greatly influenced by water deficit in both wood core and bark. Severely stressed plants elevated the wood core coefficient of suppleness above those of the control of Everglades 41 (V3) variety by the 10th week of growth and was reduced below those of the control by the 12th week of growth. In the bark, this value was consistently lower with stress after an initial increase with severe stress at the 8th week of growth. At the termination of the growth period, water deficit had significant coefficient of suppleness in both the wood and the bark.

Analysis of variance showed that differences between the wood coefficient of suppleness as well as those of the bark were not significant as influenced by variety effect. Similarly, there were no significant differences at $P = 0.05$ between the wood coefficient of suppleness as affected by watering regimes (Table 7). But the differences between the bark coefficients of suppleness were significant at the 8th week of harvest.

DISCUSSION

Fibre dimensional properties

The fibre dimensional properties of both kenaf wood core and bark were not seriously affected by water stress and variety effects. The results of this experiment show that average wood fibre length ranged from 0.5 to 0.65mm while that of bast fibre length ranged from 2.4 to 2.9mm. These values fall within the range for making pulp blends with short fibres (Miller, 1965) . They also compare favourably to those of soft-woods.

The true relevance of fibre length to paper quality is better evaluated in terms of slenderness ratio. In earlier studies, Okereke (1962) and Rydholm (1967) have reported that the suitability of fibre for pulp paper making is not

Table 4. Effect of watering regime on cell wall thickness of Kenaf care and bark of three Kenaf cultivars – Taining #2 (V1), SF459 (V2) and Everglades 41 (V3) grown in the field.

Fibre cell wall thickness (mm) Age (weeks)	Variety/Fibre type	Watering Regime			
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	Mean
Cell wall thickness (mm) at 8th week	Tainung #2 (V1)				
	Core	0.0071	0.0077	0.0066	0.0071 a
	Bark	0.0072	0.007	0.0083	0.0083 b
	SF 459 (V2)				
	Core	0.0069	0.0059	0.0067	0.0065 a
	Bark	0.0085	0.0073	0.0083	0.0080 b
	Everglades 41 (V3)				
	Core	0.0068	0.0056	0.0069	0.0064 a
	Bark	0.0072	0.0057	0.0077	0.0069 b
Cell wall thickness (mm) @ 10th week	Tainung #2 (V1)				
	Core	0.0053	0.0053	0.005	0.0052 a
	Bark	0.006	0.0068	0.0065	0.0064 b
	SF 459 (V2)				
	Core	0.005	0.0053	0.0057	0.0053 a
	Bark	0.005	0.006	0.0053	0.0054 b
	Everglades 41 (V3)				
	Core	0.005	0.0053	0.006	0.0054 a
	Bark	0.003	0.0058	0.0057	0.0059 b
Lumen diameter (mm) @ 12th week	Tainung #2 (V1)				
	Core	0.0067	0.005	0.005	0.0056 a
	Bark	0.0054	0.0058	0.0064	0.0059 b
	SF 459 (V2)				
	Core	0.0065	0.005	0.005	0.0055 a
	Bark	0.0056	0.0058	0.0059	0.0058 b
	Everglades 41(V3)				
	Core	0.005	0.005	0.005	0.005 a
	Bark	0.0056	0.0058	0.0063	0.0059 b

not only dependent on the fibre length but also involves in other fibre dimensional properties as well as chemical composition. Kramer (1963) demonstrated that water stress reduced fibre dimensions and attributed it to role water plays in turgidity maintenance necessary for cell enlargement.

Similarly, other fibre dimensional properties such as fibre diameter, lumen diameter and cell wall thickness were not adversely affected by water deficit. The mean core fibre diameter ranged from 0.035 to 0.048 mm while that of bast ranged from 0.026 to 0.032 mm. The differences between the wood core fibre diameter as well as that between the bast fibre diameters were not significant. Also observed in this experiment was that, the fibre dimensional properties of word core obtained were lower than that obtained for bast fibres. However, these results contradict those obtained for fibre length and cell wall thickness, that is, the bast fibre values obtained were higher than those of the wood core. The thickening of fibre walls of bast fibres above that of woody core may have resulted from an unusually high degree of hydration of their constituents (Swanson, 1959).

Derived values of fibre dimensions

The slenderness ratio, coefficient of suppleness or flexibility coefficient and the runkel ratio were computed from fibre dimensional values. These values are very essential in the determination of fibre's suitability for pulp and paper making (Okereke, 1962; Rydholm, 1967). In current study, the usefulness of fibre length to paper quality is evaluated in terms of its slenderness ratio. Rydholm (1967) has reported the importance of slenderness ratio to pulp and paper production by confirming that pulp's resistance to tearing is better enhanced by high slenderness ratio. The results obtained in this study revealed that bark slenderness ratio of kenaf is better suited for producing pulp and paper with superior tearing resistance

Table 5. Effect of watering regime on slenderness ratio of kenaf core and Bark of three kenaf cultivars – Tainung #2 (V1), SF 459 (V2) and Everglades 41 (V3) grown in the field.

Slenderness Ratio/ Age (weeks)	Variety/Fibre type	Watering Regime			Mean
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	
Slenderness Ratio at 8th week	**Tainung #2 (V1)**				
	Core	15.90	18.11	15.71	16.57 a
	Bark	96.06	112.00	92.86	100.31 b
	SF 459 (V2)				
	Core	17.37	14.86	16.76	16.33 a
	Bark	83.33	100.00	91.67	91.67 b
	Everglades 41 (V3)				
	Core	20.00	18.00	15.41	17.80 a
	Bark	92.86	92.31	85.71	90.29 b
Slenderness Ratio at 10th week	**Tainung #2 (V1)**				
	Core	14.15	17.95	14.25	15.45 a
	Bark	88.24	96.77	93.55	92.85 b
	SF 459 (V2)				
	Core	13.72	15.50	13.50	14.24 a
	Bark	100.00	103.45	116.00	106.48 b
	Everglades 41 (V3)				
	Core	13.72	15.50	13.50	14.24 a
	Bark	100.00	93.10	96.67	96.59 b
Slenderness Ratio @ 12th week	**Tainung #2 (V1)**				
	Core	17.14	12.65	16.05	15.28 a
	Bark	100.00	78.79	96.55	91.78 b
	SF 459 (V2)				
	Core	12.55	13.72	13.90	13.39 a
	Bark	89.66	86.21	80.00	85.29 b
	Everglades 41(V3)				
	Core	11.15	16.90	12.34	13.46 a
	Bark	87.50	84.85	82.76	85.04 b

than woody core slenderness ratio that has values of less than 50(<50) these results show that water deficit has little or no effect on the wood and bast slenderness ratio when compared with adequately watered control. These results confirmed the findings of idem and Adeoti (1988) and Ogbonnaya et al. (1997).

Histochemical studies have shown that a higher coefficient of suppleness (50 but preferably >60) is necessary for fibres utilized in paper making (Petri, 1952; Okereke, 1962; Rydholm 1967) . It has been demonstrated that paper strength tends to improve with increasing coefficient of suppleness (references?). Further studies (references?) have confirmed that fibres with high coefficient of suppleness are flexible, collapse readily and produce good surface contact as well as fibre-to-fibre bonding. In fact, this promotes low bulk paper yield with excellent physical characteristics such as burst, tensile and fold properties. In this experiment, water deficit enhanced this property in the wood core more than that recorded by the bark. This result could be explained partly due to increased fibre lumen diameter of wood core with reduced wall thickness of fibre or due to reduced fibre lumen diameter of bark with increased wall thickness of fibre

The guidelines of Okereke (1962) and Rydholm (1967) reveal that a low runkel ratio ($\leq$ I) is very important for good paper characteristics. Therefore, it implies that runkel ratio determines the suitability of fibre for paper production. Histochemical studies (references?) have shown that a low runkel ratio of < I and a high coefficient of supple-ness of > 60 are necessary in fibres for paper making because paper strength tends to improve with decreasing runkel ratio and increasing coefficient of suppleness. This is due to the fact that fibres with such characteristics readily collapse and produce good surface contact in addition to fibre-to-fibre bonding. In contrast to this, fibre of high runkel ratios and low coefficient of suppleness tend to retain their pipe-like shapes to a large extent during the beating and sheet-forming process resulting in minimal fibre-to-fibre bonding. The present work revealed that runkel ratios decreased with maturity. It also showed that

Table 6. Effect of Watering Regime on Kenaf Core and Bark Runkel Ratio of three Kenaf varieties – Tainung #2(V1), SF 459(V2) and Everglades 41(V3) grown in the field**.**

Runkel Ratio/ Age (Weeks)	Variety/fibre type	Watering Regime			
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	Mean
Runkel Ratio @ 8th Week	**Tainung# 2(V1)**				
	Core	0.57	0.67	0.60	0.61 a
	Bark	1.44	0.93	1.38	1.25 b
	SF 459 (V2)				
	Core	0.55	0.45	0.61	0.54 a
	Bark	1.31	1.04	2.08	1.48 b
	Everglades 41(V3)				
	Core	0.59	0.45	0.28	0.44 a
	Bark	1.03	0.76	1.10	0.96 b
Runkel Ratio @ 10th week	**Tainung # 2(V1)**				
	Core	0.34	0.37	0.33	0.35 a
	Bark	0.52	0.72	0.68	0.64 b
	SF 459(V2)				
	Core	0.29	0.34	0.38	0.34 a
	Bark	0.59	0.71	0.71	0.67 b
	Everglades 41(V3)				
	Core	0.30	0.37	0.38	0.35 a
	Bark	0.79	0.68	0.60	0.69 b
Runkel Ratio @ 12th Week	**Tainung # 2(V1)**				
	Core	0.48	0.26	0.36	0.37 a
	Bark	0.60	0.53	0.80	0.64 b
	SF 459(V2)				
	Core	0.34	0.30	0.32	0.32 a
	Bark	0.62	0.64	0.66	0.64 b
	Everglades 41(V3)				
	Core	0.24	0.31	0.27	0.27 a
	Bark	0.53	0.55	0.79	0.62 b

Table 7. Effect of Watering Regime on Core and Bark Suppleness of three Kenaf cultivars – Tainung #2(V1), SF 459 (V2) and Everglades 41(V3) grown in the field.

Coefficient of suppleness/Age (Week)	Variety/fibre type	Watering Regime			
		Well-watered (L1)	Moderate stress (L2)	Severe stress (L3)	Mean
Coefficient of suppleness @ 8th Week	**Tainung# 2(V1)**				
	Core	64.10	62.16	62.16	63.04 a
	Bark	40.00	60.00	42.86	47.62 b
	SF 459 (V2)				
	Core	65.79	74.29	64.71	68.26 a
	Bark	43.33	53.85	33.33	43.50 b
	Everglades 41(V3)				
	Core	69.70	71.43	67.57	69.57 a
	Bark	50.00	57.69	50.00	52.56 b

Table 7. Contd.

Coefficient of suppleness @ 10th week	**Tainung # 2(V1)**				
	Core	75.61	74.36	75.00	74.99 a
	Bark	67.65	61.29	61.29	63.41 b
	SF 459(V2)				
	Core	77.78	75.61	75.00	76.13 a
	Bark	62.96	58.62	60.00	60.53 b
	Everglades 41(V3)				
	Core	76.74	72.50	80.00	76.41 a
	Bark	57.14	58.62	63.33	59.70 b
Coefficient of suppleness @ 12th Week	**Tainung # 2(V1)**				
	Core	66.67	79.59	76.32	74.19 a
	Bark	62.07	66.67	55.17	61.30 b
	SF 459(V2)				
	Core	74.51	76.74	75.61	75.62 a
	Bark	62.07	62.07	60.00	61.38 b
	Everglades 41(V3)				
	Core	80.77	76.19	78.72	78.56 a
	Bark	65.63	63.64	55.17	61.48 b

water stress increased the runkel ratio of the bark and the wood core of Kenaf plants when compared with those of adequately watered control. Also observed in this study was the abnormal increase of bark runkel ratio to greater than one (>1) at the 8th week of growth above those of the 10th and 12th week of growths. Ogbonnaya et al. (1992) have also indicated in their earlier studies on a tree species that water stress has effect on the quality of pulp and paper produced from *Gmelina arborea.* These findings suggest that age of the plants, some level of water stress as well as proper timing are important aspects of Kenaf production that must be given attention especially when cultivating Kenaf plants for pulp and paper production.

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