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Fibre and Elemental Contents of *Thaumatococcus daniellii* Stalk and its Implications as a Non-Wood Fibre Source

Sotannde O.A.
Department of Forestry and Wildlife
Faculty of Agriculture
University of Maiduguri, Maiduguri, Borno State, Nigeria

Oluwadare A.O.
Department of Forest Resources Management
Faculty of Agriculture and Forestry
University of Ibadan, Ibadan, Oyo State, Nigeria

Abstract

The fibre and elemental content of Thaumatococcus daniellii stalk was evaluated to assess its potential as a Non-Wood Fibre Source (NWFS). The stalks were harvested under cocoa plantations within a 10mx10m plot from three locations in the south-western part of Nigeria. Each plot was subdivided into two for Early Harvest Stalks (EHS) and Late Harvest Stalks (LHS). The EHS with characteristic green and glossy leaves were classified as young stalks and LHS with emerged flower and fruits as mature stalks. Both were analyzed for crude fibre, ash, silica, lignin, holocellulose, alpha-cellulose, hemicellulose and mineral contents. Site variations had significant effect on the fibre and elemental contents of the stalk ($p < 0.05$). In contrast little variation was observed with maturity stage. The stalk could be classified as NWFS based on its high crude fibre (33.36%), holocellulose (66.80%), α-cellulose (39.0%) and hemicellulose (27.81%) contents and low ash (2.79%), silica (0.85%), lignin (13.03%) and elemental accumulations. Except lignin and ash, the fibre contents are strongly correlated with one another ($p < 0.01$) but nutrient elements did not. Among the nutrient elements, only nitrogen, potassium and iron showed significant correlations with crude fibre and cellulose contents. It is therefore concluded that nitrogen, potassium and iron are the main elements contributing to the physiological development and fibre quality of T. daniellii stalk. Thus nitrogen and potassium based fertilizer is suggested for T. daniellii production to obtain high fibre quality.

Keywords: fibre contents, nutrient elements, inter-relationship, *T. daniellii*, non-wood fibre source

1.0 Introduction

Globally, the growth in pulp and paper production entails massive felling of trees, which in turn leads to deforestation. In Nigeria, the huge investment on the importation of long fibre pulp and inability to have sustained local long fibre resource base are two of the major reasons for the moribund and complete closure of the Nigerian pulp and paper mills (Udihitinah and Oluwadare, 2011). The major concern now is how to meet the increasing demand for pulp, paper and paper products in the Country. To avoid mistakes of the past, there is the need to consider alternative Non-Wood Fibre Source (NWFS) option for papermaking. *Thaumatococcus daniellii*, which is the focus of this work, can readily fit in as one of the NWFS with tremendous potentials.

T. daniellii is a renewable fast growing annual crop capable of self-regeneration after harvest. It is a perennial, rhizomatous and monocotyledonous herb which grows through its rhizomes up to 3m in height. It is a member of the Maranthaceae family with *Megaphrynium macrostachyum* (K.Schum) (Jennings et al., 2001). It is indigenous to the rainforest of West Africa particularly the southern parts of Ghana, Cote d'Ivoire and Nigeria (Arowosoge and Popoola, 2006). It has a simple smooth stem bearing stalked leaf. The stalk terminates into a single tough, almost round and versatile leaf that is about 40-50cm long and 30-35cm wide depending on the age and habitat of the plant (Makinde and Taiwo, 2004). At maturity, the plant produces flowers, which later develop into an edible berry (fruit) containing high amount of thaumatin. Quite many populations depend on miraculous berry for economic benefits. The sweetener can be used in pharmaceutical "mineral drinks", beverages and confectioneries industries. The leaf is widely used for wrapping, stalks for weaving and its roots for curing many ailments (Ojekale et al., 2007).

Lately, the stalk has been discovered to be a potential NWFS for pulp and papermaking (Oluwadare and Sotannde, 2005; Oluwadare and Sotannde, 2006; Ogunsanwo et al., 2012).

The fibrous and nutrient element constituents of a plant give an idea of how feasible the plant is as a NWFS for papermaking. For a candidate plant, the cell-wall must have high cellulose (holocellulose and alpha cellulose) and low lignin, ash, silica and nutrient element contents. While crude fibres and cellulose correlates with pulp yield, the lignin content gives an idea of chemical requirement for pulping. The nutrient elements on the other hand are essential for the growth and development of a plant (Nasri et al., 2008). The nutrient element requirements by individual plant determined their concentration in the plant tissue (Gumuskaya et al., 2007). Essential roles of nutrient elements in the plant notwithstanding, they are regarded as impurities in pulp and papermaking process. Silicon is the most deleterious element in the raw material for papermaking, because it complicates the recovery of chemicals and energy in pulp mills (Gonzalez et al., 2008).

Furthermore, nutrient elements like Nitrogen (N), Phosphorus (P), Potassium (K), Iron (Fe), Copper (Cu), Lead (Pb) and Manganese (Mn) may have a negative effect on different steps of pulp and paper manufacturing processes (Pahkala and Pihala, 2000). Hence, for a non-wood fibre to be qualified for inclusions into global non-wood fibre resource base it must fulfill all the technical requirements for pulp and paper production. One of such requirement is high fibre yield and low nutrient element composition. This study was therefore undertaken to analyze the fibre and nutrient element contents of *T. daniellii* stalk and its utilization potentials for pulp and papermaking. Also, the influence of location and maturity stage on the fibre and nutrient element composition of the plant was studied. Lastly, the relationship between the fibre and elemental contents was studied to determine the traits responsible for the variations in fibre properties and elemental requirement of the plant.

2.0 Materials and Methods

The stalks of *T. daniellii* used for this study were harvested within a 10m x 10m sample plot under cocoa plantations in Aderupatan (Lat. 6° 57' 0" N, Long. 3° 30' 0" E), Ikeji-Ile (Lat. 7° 41' 04" N, Long. 4° 49' 01" E) and Odo-Owa (Lat. 7° 53' 05" N, Long. 5° 4' 11" E) in Ogun, Osun and Ekiti States Nigeria, respectively. Each plot was subdivided into two for Early Harvest Stalks (EHS) in July and Late Harvest Stalks (DHS) in January. The EHS with characteristic green and yellowish leaves were classified as young stalks and LHS with emerged flowers and fruits as matured stalks. Both EHS and DHS were harvested at the ground level, de-capped of their leaves and transported fresh to the laboratory for analysis. Twenty stalks from each location and maturity stage were randomly selected, cut to short lengths of 5cm, dried separately at first for 2hours at 105^{O}C and then 17hours at 60^{O}C to constant moisture content.

The oven dried samples were milled to less than 1mm diameter. From the milled samples, the Crude Fibre (CF) content was determined based on modified acid-alkaline (1.25% H_2SO_4 - 1.25% NaOH) extraction sequence described in Association of Analytical Chemist (AOAC, 1980) using Fibretec system consisting of hot (1020 hot extractor) and cold (1021 cold extractor) extraction units. The ash content was obtained by heating the samples in a furnace at 500^{O}C for 4hours based on ASTM Designation D1102-50T while the ash obtained was digested with hydrochloric acid to obtain the silica content. To obtain the holocellulose, alpha cellulose, hemicellulose and lignin contents. The milled samples were first extracted with ethanol-benzene to make the samples extractive free. The holocellulose content of the extractive free samples was determined by extraction in 50ml of 95% ethanol and hot ethanol-monoethanolamine solution based on ASTM designation D1104-50.

The holocellulose obtained was treated with sodium hydroxide and glacial acetic acid to obtain its alpha cellulose content based on ASTM designation D1103-60. The hemicellulose content was then obtained by subtracting the alpha-cellulose fraction recovered from the holocellulose. The acid-insoluble lignin content was obtained by digesting the the extractive free milled samples with 72% cold sulphuric acid based on ASTM designation D1106-96. The concentrations of K, Fe, Mn and Cu were measured using Perkin Elmer 200 Flame Atomic Absorption Spectrometer (AAS). The Nitrogen content was determined using the Kjeldahl method (Tecator 1981) with Kjeltec Auto 1030 Analyzer (Tecator, 1981) and P by spectrophotommetry. Each test was replicated five times. The data obtained was subjected to analysis of variance, descriptive statistics and correlation analysis.

3.0 Results and Discussion

3.1 Fibre Properties

Site variations had significant effect on all the fibre contents evaluated ($p < 0.05$). By contrast, only the crude fibre ($p=0.014$), ash ($p=0.013$) & lignin content ($p=0.033$) were significantly influenced by maturity stage (Table 1).

The stalks harvested from Ikeji-Ile had the highest crude fibre (34.14%), lignin (13.04%), holocellulose (67.36%) and alpha-cellulose (39.71%) contents while the highest hemicellulose (27.97%), ash (3.12%) and silica (1.02%) contents were obtained in those harvested from Odo-Owa. Without exception, the stalks harvested from Aderupatan had the least fibre content accumulations (Table 2). This implied that site differences in terms of soil conditions, climate and farming practices could play significant role in determining the amount of fibre contents deposited in the plant cellular structure. High crude fibre, holocellulose, alpha-cellulose and hemicellulose contents are desirable for the utilization potential of a NWFS for pulp and papermaking.

This is because crude fibre and cellulose content of a woody plant have been discovered to be positively correlated with pulp yield (Shakhes et al., 2011). Also, Singh et al. (2011) reported that the higher the cellulose contents of a plant material, the better the swelling behaviour of the pulp produced from it. On the average, *T. daniellii* could be classified as a fibrous plant as evidenced by the relatively high crude fibre (33.36%), holocellulose (66.80%), alpha-cellulose (39.0%) and hemicellulose (27.81%) of its stalks. According to the rating system designed by Nieschlag et al. (1960), NWFS with alpha-cellulose ≥ 34% are characterised as promising for pulp and paper manufacture from chemical composition point of view. On the contrary, high ash, silica and lignin contents are undesirable during pulping, as they affect normal alkali consumption and give problem during recovery of cooking liquor (Rodriguez et al., 2008). The average ash (2.79%), silica (0.85%) and lignin (13.03%) contents of *T. danellii* stalks are quite low and compared with those in notable NWFS like kenaf and hemp (Dutt *et al*., 2009), Jute (Marques et al,. 2010), bamboo (Ogunsile and Uwajeh, 2009). This in practice implied that mild pulping conditions will be required for *T. daniellii* stalk.

Meanwhile, all the fibre contents but ash increased as the stalks become more matured. Thus, LHS had comparative higher crude fibre (33.80%), silica (0.91%), lignin (13.16%), holocellulose contents (67.10%), α-cellulose (39.25%) and hemicellulose (27.85%) compared to 32.93, 0.78, 12.93, 66.51, 38.74 and 27.77% obtained for crude fibre, silica, lignin, holocellulose, α-cellulose and hemicellulose respectively in EHS (Table 2). Also, higher degree of variability as expressed by coefficient of variation was obtained in EHS compared to LHS across the three sites (Table 3). The higher fibre contents except ash in LHS could be attributed to the relative increase in the amount of plant cell-wall contents as the plant become more matured. Another possible reason for the fibre increase in LHS could be attributed to higher weight of the dried stalk biomass and associated cell wall concentration which is higher in mature plant (Pahkala, 2001). The decrease in ash content as the plant gets matured, suggests that it is possible to decrease the ash content of the stalks by delaying the harvesting time.

3.2 Elemental Properties

All the nutrient elements (N, P, K, Fe, Mn, and Cu) evaluated in *T. daniellii* stalks varied significantly with location ($p < 0.001$). Out of these, only K ($p = 0.014$) and Cu ($p = 0.042$) varied with maturity stage (Table 4). Among these nutrient elements, K and N were the most abundant in the stalks harvested from the three sites while Fe and Cu were the least. It was also evident that concentrations of nutrient elements deposited in the EHS were always higher than those in LHS (Table 5). Many authors have adduced reasons for the differences in nutrient composition in plant tissues with maturity.

Pahkala (2001) attributed this to variation in soil type and availability of nutrients in the soil. This is evidenced when nutrient elements in the stalks from each location were compared. For example, though the stalks harvested from Odo-Owa had the highest accumulation of N and P, they had the least Fe, Mn and Cu contents. Similarly, the stalks harvested from Aderupatan were the richest in K, Fe, Mn and Cu, but were the poorest in P. Without exception, the stalks harvested from Ikeji-Ile had intermediate mean elemental concentrations (Table 5). In terms of degree of variability, the coefficient of variation of the elemental concentrations varied more among locations than between maturity stage (Table 6). This result suggests that site was the factor that is more strongly associated with variation in elemental contents of *T. daniellii* stalk than the maturity stage.

Meanwhile, all the elemental concentrations but cupper decreased the more the stalks become more matured. Hence the comparative higher N (0.401%), P (0.055%), K (0.516%), Fe (0.0133%) and Mn (0.0198%) obtained in the EHS compared to 0.397, 0.052, 0.491, 0.0131 and 0.0195% recorded for N, P, K, Fe, and Mn in LHS (Table 5). Thus, the requirement of these nutrients by plant for growth and physiological processes determines its concentration in the plant tissue. This could be the reason why EHS with ability to grow with vigour had higher nutrient concentration in its tissue than LHS. Though, these elements are essential for the growth and development of a plant, they have negative effects on different steps of pulp and paper manufacturing processes (Gonzalez et al., 2008).

For instance, high concentration of nutrient elements such nitrogen in the spent liquor can lead to generation of NOx in the chemical recovery furnace, Potassium can combine with chlorine (KCl) leading to corrosive effect on metal parts in the furnace and boiler (Salmenoja and Makela, 2000), as well as particulate emission while high content of phosphorus in the spent liquor can prolong thermo-chemical conversion process (Nussbaumer, 2002), thereby leading to extra costs. Similarly, high contents of heavy metals like Fe interferes with hydrogen peroxide and oxygen bleaching thereby requiring treatment with chelating agents (Agnihotri et al., 2010). Mn and Cu can enhance the formation of deposits on recovery furnace.

They also react together with other transition elements unselectively with pulp causing loss of yield and strength properties (Rousu et al., 2002). All these made the quality of paper pulp to be dependent on quality and homogeneity of the biomass used as raw material, as well as the impurities originating from soil. Thus, the low concentrations of nutrient elements in the stalk of *T. daniellii* offers great advantage because of the expected low NOx and particulate emission, low deposition and corrosion of metal parts in the furnace and boiler and un-prolonged thermo-chemical conversion process during pulping and recovery of cooking liquor.

3.4 Relationships between Fibre and Elemental Properties

The bivariate correlation analysis of the fibre and nutrient elements are presented in Table 7. The relationship between crude fibre and cellulose contents (holocellulose, alpha-cellulose and hemicellulose) was positive and significantly different from zero ($p < 0.01$). In contrast, a strong negative correlation exists between cellulose and ash content. Thus except lignin and silica contents, the fibre contents are strongly inter-related. The implication of this is that the cellular processes inducing fibre content variations were highly dependent on each other. However, unlike fibre contents, the cellular processes inducing elemental variations were less dependent of each other. Among all the nutrient elements evaluated, only nitrogen exhibited significant and positive correlations with phosphorus, potassium and iron ($p < 0.05$) while others were weakly correlated with one another ($p > 0.05$).

Meanwhile, poor correlations were found between elemental and fibre contents. This is similar to what obtains in savanna grasses (Geogladis and McNaughton, 1990). The implication of this is that fibre and elemental contents are not good indices for explaining each other. The only exception to this is ash which had significant positive correlation with all the nutrient elements. Hence, the ash content is indicated as the totality of inorganic constituents in a plant fibre and its concentration is strongly dependent of elemental content accumulated in the plant tissue. Of all the nutrient elements, only nitrogen, potassium and iron showed significant correlations with crude fibre and cellulose content. This could be due to the importance of these elements in most biological processes of the plant. For instance, nitrogen is important in nucleic acid synthesis (Tatar et al., 2010) and has significant correlation with fibre yield (Liu et al., 2000), potassium is the main contributor to the cytoplasmic and osmotic potential of fibre cells (Pervez et al., 2004) while iron is important in photosynthetic process and in the formation of the chlorophyll molecule (Curie et al., 2009). Hence, their concentrations are expected to vary with the processes that induced physiological development and fibre quality of the stalk. Therefore, to enhance higher fibre yield, nitrogen and potassium based fertilizer is suggested for *T. daniellii* production.

4.0 Conclusion

1. The result of this work showed that site distinctions significantly influenced the fibre and elemental contents of *T. daniellii* stalk. In contrast little variation was observed with respect to maturity stage. This suggests that fibre and elemental composition of a plant can be linked to its genetic base, maturity stage (actual and biological) and the environment where it is grown.

2. The stalk has enormous potential as a NWFS based on its high holocellulose, alpha-cellulose and hemicellulose contents and low lignin, ash, silica and elemental contents.

3. The crude fibre and cellulose (holocellulose, alpha-cellulose and hemicellulose) contents of the stalk are strongly interrelated. In contrast, the cellular processes inducing elemental variation were less dependent on each other. Also, the weak correlation between fibre and elemental contents showed that it is difficult to fully explain the fibre content variability based on elemental content accumulation.

4. Among the elements, only nitrogen, potassium and iron had significant influence on crude fibre and cellulose contents while all the nutrients elements are strongly correlated with ash content.

5. The study concluded that nitrogen, potassium and iron are the main elements contributing to the physiological development and fibre quality of *T. daniellii* stalk. Therefore, nitrogen and potassium based fertilizer is suggested for *T. daniellii* production to obtain high fibre yield.

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Table 1: Significance (P values) of Variations in Location and Maturity Stage on the fibre properties of *T. daniellii* Stalk

Sources	Df	Crude fibre	Ash	SiO_2	Lignin	Holo cellulose	Alpha cellulose	Hemi cellulose
Locations (L)	2	0.004	0.023	0.001	0.004	0.027	0.008	0.018
Maturity Stage (MS)	1	0.014	0.013	0.078	0.033	0.060	0.097	0.086
L x MS	2	0.986	0.657	0.351	0.166	0.913	0.659	0.516
Error	24							
Total	29							

* P-values > 0.05 are not significant.

Table 2: Effect of Locations and Maturity Stage on the fibre properties of *T. daniellii* Stalk

Source	Crude fibre %	Ash %	SiO_2 %	Lignin %	Holo cellulose %	Alpha Cellulose %	Hemi cellulose %
Location							
Aderupatan	32.61^{b}	2.39^{b}	0.65^{b}	12.82^{b}	66.30^{b}	38.51^{b}	27.65^{a}
Ikeji-Ile	34.14^{a}	2.87^{ab}	0.87^{a}	13.04^{ab}	67.36^{a}	39.71^{a}	27. 79^{a}
Odo-Owa	33.35^{ab}	3.12^{a}	1.02^{a}	13.28^{a}	66.75^{ab}	38.77^{b}	27.97^{a}
Maturity Stage							
EHS (Young)	32.93	3.07	0.78	12.93	66.51	38.74	27.77
LHS (Matured)	33.80	2.52	0.91	13.16	67.10	39.25	27.85
Mean	33.36	2.79	0.85	13.05	66.80	39.00	27.81

* Means of 5 replicate samples. Values with the same alphabet in each column are not significantly different at $\alpha = 0.05$ using Duncan multiple range test.

Table 3: Descriptive Statistics of the fibre properties of *T. daniellii* Stalk

Fibre content	EHS (Young)			LHS (Matured)		
(%)	Aderupatan	Ikeji-Ile	Odo-Owa	Aderupatan	Ikeji-Ile	Odo-Owa
Crude fibre						
Mean	32.88	33.74	32.16	33.81	34.54	33.06
CV %	2.89	1.45	2.55	3.76	1.80	3.24
Ash						
Mean	2.54	3.25	3.42	2.24	2.49	2.83
CV %	19.29	13.85	16.96	23.21	28.51	20.49
Silica						
Mean	0.64	0.82	0.88	0.66	0.92	1.16
CV %	35.94	17.07	17.06	34.85	7.61	25.86
Lignin						
Mean	12.72	12.80	13.27	12.92	13.28	13.29
C.V (%)	1.89	3.28	1.43	1.86	2.18	1.33
Holocellulose						
Mean	66.02	66.98	66.52	66.58	67.75	66.97
C.V (%)	0.89	1.81	0.65	0.93	1.74	0.79
α-cellulose						
Mean	38.36	39.54	38.32	38.66	39.88	39.22
C.V (%)	0.76	1.77	4.12	1.45	1.73	0.79
Hemicellulose						
Mean	27.66	27.44	27.75	27.92	27.86	28.20
C.V (%)	2.13	4.23	0.79	1.00	1.76	5.74

Table 4: Significance (P values) of Variations in Location and Maturity Stage on the Nutrient Element Contents in *T. daniellii* Stalk

Sources	Df	N	P	K	Fe	Mn	Cu
Locations (L)	2	0.001	0.001	0.001	0.001	0.001	0.001
Maturity Stage (MS)	1	0.094	0.141	0.014	0.365	0.415	0.042
L x MS	2	0.451	0.766	0.414	0.347	0.135	0.861
Error	24						
Total	29						

* P-values > 0.05 are not significant

Table 5: Effect of Locations and Maturity Stage on the Nutrient Element Content in *T. daniellii* Stalk

Source	N %	P %	K %	Fe %	Mn %	Cu %
Location						
Aderupatan	0.381^{c}	0.048^{c}	0.544^{a}	0.015^{a}	0.021^{a}	0.0071^{a}
Ikeji-Ile	0.401^{b}	0.054^{b}	0.474^{b}	0.013^{b}	0.020^{a}	0.0056^{b}
Odo-Owa	0.415^{a}	0.059^{a}	0.493^{b}	0.012^{c}	0.018^{b}	0.0055^{b}
Maturity stage						
EHS (Young)	0.401	0.055	0.516	0.0133	0.0198	0.0058
LHS (Matured)	0.397	0.052	0.491	0.0131	0.0195	0.0063
Mean	0.399	0.054	0.504	0.0132	0.0197	0.0061

* Means of 5 replicate samples. Values with the same alphabet in each column are not significantly different at α = 0.05 using Duncan multiple range test.

Table 6: Descriptive Statistics of the Nutrient Element Content in *T. daniellii* Stalk

Nutrient elements (%)	EHS (Young)			LHS (Matured)		
	Aderupatan	Ikeji-Ile	Odo-Owa	Aderupatan	Ikeji-Ile	Odo-Owa
Nitrogen						
Mean	0.382	0.405	0.417	0.381	0.397	0.414
CV %	2.36	0.99	1.20	2.36	1.01	1.45
Phosphorus						
Mean	0.048	0.055	0.061	0.047	0.052	0.057
CV %	8.33	9.09	9.84	8.51	9.61	8.77
Potassium						
Mean	0.547	0.492	0.509	0.540	0.455	0.477
CV %	9.87	4.88	2.75	2.59	1.54	2.94
Iron						
Mean	0.015	0.013	0.012	0.015	0.012	0.012
CV %	1.34	3.94	1.63	2.65	3.23	1.67
Manganese						
Mean	0.021	0.021	0.018	0.021	0.019	0.018
CV %	4.76	9.52	1.67	4.76	21.05	5.56
Cupper						
Mean	0.007	0.005	0.005	0.008	0.006	0.006
CV %	14.29	0.40	0.60	12.5	16.67	16.67

Table 7: Correlation Matrix of the Fibre and Elemetnal content of *T. daniellii* Stalk

	CF	Ash	Silica	Lignin	holocel	α-cel	hemicel	N	P	K	Fe	Mn	Cu
CF	-												
Ash	-0.57**	-											
Silica	0.02	0.55**	-										
Lignin	0.24	-0.13	0.31	-									
holocel	0.70**	-0.51**	0.21	0.13	-								
α-cel	0.64**	-0.48*	0.27	0.16	0.60**	-							
hemicel	0.52**	-0.35*	0.21	0.15	0.56**	0.50**	-						
N	0.41*	0.54**	0.39*	0.26	0.41*	0.37*	0.35*	-					
P	0.01	0.49*	0.46*	0.23	0.03	0.04	0.08	0.45*	-				
K	0.52**	0.46*	-0.37*	-0.31	0.48*	0.46*	0.44*	0.44*	0.34	-			
Fe	0. 38*	0.48*	-0.44*	-0.25	0.36*	0.42*	0.34	0.37*	0.19	0.34	-		
Mn	0.26	0.50**	-0.38*	-0.31	0.02	0.12	0.27	-0.26	-0.14	0.04	0.30	-	
Cu	0.22	0.63**	-0.42*	-0.22	0.04	0.12	0.10	-0.32	-0.24	0.21	0.34	0.22	-

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Note: CF: Crude fibre, Holocel: Holocellulose, α-cel: Alpha-cellulose