High Bio-Mass Sorghum (Sorghum bicolor) - An Alternate Raw Material For Pulp And Paper Making In India

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ABSTRACT

Shortage of conventional raw material for the pulp and paper products together with the increasing world demand for paper has renewed interest in non-wood fibres. It is estimated that commercial production from non wood pulp is about 8 %. The main sources of this depends upon the availability of the non wood material and crop residue such as wheat straw etc. with in the vicinity of the paper producing area. Each year it is estimated that about 11.2 million hectares of forest disappear. A convergence of environmental concerns and wood fibre shortage constraints has led to an increase in non-wood fibre production even in seemingly forest rich regions.

As such, efforts are being made to search for the crop, which not only can produce food but also energy, feed and fiber. The practices indicate that the high-bio mass sorghum meets partly the challenge.

High bio mass sorghum (*Sorghum bicolor* (L) Monech), as other types of sorghum is a C 4 crop. Having high photosynthetic efficiency it grows quickly. The essence of high biomass sorghum is not from its seed, but from its stalk, which grows tall above 14 feet. The bio mass production ranges between 215- 418q/ha, in duration of about 3.5 months. The stem of high bio mass sorghum contains 14-18% of cellulose. High bio mass sorghum contains high density of fiber structure (ranging between 0.8-1.6 microns in length and diameter between 30-60 microns) , the stalk is very suitable to be used as a raw material for papermaking industry

High bio mass sorghum has a wide adaptability. It can be grown in different types of soils with pH = 5 - 8.5. High bio mass can be grown in tropical, subtropical and temperate zones where so long as the temperature are above 10°C. In fact it can be grown in most of the areas of India if the appropriate cultivars are chosen carefully.

The studies conducted on high bio mass sorghum indicated that it could be pulped easily with the conventional soda pulping process. Pulping yields averaged 45%, and kappa numbers averaged 14-18, using 16-20% soda (NaOH) and 1.5 h cooking at 160°C. The pulp from high bio mass sorghum is characterized by short fibers and high proportions of fines. It can be used to produce low luminosity printing and kraft paper. The production of high bio mass sorghum stalk pulp only needs fewer chemicals than producing woody pulp, so it is quite suitable to be used for making quality paper.

Development of high biomass sorghum will play an important role in promoting the development of agricultural production paper making etc. Thus high biomass sorghum can be an alternate material source for the paper industry. If substituted for hardwoods or recycled paper these pulps could impart good printability properties to paper.

The present paper deals with the management practices for production of high bio-mass sorghum and preliminary laboratory results on pulp and paper making parameters.

Introduction

The pulp and paper industry in India is characterized by the dominance of small units below 10,000 tones per annum (TPA) capacity. While mills of large capacities mainly use wood and bamboo as raw materials, small mills depend on agricultural residues and waste paper. The contribution of forest (wood and bamboo), agricultural residues and recycled fiber sources is 38%, 36% and 26% respectively. (FAO Pulp and Paper Capacity Surveys).

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The most critical issue facing the Indian paper industry is the availability of cost-effective fibrous raw materials. There has been a chronic shortage of forest-based raw materials, viz. bamboo and pulpwood. The shortage is likely to escalate with dwindling forest cover. In present scenario, the paper is manufactured from three major kind of raw material, i.e., wood, agriculture residues and recycled fiber. The total wood used in paper manufacturing is 5.8 million tones per year in India. Due to shrinking forest land, one has to search for the alternative sources of fiber. Agriculture residue and the recycled fiber offer a great opportunity to replace the wood fiber.

Demand for papermaking fiber is projected to increase by 125 million tons per annum by 2015. This demand will be met by about 70 million tones of recovered waste paper with the balance being provided by fast-growing wood plantations and non-wood plant fibers.

Agricultural residues are a promising alternative to virgin wood fiber as an industrial feedstock. Residues are abundant, cheap, and their use will yield economic as well as environmental dividends. Paper manufacturer's use wheat straw and other agricultural bi products for production of paper on large scale. These are becoming scarce; hence there is a need to identify suitable agricultural produces/bi-products which can be utilized in manufacturing of paper. The

Paper Task Force report argued, "Using agricultural residues to make paper helps solve a waste management problem for farmers and provides an additional source of fiber for papermaking.

Sorghum [*Sorghum bicolor* (L) Monech] is one of the most important cereals of the semi-arid tropics of the world popularly called *poor man's food*. India is the second largest sorghum grain producer of the world and occupied seventh position in its productivity and one of the nine major growing countries. It is the major grain crop in India currently occupies 10.4 m ha areas with maximum areas in Maharashtra, Karnataka, Madhya Pradesh and Andhra Pradesh because of its diverse in use as food, feed, fodder, and fuel.

High biomass sorghum (sweet sorghum) straw is an excellent alternative to using virgin wood fiber for manufacturing of paper for many reasons. Aside from their abundance and renewability, using sorghum bio mass will benefit farmers, industry and human health and the environment. Reports have indicated that sorghum bio mass is being used in various countries for manufacturing paper.

Sorghum has better fiber content as compared to wheat thus making it a candidate suitable for manufacturing paper. Sorghum bio mass can be a cash crop. Traditionally farmers have harvested grain and burnt or otherwise disposed of straw and other residues (stalks, stover, etc.), but the heightened interest in making paper out of sorghum bio mass means that farmers can reap a "second harvest" from grain plantings. It has been estimated that a farmer could expect to see a 35 percent increase per ha in net farm income from selling sorghum straw.

The possibility of using high bio mass sorghum for pulp and paper making is not an innovation. However despite availability of diverse germplasm, little has been done to determine the feasibility of sorghum for this purpose. Byproducts of sorghum related plants have been used for making pulp in different countries.

Review of literature

A. K. Rajvanshi and N. Nimbkar (2006) assessed possible use of fiber from sweet sorghum bagasse for paper manufacturing. Some samples of bagasse from our sweet sorghum hybrid “Madhura” were given to M/s Shirke Paper Mills Pvt. Ltd., Shirwal for testing. They are one of the few bagasse-based paper manufacturing units in India. They carried out laboratory trials of cooking and bleaching on this material to determine its suitability for paper manufacture. The pulp evaluation showed that good quality pulp could be produced from sweet sorghum bagasse. The only problem envisaged by the paper mill was the handling of bagasse, which is very bulky. This was also expected to reduce the packing density in digesters.

Hallgren, L., et at. (1992) reported that pulps of sweet sorghum lines can be used for the manufacture of fine quality writing and printing paper as well as corrugated and solid particle board

Jianqiu Zou & Yuxue Shi (1995), Comparing other papermaking materials, sorghum leaves and stalks are easy to convert into pulp size chemical pulp use only a small amount of chemicals to fabricate paper products that are homogeneous and smooth. However, the paper made from sorghum stalks and leaves show strong transparency and brittleness plus poor folding and bursting.

Larbi Belayachi and Michel Delmas (1997) using sweet sorghum bagasse to manufacture chemical pulp concluded that the quality of the pulp obtained is excellent for the paper industry. Sweet sorghum can be considered as a major raw material for the paper industry. The pulp exhibits a degree of cohesion higher than 80%, a low kappa number indicating a good delignification, a high degree of polymerization, and exceptional physico-mechanical properties. Unexpectedly, the final results allow us to consider sweet sorghum as a major raw material for the paper industry in every region where it will be possible to grow it in association with sugar cane. These pulps can be used in sectors usually restricted to superior chemical pulps such as those obtained from softwood.

Li Dajue (2007), the stem of sweet sorghum contains 14-18% of cellulose. The output of cellulose of sweet sorghum reaches 7.5-15 t/ha. It is a fine material for papermaking industry. Because of the high density of the fibre structure of sweet sorghum, and it generates homogenetic lamina, the stalk residue is very suitable to be used as a raw material for papermaking industry.

Palmina Khristova, Suleiman Gabir (1990): Soda-AQ pulping of sorghum stalks increased the rate of delignification and the pulp yield and improved the strength properties compared to soda pulping, but the effect of AQ addition (0·13% on oven-dry raw material) was less pronounced than for tropical hardwoods. The wet-depithing of the stalks contributed considerably to the yield and strength properties, while the alkali consumption and rejects were decreased. The soda-AQ pulping makes pulping of sorghum stalks much more attractive and feasible, once the other technical constraints are overcome by employing the recent techniques developed for other agricultural residues.

Ratnavati, SS Rao and Chari Appaji (2010) evaluated 16 high bio mass sweet sorghum cultivars for their cellulose, hemicellouse and lignin contents. They observed that the cultivars NSSV 13, NSSV 254, NSSV 255 had high bio mass ranging between 7-8t/ha. They also reported low lignin content upto 4.1%, which is favorable indicator for sweet sorghum to become a candidate material for paper making.

Promising high biomass sorghum cultivars

High biomass sorghum (sweet sorghum) is well adapted to different types of climatic conditions and is one of the most efficient dry land crop which can convert atmospheric CO_2 into sugar. The duration of the crop is about 115 days.

High bio mass sorghum can be cultivated at an elevation between sea level and 1500 m above sea level, under temperatures ranging between 15 to 37°C, the optimum temperature for growth and photosynthesis is 32 to 34°C, 10-14 hrs day length, rainfall between 550-800mm. It can be cultivated under varied types of soils Alfisols (red) or Vertisols (black clay loamy) with pH 6.5-7.5.

High bio mass sorghum will survive with less then 300 mm rainfall over the season of about 105 days. It responds favorably with additional rainfall or irrigation water. In order to achieve good yields of over 50 tons/ ha total biomass fresh weight, typically sorghum will require 500-1000 mm of water (additional or /and irrigation).

Some of the promising released high biomass cultivars sweet sorghum for cultivation in the country is given in table 1.

Production technology for High energy sorghum (sweet sorghum) cultivation (*CV Ratnavatji et.al*)

The following package of practices are recommended for achieving high bio

Table 1: Promising high biomass sorghum cultivars.

Variety/ Hybrid	Pedigree	Plant heigh t (m)	Stalk yield (t/ha)	Remarks
SSV 84 (Variety)		2.8	35.6	First high bi mass sweet sorghum variety developed at MPKV, Rahuri, in 1992
CSH 22 SS (Hybrid)	ICSA 38 X SSV 84	3.5	46.5	Developed by Directorate of Sorghum research, Rajenderanagar, Hyderabad. Released for cultivation in India in 2005.
CSV 19SS (Variety)	RSSV 2 X SPV 462	3.3	36.8	Developed at AICSIP centre, Rahuri, Maharashtra India. Released for cultivation in India in 2005. This variety is shoot fly tolerant.
NSSV 13 (Variety)	NSS 1005A X (SSV 84 X 401 B	4.02	42.5	Tested as SPSSV 6 under All India Coordinated sorghum improvement project. High biomass tall, highly suitable for all types of climatic and soil conditions.
NTJ 2	Pure line selection from E -1966 *ZeraZera* land race.	2.9	34.7	The variety has excellent fodder quality when grown in rainy season. It is resistant to leaf diseases. Was released as a rabi variety for cultivation in Andhra Pradesh in 1990 as *Nandyala tella jonna* by ANGRAU

mass along with considerable quantity of grain. Prepare the field with deep plough, tilling etc, with fairly powdered soil. Organic manure if available should be applied @ 15 t/ha in red soils and 10 t/ha in black soils. Recommended nitrogen (N), phosphorus (P) and potash (K) dose is 80:60:40 with 50% N and full P_2O_5 and K_2O at final land preparation as basal and remaining 50 % N may be top dressed in two equal installments at 40^{th} and 60^{th} days after sowing.

Planting can be done on ridges and furrows made 60 cms apart, within ridges and furrows spacing is 15/20 cms. Optimum Seed rate is about 8 kg/ha. Dibble the seed in furrows/ridges with 3-4 seed per hole.

It is desirable to apply 20 kg/ha Furadon granules applied at the time of sowing. Granules may be applied along the furrows/ridges after marking a shallow furrow on ridge. Furadon is recommended as prophylactic treatment for insect pest control more specifically shoot fly in areas where the pest is sever. Planting is usually done in the month of June. Spraying of Atratof soon after sowing but before germination @0.5 a.i. at the rate of 25g/ha could control di-cot weeds. Inter-cultivation operations carried out twice once 30 days after sowing and 2^{nd} 45 days after sowing control unwanted weeds. Ensure irrigation if necessary.

Evaluation of high biomass sweet sorghum for paper making potential

Proximate Chemical analysis of sorghum:

For proximate chemical analysis the sample of sorghum first dried and dust was prepared in dust making machine. Proximate chemical analysis of sorghum for various parameters as lignin, solubility, holocellulose etc. was carried out following standard procedure.

Raw Material Preparation: Raw material after harvesting collected in bundles. It contains very high moisture, which was initial more than 50%. The sorghum stems were spread for drying. After one week the dried material was collected, with dried material 66% and moisture content 34% . Sorghum stalks are of length around 14 feet, which needed to be chopped before pulping. For laboratory scale pulping trials stalks were chopped in length of average 2 inch. Sufficient quantity of chopped sorghum was collected on polythene bags. The moisture content of chopped sorghum sample of both species was determined before pulping.

Pulping of Sorghum:

Pulping experiments were carried out using different cooking chemical dose. Experiments were performed in a series digester consisting of six bombs of 2.5-liter capacity, rotating in an electrically heated polyethylene glycol bath. At the end of the cooking, the bombs were removed and quenched in the water tank to depressurize .The cooked mass from each bomb was taken for washing. Washing was carried out with hot water till the cooked mass was free from spent liquor. After thorough washing, the unscreened pulp yield was determined and the pulp was screened in laboratory 'Serla' screen by using mesh of 0.25 mm. slot width. Kappa number of the screened pulp was determined as per the Tappi standard procedure T-236-OS-76.

Viscosity and Brightness:

Intrinsic viscosity of the pulp is measured for different pulp samples of using Scan procedure C-15:65. The brightness of the unbleached pulps was measured using as per ISO method.

Table 2: Performance of two high biomass sorghum genotype (crop duration 115 days)

Characteristics	HSSV 46	NSSV 13
Pedigree	IS 8218 X IS 6962	NSS 1005A X (SSV 84 X 401 B) NSS 1005 A = 11B1, SSV 84= Sel. From *ZeraZera* sorghum IS 23568
Plant height (ft)	12.3	13.2
Stem thickness (cm)	3.25	3.4
Biomass yield (t/ha)	40.8	42.5

Result and discussion

Evaluation of 2 high biomass sorghum cultivars for production potential

The Two high biomass sorghum cultivars tested are in terms of the evaluated parameters such as plant height, stem thickness and biomass yield. However the crop could not harvest any seed due to heavy damage of the ear heads by birds. The performance indicated that green bio mass yield in the range of 40 - 42 t/ha can be obtained, with the plant height ranging between 12- 13 feet.

Proximate Chemical analysis of high biomass sorghum

The proximate chemical analysis of high biomass sorghum was carried out following standard methods. The results of proximate chemical analysis of both species are shown in table 3 below**.**

It is evident from table 3 that the holocelluoce content in high bio mass sorghum is 61.15 per cent. This is indication that composition of fibre supports the production of paper pulp from sorghum.

Table 3- Proximate chemical analysis of sorghum

S.No.	Parameters	Unit	Sorghum	Wheat straw	Bagasse
1.	Ash content	(%)	4.195	5.7	2.5
2.	Cold water solubility	(%)	13.97	5.4	3.0
3.	Hot water solubility	(%)	18.27	9.6	5.1
4.	Alkali solubility (N/10)	(%)	48.61	36.1	35.5
5.	Pentosan content	(%)	19.73	19.8	26.0
6.	Holocellulose content	(%)	61.15	74.0	71.5
7.	Acid insoluble lignin content [1]	(%)	21.45	19.9	21.2
8.	Acid soluble lignin content [2]	(%)	1.33	1.5	2.0
9.	Alcohol benzene solubility	(%)	9.92	2.8	2.5
10.	Alpha cellulose	(%)	58.53	39.2	41.7
11.	Beta cellulose	(%)	23.27	18.6	17.7
12.	Gama cellulose	(%)	18.19	16.2	12.1

[1]Total lignin corrected for ash content.
[2].Holocellulose corrected for ash & lignin content.

Acid insoluble lignin is 21.45 per cent, which is comparable to other fibrous raw materials used for paper making. This is comparable to other agro based fibrous raw materials used for paper making like wheat straw (19.9%) and bagasse (21.2%).

Alkali solubility is higher due to pith and other degradable components. The depithing of sorghum will help in further improvement of raw material composition before the cooking.

Chemical composition of sorghum

The evaluation of sorghum for its chemical properties indicated that sorghum contains about 90% dry matter and 6 % crude protein. The cell wall percentage of sorghum is about 65%.(Table 4)

Table 4: Chemical composition of sorghum

	DM %	CP%	Cell wall %
High bio mass Sorghum	90	6	65

DM: Dry matter, CP: Crude Protein, %: percent.

The fiber dimension of sorghum indicated that the fiber length ranged between 0.8 to 1.2 microns, while the diameter ranged between 30 to 80 microns. This indicates that sorghum biomass is highly suitable for use in pulp and paper making (Table 5)

Fiber dimension

Table 5: Fiber dimensions of high bio mass sorghum

	Length (Microns)		Diameter (Microns)	
	Min	Max	Min	Max
High bio mass Sorghum	0.8	1.6	30	80

Pulping Optimization of high bio mass sorghum sample

Pulping experiments of sorghum were carried out for both high bio mass sorghum varieties *viz* HSSV 46 and NSSV 14. The cooking condition for analysis of high biomass sorghum was undertaken using the standard analysis procedures of TAAPI. The bath ratio (raw materials to liquor ratio) used was 1:4. The cooking schedule followed is given in table 6.

Table 6: Cooking conditions for analysis of high biomass sorghum

Raw Material taken in each bomb	200 gm. (B.D.)
Bath Ratio (raw material to liquor ratio)	1:4
Cooking Schedule	
Cooking time	90 min.
Ambient to 100 ^{o}C	30 min.
100 ^{o}C to 165 ^{o}C	90 min.
At 165 ^{o}C	90 min.

Table 7 depicts the pulping optimizations results. It is clear that the pulping optimization of soda AQ process of high bio mass sorghum of both varieties is different, where in HSSV 46 the chemical demand is low, for NSSV 14 it is on higher side.

To achieve bleachable grade chemical pulp of high bio mass sorghum requires 18% alkali with 0.05% Antraquinone. The kappa number obtained was 16.06. Of the two varieties evaluated, HSSV 46 required 16% alkali with 0.05% Antraquinone to achieve bleachable grade chemical pulp, the kappa number obtained was 14.11. The yield obtained was 48.8% with 0.82% rejects. The pulp has shown very good intrinsic strength of 1126 cc.g. While for NSSV 14 at the 18% alkali with 0.05% Antraquinone was required for achieve bleachable grade chemical pulp the kappa number obtained was 19.6 and unbleached pulp yield of 45.0. The pulp viscosity was 1258cc/g. This indicates that the chemical demand of sorghum varies with the type/species of sorghum.

Unscreened pulp yield of high biomass sorghum ranges from 45 to 48%, which is comparable to other agro residual raw material.

Physical Strength Properties Of Sorghum Pulp And Its Comparison With Wheat Straw and bagasse Pulp

The results of physical strength

Table 7: Pulping Optimization Sorghum

Single Stage	Unit	HSSV 46			NSSV 14			Mean
Cooking Process		S-AQ	S-AQ	S-AQ	S-AQ	S-AQ	S-AQ	S-AQ
Moisture in Raw material	%	66	66	66	66	66	66	66
OD weight, taken	g	200	200	200	200	200	200	200
Material weighed	g	303	303	303	303	303	303	303
Alkali Applied as Na_2O	%	16	18	20	16	18	20	18
Additive , AQ	%	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Bath Ratio	-	1:04	1:04	1:04	1:04	1:04	1:04	0.04
Unscreened Yield	%	48.8	45.7	45.6	46.02	45	44.8	45.99
Rejects (0.2mm sieve size)	%	0.82	1.04	0.82	1.62	1.17	1	1.08
Kappa Number	-	14.11	10.73	9.74	24.2	19.6	18	16.06
Brightness, I.S.O.	%	26.02	27	28.5	22.1	23	24.4	25.17
Viscosity	cm^3/g	1126	-	-	-	1268	-	1197

properties are depicted in table 8. The burst index of sorghum 3.77 K Pam^2/g respectively, which is comparable to wheat straw (4.32) and bagasse (4.5) chemical pulp. Tensile index of sorghum pulp recorded is 71.6 Nm/g. This is better when compared with wheat straw pulp (62.1Nm/g) and bagasse pulp. Tear index for sorghum is 5.8 mNm^2/g respectively which is also comparable to that of wheat straw (5.0mNm^2/g) and bagasse (5.10 mNm2/g)

Conclusion

High bio mass (sweet sorghum) sorghum being a short duration crop can be a cash crop. It can be a supplement to the other agro-residues in the off season when wheat straw/baggasse is not abundantly available. The heightened interest in making paper out of sorghum means that farmers can be benefited through cultivation of high bio mass sorghum which can produce high quality biomass. It has been estimated that a farmer could expect to see a 35 percent increase per ha in net farm income from selling high bio mass sorghum.

Sorghum leaves and stalks are raw materials suitable to manufacturing paper pulp, which can be used to manufacture writing paper (rough straw paper), wrapping paper, and other paper products. The study carried out on whole sorghum. Chemical analysis of sorghum justifies its suitability for a potential papermaking raw material, where all parameters are comparable to other agro residual raw materials as baggasse and wheat straw.

Compared to other raw materials (wheat and baggasse) used in paper manufacturing, sorghum leaves and stalks are easier to convert into pulp. They even have the paramount advantage of requiring smaller usage of chemical ingredients during the pulping process. The resulting pulp being more homogeneous, smooth and malleable the paper made from sorghum stalks and leaves show strong transparency and brittleness plus better folding and bursting qualities. Yield of sorghum pulp ranges from 45 to 48%, which is comparable to other agro residual raw material. A better quality pulp with higher yield can be produced after proper depithing of sorghum.

The study on sorghum pulping allows us to consider sorghum as a major raw material for the paper industry in every region where it will be possible to grow.

Table 8: Physical Strength Properties Of Sorghum Pulp And Its Comparison With Wheat Straw and bagasse Pulp

Particulars	PFI (rev)	Freeness ml, C.S.F.	Apparent Density g/cm^3	Burst Index $KPam^2/g$	Tensile index Nm/g	Tear Index mNm^2/g	Fold Kohler Molin (log)	Porosity Bendsen ml/min.
Sorghum	500	305	0.72	3.77	71.6	5.8	1.99	185
Wheat straw soda pulp	500	260	0.72	4.32	62.1	5.0	1.72	25.5
Unbleached bagasse pulp	500	300	0.88	4.5	76	5.1	2.63	21.8

References

1. A. K. Rajvanshi and N. Nimbkar (2006): Sweet sorghum R&D at the Nimbkar Agricultural Research Institute (NARI), www.naripaltan.org .
2. CV Ratnavathi, B.Dayakar Rao, PG Padmaja, S. Ravi Kumar, Ch. Shashidhar Reddy (2005) Sweet sorghum: the wonder crop for biofual production.NRCS, Rajendernagar, Hyderabad AP 500 030 India. Pp24.
3. CV Ratnavati, SS Rao and Chari Appaji (2010) Sweet sorghum bagasse as raw material for paper making, Jowar Samachar, Vol. 6 No.1, Feb 2010, NRCS, Hyderabad.
4. Hallgren, L., Rexen, F., Peterson, P. B., and Munck, L. 1992. Industrial utilization of whole crop sorghum for food and industry. Pages 121-130 in Utilization of sorghum and millets : proceedings of the international workshop on policy, practice, and potential relating to uses of sorghum and millets, 8-12 Feb. 1988, ICRISAT Center, Bulawayo, Zimbabwe. International Crops Research Institute for the Semi-Arid Tropics.
4. Jianqiu Zou & Yuxue Shi(1995) Industrial use of sorghum, Chapter VIII, http://www.fao.org/inpho/content/compend/text/ch08.htm
5. Larbi Belayachi and Michel Delmas (1997) Sweet sorghum: A quality raw material for the manufacturing of chemical paper pulp Biomass and Bioenergy, Volume 8, Issue 6, 1995, Pages 411-417
6. Li Dajue (2007): Developing Sweet Sorghum to Meet the Challenge of Problems on Food, Energy and Environment in 21st Century, www.ifad.org.
7. P. Khristova and S. Gabir, (1990) Soda-anthraquinone pulping of Sorghum stalks. *Biological Wastes* 33, pp. 243250.
8. Palmina Khristova, Suleiman Gabir (1990): Soda-anthraquinone pulping of sorghum stalks Biological Wastes, Volume 33, Issue 4, 1990, Pages 243-250.