ELSEVIER

Industrial Crops and Products 7 (1997) 9–18

INDUSTRIAL CROPS AND PRODUCTS
AN INTERNATIONAL JOURNAL

Physical and histochemical properties of kenaf (*Hibiscus cannabinus* L.) grown under water deficit on a sandy soil

C.I. Ogbonnaya [1], H. Roy-Macauley, M.C. Nwalozie *, D.J.M. Annerose

Centre d'Etudes Regional pour l'Amelioration de l'Adaptation a la Secheresse (CERAAS)/ISRA/CNRA, BP. 59, Bambey, Senegal

Received 18 December 1996; received in revised form 2 April 1997; accepted 4 April 1997

Abstract

The effects of water deficit on the physical and histochemical properties of kenaf (*Hibiscus cannabinus* L.) relevant to pulp and paper production were investigated. The plants were grown on a loose-textured sandy soil in the greenhouse at CERAAS, Bambey, Sénégal. Three watering regimes representing well watered control, moderate stress and severe stress were imposed on the plants. Each watering treatment was replicated four times in a completely randomized design. Holistic analysis of the physical and histochemical properties of kenaf relevant to pulp and paper production indicated that water deficit could improve the quality of pulp and paper produced from this plant. © 1997 Elsevier Science B.V.

Keywords: *Hibiscus cannabinus*; Histochemical; Kenaf; Paper; Pulp; Water-deficit

1. Introduction

Hibiscus cannabinus L. (Malvaceace) commonly known as kenaf, is an annual fibre crop, evaluated as a potential source for the production of pulp and paper. It is also very useful for the manufacture of twines, ropes, sacs and rugs (Wilson et al., 1965) and has become a jute fibre substitute. Kenaf also has a high potential as a board raw material with low-density panels suitable for sound absorption and thermal resistance (Sellers et al., 1993).

The stem contains two distinct fibres the bast or the outer bark fibres arc comparable to softwood fibres. The inner core of short, woody fibres are comparable to hardwood fibres. Both could be used in pulp production (Francois et al., 1992). The paper produced from kenaf pulp has excellent ink-retention çharacteristics and its high tensile strength is ideal for high-spced presses (Robinson, 1988). Kenaf papers are also as sturdy as wood-

* Corresponding author. Fax: +221 736197; e-mail: annerose@ceraas.orstom.sn

[1] Present address: Plant Ecophysiology Unit, School of Biological Sciences, Abia State University, PMB 2000, Uturu, Abia State, Nigeria.

PII S0926-6690(97)00034-4

pulp paper but are generally brighter, reyuire less ink and has less ink rub-off (Sellers et al., 1993). After numerous researches and trial runs kenaf paper is now available from several commercial retailers and is being used by some printing and publishing firms in the USA (Webber, 1993).

Water deficit may limit plant growth during intermittent periods of drought on light-textured soils with low water-holding capacity in the tropics and even in some humid cool temperate regions of north west Europe (Jensen, 1989). It is well known that water deficit affects every aspect of plant growth, modifying anatomy, morphology, physiology and biochemistry (Hsaio, 1973; Enu-Kwesi et al., 1986). Ogbonnaya et al. (1992) have shown that although water stress reduced the volume of wood produced and changed wood fibre properties, it did not significantly affect the quality of pulp and paper produced from gmelina wood. This investigation was therefore carried out to determine the effects of water deficit on the physical and histochemical properties of kenaf.

2. Materials and methods

2.1. Seed collection

Certified seeds of kenaf (*Hibiscus cannabinus* L.) were obtained from the Obafemi Awolowo University, Institute of Agricultural Research, Moore Plantation, Ibadan, Nigeria. Cuba 108 cultivar was used on the basis of its high bark-wood core ratio (Webber, 1993), since the harvest index for this experiment was the bast fibre.

2.2. Growth conditions

Sandy soil was used as the potting medium. The characteristics of the soil were as previously described by Annerose (1990). The soil was sun-dried and undecomposed plant materials were removed by sieving. A 28 kg volume of soil was packed in plastic pots (height = 40 cm, diameter = 2.5 cm) with drainage holes at the bottom, to a bulk density of 1.5852 g cm^{-3}. A total of ten kenaf seeds were planted at 0.5 cm depth and the resulting seedlings were later thinned down to one plant per pot at two-leaf stage to obtain plants with uniform growth vigour. The soil was fertilized at the beginning of the experiment and 2 months later with compound N PK (15-10-15) fertilizer at the rate of 200 kg/ha (White et al., 1970) to remove nutrient deficiency as a limiting factor. The pots were placed in a greenhouse at CERAAS, Rambey, Sénégal (latitude 16°28′ West and longitude 14°42′ North). At midday, maximum temperature was 35.5 ± 0.95°C; relative humidity was 46.25 ± 2.27%, while photosynthetic photon flux density (PPFD) was 690.55 ± 135.44 μmol s^{-1} m^{-2}.

2.3. Soil moisture treatment

The following treatments were imposed 3 weeks after germination at the four leaf stage:

1. Control (W1) soil water was maintained at field capacity by daily watering. The daily water requirements of the plants were determined as the difference between the weight of a fully irrigated pot and the weight of the pot 24 h later, after the day's evapotranspiration. This determination was done weekly to take care of changing water needs of the plants with age.
2. Moderate stress (W2)— the plants were watered at 3 week intervals.
3. Severe stress (W3) the plants were watered at 4 week intervals. The choice of these watering regimes was based on the duration of short-term drought usually experienced by this crop in the field. At each watering session, soils were fully hydrated to field capacity.

2.4. Experimental design and statistical analysis

The experimental design was a completely randomized one with three watering treatments replicated four times. Each pot represented a subplot and a square of nine subplots represented a whole plot. Whole plots were replicated four times to give a total of 12 experimental plots in a completely randomized design. The experimental plots were surrounded with a single row of border plants on all sides to receive external shocks. Data collected were subjected to analysis of variance and Duncan's multiple range test was used in partitioning the means. The SAS statistical software was used in carrying out the data analysis.

2.5. Fibre dimensions and their derived values

2.5.1. Fibre dimensions

Stem samples for the fibre studies were obtained from the second internode counting from the base. Small slivers were obtained from the bark and from the central wood core for maceration. The slivers were macerated with 10 ml of 60% nitric acid, boiled in a water bath for 10 min (Ogbonnaya, 1990). Macerates were stained with 1:1 phluroglucinol glycerol mixture. Fibre samples were viewed under a calibrated microscope, and the fibre walls presented a characteristic glistening nature, described as nacré or pearly luster. A total of 25 fibres were measured for each sample to obtain an average fibre length (f), fibre diameter (fd), fibre lumen diameter (fld) and fibre cell wall thickness (fwt) for each replicate.

2.5.2. Derived values

The following derived values were also calculated: Coefficient of suppleness (CS) or flexibility coefficient as fld/fd (Petri, 1952), slenderness ratio (SR) as fl/fd (Rydholm, 1965) and Runkel ratio (RR) as 2 × fwt/fld (Okereke, 1962).

2.6. Chemical properties

2.6.1. Alkali solubility

Alkali (1% NaOH) soluble substances content of the bark and wood core were determined by digesting 1 g of oven-dried ground material in 100 ml of 1% NaOH in a water bath at 100°C for 1 h, with three stirring periods. After digestion, the material was filtered and washed with water and 10% acetic acid solution. The residue was dried at 85°C until a constant weight was obtained. The weight of the extract expressed as a percentage of the total plant sample used for the extraction was the matter soluble in alkali (Casey, 1960).

Alkali soluble substances content (%) = $[(W_{sample} - W_{resid.})/(W_{sample})] \times 100$, where W_{sample} was the oven-dry weight of the sample and W_{resid} was the oven-dry weight of the residue.

2.6.2. Alcohol–benzene solubility

TAPPI T6m-59 method was employed in the determination of alcohol benzene soluble substances content of the bark and the wood (Grant, 1961). A total of 1 g of ground material was estracted in soxhlet apparatus with 100 ml of a mixture of 33 ml 95% alcohol and 67 ml benzene for 8 h. At the end of the extraction, the alcohol benzene solvent system was distilled off and the extract dried at 85°C until a constant weight was obtnined. The weight of the extract, expressed as a percentage of the total plant sample used for the extraction was the matter soluble in alcohol benzene solvent system. Alcohol benzene soluble substances content (%) = (weight of extract/weight of sample) x 100.

2.7. Holistic assessment of the physical and histochemical properties

The results obtained were subjected to holistic assessment in order to obtain a conclusive view. For each parameter measured the treatment effects were scored according to their relative performances. The scores ranged from one for the worst treatment effects to three (corresponding to the total number of treatments) for the best treatment effect. The total score for each treatment was obtained on the basis of which comparisons were made and conclusions drawn (Ogbonnaya, 1992).

3. Results

3.1. Stalk physical properties

3.1.1. Stalk specific gravity

Stalk specific gravity was not a variable factor within the first 6 weeks of growth of kenaf. There was a steep increase at the 8th week of growth and gradual increase thereafter. All levels of stress severely checked this attribute throughout the growth period. The difference in stalk specific gravity among the stressed plants was not found to be statistically significant (Fig. 1)

3.2. Fibre dimensions and the derived values

3.2.1. Fibre dimensions

The effects of water stress on the libre dimensional properties are shown in Fig. 2. Bark and wood fibre length fairly increased with maturity and both moderate and scvere water deficit adversely affected this important fibre dimension. Optimum values of fibre elongation were obtained by the 8th week of growth for both bark and wood for the adequately watered control and moderdte stress. 'The fibre length of the severely stressed plants continued to rise nfter an initial decrease. The bark fibre length ranged from 1.63 mm for the stressed plants to 2.19 mm for the well watered control, while thdt of the wood was in the range of 0.53-0.8 mm for the severely stressed plants and the adequately watered control, respectively. At the end of the growth period, there were no signifiant differences between thc bark fibre lengths. The differences between the bark and the wood fibre lengths were significant at $P = 0.01$ (Fig. 2A and B).

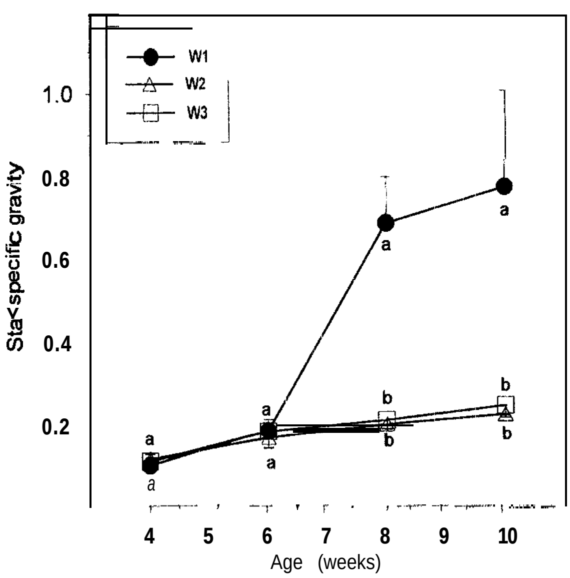

Fig. 1. Stalk specific gravity of kcnaf under three soil rnoisture regimes. Means at each age, followed by the same letter are not significantly different according to Duncan's multiple range test. W2 were watered on thc 5th and 8th weeks and W3 on the 6th week.

In contrat with the fibre length, fibre diametei (fd) decreased with maturity in both the bark and the wood. Severe stress reduced fd of the plants. while moderate stress enhanced it above the control in thc bark (Fig. 2C and D). At the end of experimental period, water stress had significant effect on fd of both thc bark and the wood. The result of the fibre lumen diametcr (fld) was similar to that of the fd, in that fld decreased with age and stress produced higher fld wfter the 6th week in the bark. The differences between the fld of the wood were not significant at the end of the growth pcriod, whereas stress sgnificantly (P = 0.05) increased it in the bark (Fig. 2E and F). The differcnes between the bark fd and fld and those of ths wood were statistically signifiant.

Fibre wall thickness (fwt). on the other hand. increased with maturity in the well watered control of both the bark and the wood, whereas stress reduced it with agc, but this began to increase after the 8th week of growth. At the end of the expeiiment, water stress had significantly reduced fwt of the wood, and only those of the severely stressed plants in the bark (Fig. 2G and H). The values between the wood and the bark were significantly different (P = 0.01) at the end of the period.

3.2.2. The fibre derived values

The difference between the wood and bark derived values wcre statistically different (P = 0.05) at the end of the growth period. The slenderness ratio (SR) increased with maturity, except that in the bark water stress reduced this value at the 6th week, that is, after the first cycle of drought. The optimal SR in both bark and wood were obtained at the 8th week of growth. At the end of the cxperiment, water deficit had no effect on thc bark SR, but it significantly reduced those of the wood (Fig. 3A and B). Coefficient of suppleness (CS) or flexibility coefficient decreased with maturity in the control for both the bark and the wood. In the wood this value was consistently higher with stress and similnrly so in the bark after an initial decrease with severe stress at the 6th week. At the termination of the experiment. water deficit had significantly enhanced CS in both thc wood and bark (Fig. 3C and D). Runkel

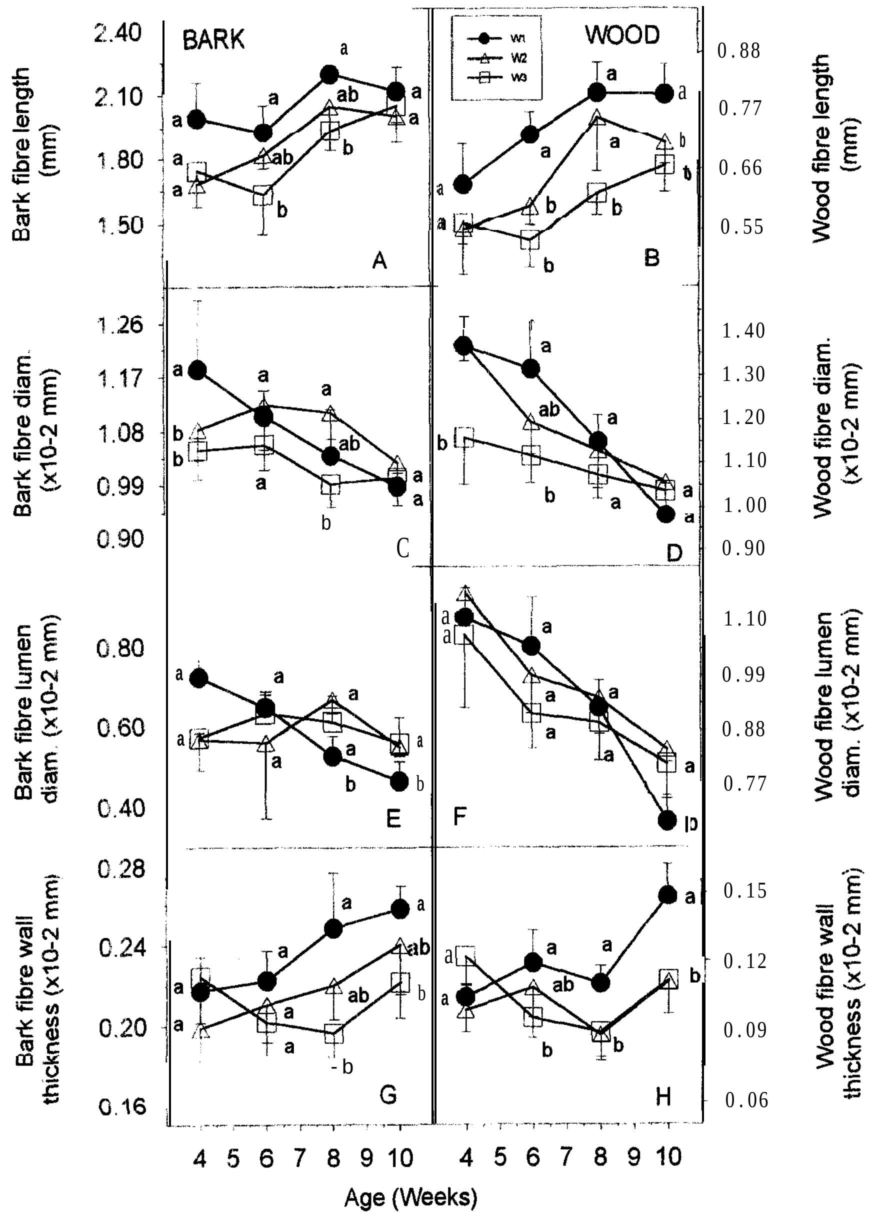

Fig. 2. Effect of water stress on the bark and wood fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness of kenaf. Within age, means followed by the same letter are not significantly different according to Duncan's multiple range test. W2 were watered on the 5th and 8th weeks, W3 on the 6th week.

ratio (RR) increased with age in the well watered control. The response with the stressed plants was rather erratic, but were significantly lower than the control at the end of the growth period (Fig. 3E and F).

3.3. Chemical properties

3.3.1. Alkali soluble substances content (1% alkali solubility)

Alkali soluble substances content decreased

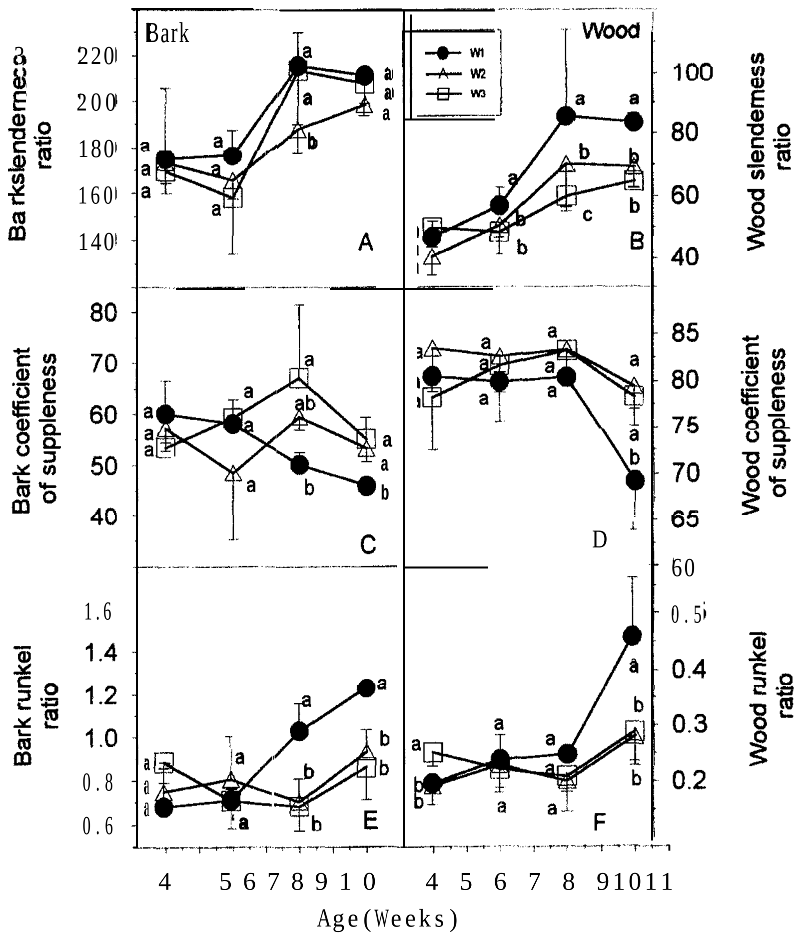

Fig. 3. Effects of water stress on bark and wood slenderness ratio, coefficient of suppleness and runkel ratio of kenaf. Within age, means followed by the same letter are not significantly different according to Duncan's multiple range test. W2 were watered on the 5th and 8th weeks and W3 on the 6th week.

with age and increased with stress in both the bark and wood core. The wood alkali solubility varied from 23.78% in the adequately watered control to 33.68% with severe stress, while that of the bark ranged from 24.71% with the control to 43.24% under severe stress (Fig. 4A and B). Whereas water stress significantly increased alkali solubility in both the bark and the wood, the differences between the wood and the bark were not significant.

3.3.2. *Alcohol-benzene soluble substances content*

Alcohol benzene solubility increased with stress in both the bark and the wood and the values ranged from 8.64% with adequately watered control in the bark, to 15.76% with severely stressed plants in the wood. At the end of the growth period. severe stress had significantly increased alcohol benzene solubilitg in the bark and with moderate stress in wood (Fig. 4C and D). Alcohol benzene soluble substances of the bark and the wood were not statistical different.

3.3.3. *Holistic assessment*

A holistic assessment of the effects of water deficit on kenaf stalk physical properties. fibre dimensions and their derived values are shown on Table 1. Severely and moderately stressed plants had the highest scores of 50 respectively. when compared with 49 obtained with the control. Thus. representing 87 72% performance for plants

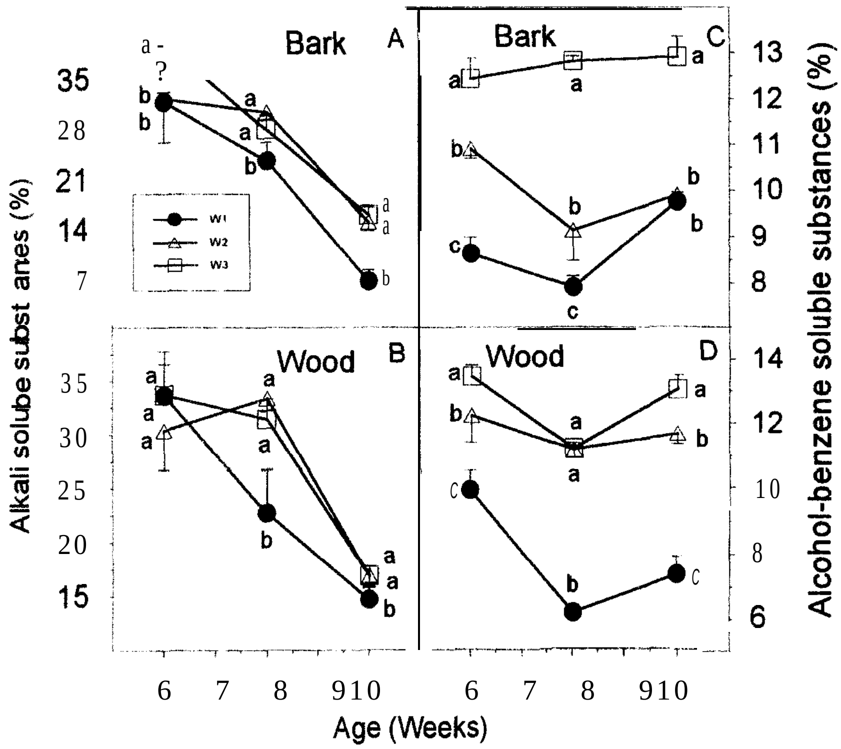

Fig. 4. Alkali (1% NaOH) and alcohol benzene soluble substances content of kenaf bark and wood as affected by water stress. Means followed by the same letter within age are not significantly different according to Duncan's multiple range test. W2 were watered on the 5th and 8th weeks and W3 on the 6th.

under stress and 85.96% for the well watered control. The differences between these performances were not statistically significant.

4. Discussions

4.1. Physical properties

4.1.1. Stalk specific gravity

Specific gravity determines the strength properties of wood, its resistance to breakage and its elasticity, durability and yield. The specific gravity of kenaf was adversely affected by water stress. This could be linked up to unfavourable carbon balance observed during drought, leading to the starvation of the plants and the under-development of the cell wall (Ogbonnaya et al., 1992). On the basis of the result obtained, kenaf would yield more fibres after the 6th week of growth and may therefore not be harvested before then.

4.2. Fibre dimensional properties

Water stress adversely influenced the fibre dimensional properties of both kenaf bark and wood core. The fibre length (fl), fibre diameter (fd), fibre lumen diameter (fld) and fibre wall thickness (fwt) were decreased, except in the bark where fibre lumen diameter was significantly increased. The reduced fibre dimension by water stress would be due in part to the role of water in turgidity maintenance necessary for cell enlargement (Kramer, 1963), because cell expansion is achieved when loosening of the cell wall yields under stress of the internal turgor pressure (Schulze and Matthew, 1993)

The higher lumen size in the bark due to stress would be due to reduction of the fibre wall thickness by dehydration rather than growth. Thickening of fibre walls apparently results from an unusually high degree of hydration of their constituents (Swanson, 1959). At the end of the ex perimental period, water deficit had no significant effect on the bast fibre length and diameter, wood fibre diameter and lumen size, similar to the earlier observation of Francois et al. (1992) on salinity.

4.3. Derived values of fibre dimensions

Preliminary tests on the quality of paper to be produced from fibre crops subjected to stress may be done by evaluating slenderness ratio, coefficient of suppleness and runkel ratio, in addition to other factors. The lhigher the slenderness ratio, the stronger the resistance to tearing (Rydholm, 1965). The results of this work showed that bark SR of kenaf was not affected by water deficit at the end of the experimental period. Petri (1952), Okereke (1962) and R.ydholm (1965) also showed that a higher coefficient of suppleness (preferably > 60) is necessary for fibres used in paper-making. This is because paper strength tends to improve with increasing CS. Fibres with high CS are flexible, collapse rcadily and produce good surface contact and fibre-to-fibre bonding. They yield low bulk paper with excellent physical characteristics (burst, tensile and fold). Water deficit enhanced this property in both the bark and the wood core as a rcsult of increased fibre lumen diameter due to rcduced fibre watt thickness.

Runkel ratio detertnines rhe suitability of fibre for paper production. The guidelines by Okereke (1962) and Rydholm (1965) show that for good paper characteristics, the RR will be ≤ 1. because paper strength tends to improve with decreasing RR. It was observed in the present investigation that watcr stress decreased RR of the bark and the wood core of kenaf, indicating that water stress would enhance kenaf paper strength. Earlier studies on a tree species (Oghonnaya. 1990) indicated no significant effect of water stress on the quality of pulp and paper produced from *Gmelina arborea*.

Table 1
Holistic assessment of the effect of water stress on kenaf stalk physical properties, fibre dimensions and their derived values

S/N° parameters	Trcatments		
	WI	W2	W3
Stalk physical properties			
Specific gravity	3	2	2
Histochemical propertics			
Wood			
Fibre length	3	2	2
Fibre diameter	3	3	3
Fibre lumen diameter	3	3	3
Fibre wall thickness	2	3	3
Slenderness ratio	3	2	2
Coefficient of suppleness	2	3	3
Runkel ratio	2	3	3
1% Alkali solubility	3	2	2
Alcohol-benzene solubility	3	2	2
Bark			
Fibre length	3	3	3
Fibre diameter	3	3	7
Fibre lumen diameter	2	3	3
Fibre wall thickness	1	2	3
Slenderness ratio	3	3	3
Coefficient of suppleness	2	3	3
Runkel ratio	2	3	3
1% Alkali solubility	3	2	2
Alcohol-benzene solubility	3	3	2
Total	49	50	50
Percentage performance	**85.96**	**87.72**	**87.72**

4.4. Chemical properties

The result of this study showed that 1% alkali soluble substances content of kenaf was increased by water deficit in both thc bark and the wood. The nlkali soluble substances are made up of pentosans, hexosans and lignin which are mainly carhohydrates and their derivatives (Casey, 1960). The increased carbohydrates and their derivatives is eusily understood, since reduced moisture decreases growth, without having as much effect on photosynthesis (Levitt, 1956). Consequently, carbohydrates (soluble or insoluble) accumulate with stress. Soluble carbohydrates can also increase due to the conversion of insoluble carbohydrates like starch to soluble substances like sugar among others, as result of starvation. High percentage of alkali solubility is, however, undesirable in pulping; it predisposes wood to decay and in sulphite pulping process, yields are reduced and more alkali is consumed (Casey, 1960).

Alcohol benzene soluble substances (lipids, waxes and resins) are mainly lipids or their derivatives. High values of alcohol benzene solubles adversely affect the pulping process by frothing and clogging of pipes and the quality of the resulting pulp (Grant, 1961). In kenaf, these substances increased with increase in water deficit. Iljin (1930) showed very early that, elimination of the vacuole by contraction or thickening of the protoplasm or by filling with these nondrying substances accompanies the development of extreme drought hardiness Schmidt (1939) reported an increase in alcohol permeability in droughted plants which was explained as an increase in lipid permeability. On the basis of conclusions of other workers he suggested that the surface lipids are more basic in the droughted plants, more acid in the moist-grown plants.

5. Holistic assessment

Holistic analysis of the effect of water deficit on the physical and histochemical properties of kenaf relevant to pulp and paper production revealed that water deficit tended to improve the resulting pulp and paper quality of kenaf A similar result was obtained with *Gmelina arborea* (Ogbonnaya et al., 1992), in which water stress affected growth but not the resulting pulp and paper quality.

Water stress is not always injurious. Although it reduces vegetative growth, it sometimes improves the quality of plant products (Kramer, 1983). Mild water stress has been found to increase the rubber content of guayule and the desirable aromatic properties of Turkish tobacco (Wolf, 1962). It can be generally hypothesized, therefore, that some level of stress may be required to improve the fibre qualities of crop plants. This level of stress which does not affect growth, however, has to be worked out for each plant

Acknowledgements

This study was conducted at Center d'Etudes Regional pour l'Amelioration de l'Adaptation à la Secheresse (CERAAS), Bambey, Sénégal. The European Union (EU) provided the fund for this research (Grant N° FED 342 RPR).

References

Annerose, D.J.M., 1990. Recherches sur les mécanismes physiologiques d'adaptation à la secheresse: Application au cas de l'arachide (*Arachis hypogea* L.) cultivée au Sénégal. Doctorat These, Sci. Naturelles, Universite Paris VII.

Casey, J.P., 1960. Pulp and Paper Chemistry and Chemical Technology, Vol. 1. 2nd ed. Edward Arnold, London.

Enu-Kwesi, L., Nwalozie, M.C., Anyanwu, D.I. 1986. Effects of pre-sowing hydration-dehydration on germination, vegetative growth and fruit yield of Abelmoschus esculentus grown under two moisture regimes. Trop. Agri. 63, 181–184.

Francois, L.E., Donovan, T.J., Maas, E.V., 1992. Yield, vegetative growth and fibre length of kenaf grown on saline soil. Agronomy J. 84, 591–598.

Grant, J., 1961. A Luboratory Handbooh of Pulp and Paper Manufacture. 2nd ed. Edward Arnold, London

Hsaio, T.C., 1973. Plant responses to water stress. Annu. Rev. Plant Physiol. 24, 519–570.

Iljin, W.S., 1930. Die orsache der ressistenz von pflanzenzellen gcgen Austrocknung. Protoplama 7, 59–71

Jensen, C.R., 1989. Plant water relations approaches and measurements. In: Persson, R., Wredin, A. (Eds.), Vattninsbehov och Narings-tillforsel. Foredrag presenerade vid NJF seminarium nr. pp. 45-63. (151 Landskron t, 3 augusti (1989))

Kramer, P.J., 1963. Water stress and plant growth. Agronomy J. 55, 31–35.

Kramer, P.J., 1983. Water Relations of Plants. Academic Press, New York.

Levitt, J., 1956. The Hardiness of Plants Academic Press. New York.

Ogbonnaya, C.I., 1991. Aspects of the mineral nutrition ecology of *Gmelina arborea* seedlings. PhD Thesis Department of Botany, University of Port Harcourt, Nigeria.

Ogbonnaya, C.I., 1992 N and P nutrition o *Gmelina arborea* Roxb. seedlings on latasolic soil II: Effects of N and P fertilizers and their combinations on histochemical properties. Pertanika 15 (3), 207–216

Ogbonnaya, C.I., Nwalozie, M.C., Nwaigbo L.C., 1992 Growth and wood properties of *Gmelina arborea* (Verbenaceae) seedlings grown under five soil moisture regimes. Am. J. Botany 79 (2), 128–132.

Okereke, O.O., 1962. Studies on the fibre dimensions of some Nigerian timbers and raw materials. Part I Res Rep. N°16. Fed. Ministry of Commerce and Industry, Lagos. Nigeria.

Petri, R., 1952. Pulping studies with African tropical woods TAPPI 35, 157–160.

Robinson, F.E., 1988. Kenaf: A new fibre crop for paper production. Calif. Agric. 42, 31–32.

Rydholm, S.A., 1965. *Pulping process*. Inter. Wiley and Sons (Eds.), New York. pp. 1270 (reprint from Robert E. Kriegcr. Malabar, Florida (facsimile edition (1985)).

Schmidt. H.. 1939. Plasmazustand und wasserhaushalt bei *Lamium maculatum*. Protoplasma 33. 25 43.

Schulze, H.R., Matthew, M.A.. 1993. Growth. osmotic adjustment. and cell-wall mechanics of expanding grape leaves during water deficits Crop Sci. 33. 287 294.

Sellers, T., Miller, G.D.. Fuller. M.J., 1993. Kenaf core as a board raw material. For. Prod. J. 43. 69 71.

Swanson. C.A.. 1959. Translocation of organic solutes. In: Steward. F.C. (E:d.). Plant Physiology: A Treaties. Academic Press, New York, pp. 481 545.

Webber. C.L., 1993. Yield components of five kenaf cultivars. Agronomy J. SS. 533 535.

Wilson F.D., Summers, T.E., Joyner. J.F.. Fishler. D.W.. Seale. C.C., 1965. Everglade 41 and Everglade 71. two new varieties of kenaf (*Hibiscus cannabinus* L.) for the libre and seed. FL Agr. Exp. Sta. Cir. S-168.

White, F.D., Cummins, D.G.. Whitely. E.L.. Fike. W.T.. Grieg, J.K., Martin, J.A.. Klinpcr. G.B.. Higgins, J.J. and Clark. F.T.. 19 70. Cultural and harvesting methods for kenaf an annual crop source of pulp in thc southeast. ARS U.S. Department of Agric. Prod. Res. Report 113

Wolf, F.A., 1962. Aromatic or Oriental Tobaccos. Duke University Prcss. NC.