Original Research Article

Cotton stalk fibers used as natural binders for the manufacture of thermal insulation panels: state of the art of the last decade

Abstract:

This article is a review of the state of the art of the last decade on new materials based on cotton stem fibers (CTF) and natural binders such as Grewia Venusta Fresen bark, hulls fruits of Parkia Biglobosa, calyces of Bombax Costatum, etc ...

The results reported in the literature revealed respectively that lignin and cellulose are present in plant materials such as FTC and binders in proportions of 20-26% and 3.82-32.95% respectively, then 32- 46% and 22.58-60.32%, which indicates the presence of mucilages and fibers. For better structuring of these composites, the pressing temperatures obtained in the previous works are of the order of 110 to 240 ° C. It has been reported that a 15% increase in binder powder in the base mix or an increase in fiber size from 0.063-0.63mm to 1.25-2mm leads to a decrease in the density of 10-30% and thermal conductivity of 20-30%, respectively. The variation of the rate of binder extract from 10 to 15% has no significant effect on the mechanical characteristics such as the Young's Modulus (MOE) (Modulus of Elasticity in Folding), the Modulus of Rupture in Folding (MOR), the Internal Liaison Force (IB). These characteristics decrease significantly when the pressing time and temperature vary from 5 to 25 min and from 140 to 180 ° C, respectively. They also decrease with the increase in the binder content and the granular class beyond the well-defined thresholds that we will best explore in our work.

We retain from previous work that an optimal formulation for a better material consists of homogeneous particles of 0.063-2 mm, a quantity of binder (60% by mass of powder or 10% by mass of extract) allowing better thermal insulation of conductivity 0.08 $Wm^{-1}K^{-1}$ at a temperature of 130 ° C for a pressing time of 10 to 15 minutes under a load of 10 to 15 KN.

Keywords: Cotton Stem Fiber (CTF) Materials; natural binders such as the bark of Grewia Venusta Fresen; lignin and cellulose are present in plant materials; a better material is made of homogeneous particles; better thermal insulation.

1. Introduction

During the last 80 years, wood has been mainly used as a lignocellulosic raw material for the production of chipboard (Fiorreli et al., 2019). Indeed, green materials such as natural fibres and biodegradable polymers are considered as innovative alternatives for the development of new composite materials (Mittal et al., 2014).

From a sustainable development point of view, the option is unquestionably promising. Similarly, from a scientific point of view, the prospects for technological innovation are attractive, but the challenge is considerable; not only must a suitable binder be found that acts as a matrix in the composite material, but also the safety for human and environmental health and the durability of this composite against weathering, insect pests and microbiological agents (fungi and fermentative bacteria in particular) must be ensured (Nenonene, 2009).

In this context, co-products from agriculture, such as the stems of annual crops, are an interesting alternative since these resources are abundant, renewable and safe for human health. Moreover, due to their porous structure, they have very interesting properties for building materials, for which they can provide good thermal insulation properties (Mahieu et al., 2015).

In the automotive industry, for example, interest is increasingly focused on recyclable and biodegradable parts. Composite materials based on biodegradable polymers and plant fibres are also being targeted. From a technical point of view, their mechanical resistance and acoustic performance, their low density and their low production cost improve passenger safety and the breaking strength of the material under wide thermal variations (A. Ashori, 2008).

In this vision of technological innovation, the aim is to develop materials containing plant fibres with the required characteristics adapted to reinforce the natural binder and increase its strength and rigidity. The material thus obtained is biodegradable and renewable with low density, low CO_2 emissions through the reduction of the formaldehyde compound, and a reduction in production costs, thus ensuring diversity of use in the construction industry.

As far as organic binders are concerned, adhesives such as urea-formaldehyde, phenol-formaldehyde and others have proven their technical performance. However, they are now being banned for environmental health protection reasons due to the proven toxicity of their formaldehyde emissions. Particleboard that does not emit formaldehyde is sought after by consumers who are concerned about their health. As a result, the development of new binders with low or zero formaldehyde emissions is a very current and relevant research objective (Nenonene, 2009).

In order to satisfy these numerous conditions, a good mastery of synthesis and characterisation methods (physical, chemical, thermal and mechanical) of raw materials, production processes and the development of prototypes and the characterisation of finished products are important and very worrying in order to better address the issue of new sustainable materials and improve existing knowledge. This review of bibliographies could contribute to the state of knowledge over the last decade on composite materials derived from plant resources: cotton stem fibres and natural binders, in this case the bark of Grewia venusta Fresen. Many authors have worked on the physico-chemical, mechanical and thermal characterisation of cotton stalks and some natural binders.

2. *Physico-chemical, mechanical and thermal characterisations Cotton Stems*

2.1. Cotton stalks

From its scientific name *GOSSIPIUM Hirsutum*, the cotton plant comes from the Malvaceae family. It is cultivated throughout the world and especially in Africa. In Benin, for example, it is the subject of a cash crop which is practiced more in the central regions of the country (Abomey, Djidja, Lalo,) and especially in the north (Parakou, Banikoara, Péhounco, Kérou, etc...). "Avokanfoun" from its Fon dialectal name, cotton is the main agricultural export resource in Benin. Cotton production growth in Benin rose from 32.55% in the 2017-2018 season to 50.29% in the 2018-2019 season, reaching more than 678,000 tonnes per year.

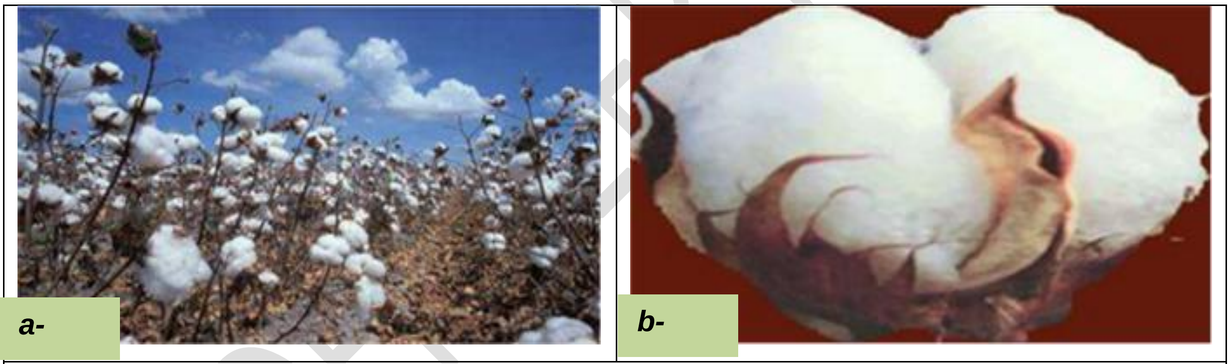


Photo N°1 : a- View of a cotton field ; b- View of the harvested cotton seeds (Nenonene, 2009 ; Ahouannou et al., 2019)

2.1.1. Fibre synthesis

The use of plant materials in the elaboration of composites requires a thorough knowledge of their physico-chemical, mechanical and thermal characteristics.

This characterisation of cotton stem fibres involves a synthesis of the material after the stems have been collected from the fields. According to Nenonene, 2009 and Ahouannou et al., 2019**,** the synthesis procedure can be summarised as :

- drying in the sun for 72 hours, then in an oven for the same period at 70°C,

- shredding in a knife mill; this makes it possible to obtain shreds with a diameter of less than 2.5 mm,
- sizing and screening to obtain fibres of different granular classes.

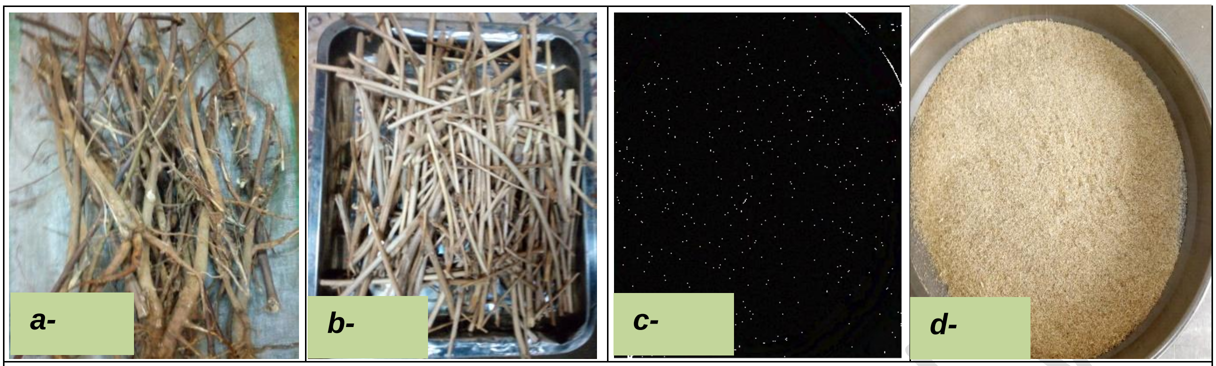


Photo N°2 : View of a- Cut unpeeled cotton stalks; b- Cut and peeled cotton stalks; c- Crushed cotton stalks (mixture of different granulometries); d- Ground and calibrated cotton stalks. (Ahouannou, 2019).

2.1.2. *Physico-chemical and thermal characterisation of cotton stem fibres*

The three main chemical components of a natural fibre are cellulose, hemicellulose and lignin. Hemicellulose forms cross-linking molecules with cellulose, forming the main structural component of the cell. Lignin reinforces the coupling on the hemicellulose-cellulose network and, in some cases, serves as a protective barrier. In many applications, the fibres are used in the form of bundles still bound together by pectin (Dittenber and *GangaRao*, 2012). According to (Saheb and Jog, 1999), the chemical composition of natural fibres varies according to the type of fibre. The properties of each constituent contribute to the overall properties of the fibre. Hemicellulose is responsible for the biodegradation, moisture absorption and thermal degradation of the fibre because it is less resistant, whereas lignin is thermally stable but is responsible for UV degradation. The physical characteristics mainly concern the mineral, fat, organic and nitrogen content as well as the protein content. The density and the of swelling are also determined.

Table N°1 summarises the results of the physico-chemical characterisation of cotton stem fibres obtained by some authors.

Table N°1 : Physical and chemical characteristics of cotton stalk fibres

Lieu d'investigation	**References**				
	Soumala 2015 ; Soulama et	**Ahouannou et al., 2019**	**Xiao-yan et al., 2010**	**Kadja, 2013**	**Bajwa, 2011**

	al., 2015				
Chemical parameters			*Benin*		
Dry materials (%)	*91,500*	*91,373*	-	*89,500*	-
Mineral materials (%MS)	*3,400*	*2,013*	*8,160*	*2,100*	-
Organic material (%)MS	*88,100*	*89,360*	-	-	-
Fat content (%)	*1,400*	*0,580*	-	*1,400*	-
Material nitrogen (%)	*1,200*	-	-	-	-
Protein content (%)	*1,200*	*1,680*	-	*1,400*	-
Raw cellulose (%)	*42,450*	-	*39,160*	*42,450*	*29,700*
Raw hemicellulose (%)	*28,960*	-	*13,380*	*28,960*	*20,800*
Lignin (%)	*20,60*	-	*25,750*	*20,500*	*20,700*
Moisture and Volatile Matter Content (%)	*10,960*	*8,627*	-	*10,500*	-
Particle density (Kg/m^3)	-	*178,570*	*250-450*	-	-
Particle swelling (%)	-	*35,710*	-	-	-

From the analysis in Table 1, it can be seen that the dry matter content of cotton stem fibres varies from 89.50 to 91.50% for a moisture content of 8.50 to 10.50%. This variation in dry matter and consequently in moisture content could be explained by the climatic conditions of the production zones of the said plants and the consideration of the bark when formulating new materials. This assertion was confirmed by Soumala, 2015.

Mineral matter represents 2.01 to 8.16% of dry matter for a variation of 86.460 to 89.360 % of organic matter. Soulama, 2015 reported that the bark of the plant matter is the part rich in mineral matter; this justifies the result of 3.16% on whole stems (with bark) against 2.01% obtained by Ahouannou et al., 2019 on stems without bark. The same applies to the values of 8.16% and 2.10% obtained respectively by Xiao-yan et al., 2010 and Kadja, 2013 on whole (unbarked) stems for the former and debarked stems for the latter. For Xiao-yan et al., 2010, this very high proportion could also be explained by the variation in soil pedology (their mineral content) and the climate of the biomass production regions, which may have variable mineral content.

The fat content varies from 0.58 to 1.40% with a more likely value of 1.40% reported by the majority of authors. This rate varies according to whether the stem is whole or debarked.

On debarked stems, it varies from 0.58 to 1.20%, which could be justified by the hydrogeological conditions of plant production; and from 1.20 to 1.40% for whole stems.

The determination of nitrogen content has not been addressed by many authors, Soulama et al., 2015 reports a value of 1.20%. The density of the stems has a wide range of values, i.e.

178.57 to 450 kg/m3 ; this variation is mainly justified by the variation in the granular class of the stems studied, but also and above all the structural constitution of the material, in a word the climatic and hydrogeological conditions of the places of production. Ahouannou et al., 2019 experimentally determined the swelling rate of the fibres and obtained a value of 35.71%. The protein content of the fibres varies from 1.20 to 1.68%.

Chemical characteristics such as crude cellulose, crude hemicellulose and lignin vary respectively from 29.70 to 42.45%, 13.38 to 28.96%, 20.500 to 25.750%. These rates adequately reflect the presence of fibres and binders in the vegetal matter of cotton stalks. The highest proportions of cellulose and hemicellulose are obtained from both debarked and unbarked stems, which justifies that bark is not a fundmental source of these chemical compounds. As for the lignin rate, it remains almost around an average value of 20.60% for most of the work of the authors studied. However, a lower hemicellulose value of 13.380 and a higher lignin value of 25.75 should be noted. This could be justified by the variation in climatic and pedological conditions as well as in the parts of the plant being exploited.

Thermal caracteristics of cottom stem fibres

The thermal characterization of natural plant materials includes :

- thermogravimetric analysis (ATG) which aims to determine the upper limits of the temperatures to which cotton stems and natural binders can be subjected without prejudice to degradation. According to Nenonene, 2009, this test is carried out under nitrogen and air with materials subjected to different temperature programmes . According to the same author, analysis of the mass loss curves of a kenaf-based composite showed that during thermopressing no significant effects of thermal degradation of the lignocellulosic constituents leading to mass loss are expected to occur as long as the temperature remains below 200°C.
  The temperature programmes are established taking into account the characteristic values of the plant material under test. In fact, the temperature programme is a succession of temperature values to which the sample is subjected in order to study its behaviour.

- Differential Enthalpic Analysis (AED), which aims to determine the temperature ranges in which the fibres of cotton stalks undergo structural transformations favourable to their use in the manufacture of particleboard. It is also carried out under a predetermined temperature programme. According to Nenonene, 2009, in order to carry out this test on

Kenonene stems, they had to be subjected to 50°C for 1 minute followed by a gradual increase in temperature from 50°C to 200°C following a gradient of 10°C.min $^{-1}$.

ATG and AED are two analyses that allow us to determine a range of temperatures and sometimes the optimum temperature at which the rods should be pressed to ensure better structural transformation of the raw materials without damage.

In the literature review none of the authors discussed ATG and AED tests on cotton stem fibres. This is a limitation of the literature, offering a research possibility that will allow to define a specific range of thermo-pressing for the plant material under study.

2.2. *Natural binders*

Several natural plants have been studied in the bibliography in view of their chemical composition, a potential source of pectin. These plants include the bark of Grewia Venusta fresen, the calyxes of Bombax Costatum, the fruit pods of Parkia Biglobosa, the leaf sheaths of Sorghum caudatum, Pithecellobium dulce, and others...

2.2.1. Description and synthesis of powders of different natural binders

The Grewia venusta Fresen is of the family Tiliaceae, genus Grewia and species G. venusta. This tree can reach a height of 3 to 10 m with large branches (photo N°3) often square, star yellow flowers. The bodies of this plant are used as: vegetables, plant salt, rope, drink, fodder, medicine. The viscous appearance that the leaves and bark give to medical culinary or ethno preparations has led us to choose the bark of this plant as a potential source of pectin which can be used as an adhesive in the development of particle board reported Tchombi et al, 1995. This plant of the vernacular names Lilli (in Fon), Ogbolo (in Yoruba and Nago) and yima (in bariba) referring to the analytical flora of Benin is found mainly in the centre and north and the different parts are used for the same purposes.

The powder synthesis of Grewia venusta Fresen bark follows the same steps as that of other natural binders according to the bibliography. These are the :

- drying in the sun for 72 hours, then in an oven for the same period at 70°C,
- shredding in a knife mill; this makes it possible to obtain shreds with a diameter of less than 2.5 mm,
- sizing and screening to obtain fibres of different granular classes.

Photo N°3 : ***a- Branches and leaves of Grewia Venusta; b- Bark of Grewia Venusta (Ahouannou et al., 2019)***

The pods of the fruit of Parkia biglobosa (Jacq.) Benth. (Néré) is a Mimosaceae of the genus Parkia and the species *Parkia biglobosa (Jacq.) Benth*. (Nenonene, 2009). The presence of tannin in the pods of the Néré fruit makes this plant a potential source of natural binder used in the manufacture of particleboard. Nenonene, 2009 has also produced Kenaf particleboard using 10% Parkia biglobosa powder extracted from the pods, i.e. 30g of powder for 270g of Kenaf particles.

Photo N°4 : View of a-A plant ; b- the inflorescence of Parkia biglobosa (Nenonene, 2009)

Leaf sheaths of Sorghum caudatum (Hack.) Stapf (Red Sorghum): Sorghum caudatum (Hack.) Stapf is an annual grass native to tropical Africa. Nenonene 2009, used 10% extract from the leaf sheaths of the S. Cautadum to make Kenaf-based chipboard.

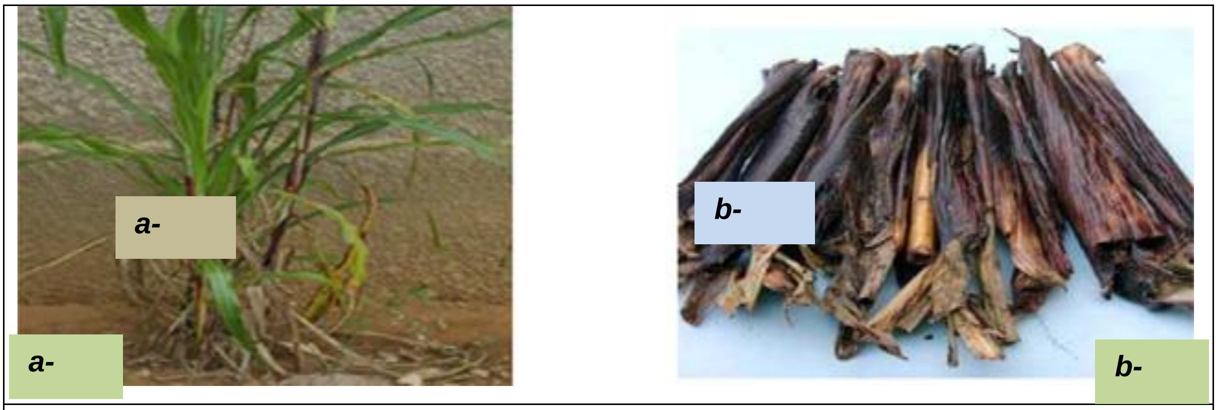


Photo N°5 : View of a- Young plant; b- Sorghum caudatum leaf sheaths (Nenonene, 2009)

Pithecellobium dulce (Roxb.) Benth. (Tamarind tree): Pithecellobium dulce Benth. is native to tropical and subtropical America, in the family Fabaceae, genus Pithecellobium and species Pithecellobium dulce. Nenonene 2009, has used 10% powdered extract of this binder to make Kenaf-basedparticle board.

Photo N°6 : View of a- Plant ; b- - Fruit of Sorghum caudatum (Nenonene, 2009)

Calyxes of Bombax costatum is a large red flower tree commonly called red kapok tree flowers in the tropical savannah. Synonymous names, Pellegr. and Vuillet, bombax vuiletii Pellegr ...and is known by various vernacular names: boumbou, diohé, loukoun .... Deciduous tree that can reach 10 to 25 m high, in Togo it is called: fula, afobil, Tode, mulodu. Resistant to bush fires and drought, this species is adapted to tropical ferruginous soils reported Kokou Esso Tchombi et al., 2015, who used this binder to make Kénaf particleboard. The binder is incorporated in the form of a dry mucilaginous powder into the particles of the Kenaf core at a rate of 10%. Nenonene, 2009, has developed Kenaf particles with the same binder proportion.

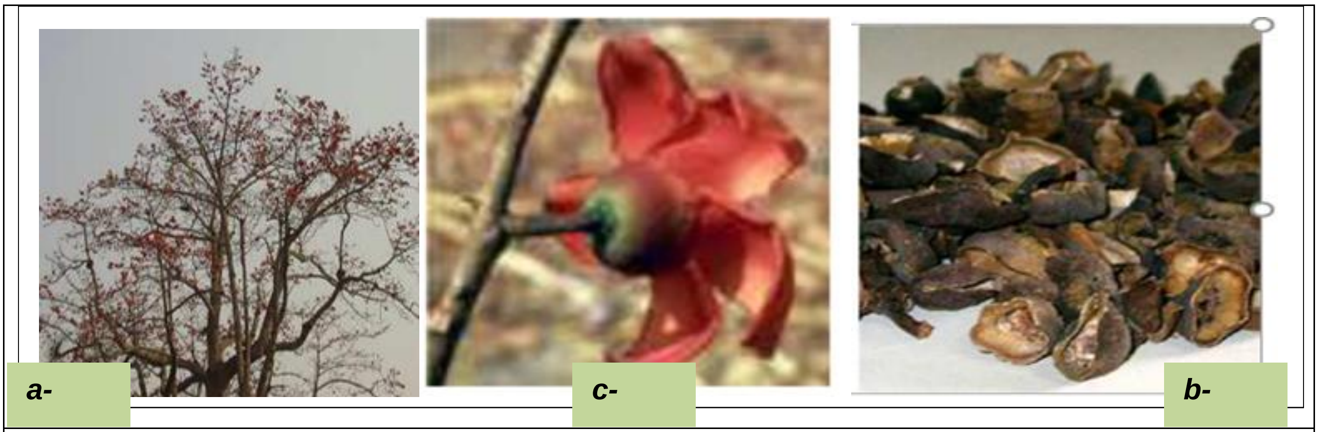


Photo N°7 :View of a- flowering tree; b- flower; c- Calyxes of the Bombax Costatum (Kokou Esso Tchombi et al., 2015)

2-2-2- Physico-chemical characterisation of different binders

The physico-chemical characteristics reported in the bibliography have made it possible to draw up the following table :

Table N°2 : Physico-chemical characteristics of different natural binders ***(Nenonene, 2009, KOKOU ESSOE et al., 2015 ; Ahouannou et al., 2019)***

Paramètres physico-chimiques	***Différents liants naturels et Références***				
	Calices de B. Costatum (Kokou Esso TCHOMBI et al., 2015)	***Ecorces de G. Venusta Fresen (Ahouannou and al., 2019 ; Kokou Esso TCHOMBI et al., 2015)***	***Cosses de P. biglobosa (Neùnonene, 2009)***	***Ecorce de P. dulce (Nenonene, 2009)***	***Graine Foliaire de S. caudatum (Nenonene, 2009)***
Dry materials (%)	-	89,330	91,680	94,132	94,800
Mineral materials (%)	*5,470*	*9,550*	*2,900*	*4,970*	*7,760*
Organic materials(%)	-	-	*88,780*	*89,150*	*87,040*
Fat content (%)	*0,830*	*1,140*	*0,900*	*0,990*	*0,950*
Material nitrogen(%)	*7,870*	*4,060*	*4,690*	*15,500*	*3,810*
Raw cellulose (%)	*22,580*	*60,320*	*49,760*	*44,610*	*32,820*
Raw hemicellulose (%)	*33,820*	*21,120*	*2,520*	*20,960*	*32,750*
Lignine(%)	*4,950*	*3,820*	*32,950*	*13,300*	*5,750*
Moisture and Volatile Matter Content (%)	-	*10,67*	*8,32*	*5,88*	-
Density of particles (Kg/m3)	-	*250,000*	-	-	-
Particle swelling (%)	-	30,000	-	-	-

From the analysis of this table, it emerges for the binders explored that the rates of dry matter, mineral, organic, fat, protein, cellulose, hemicellulose and lignin, in water and volatiles vary from 89.33 to 94.80%, from 2.90 to 5.47%, from 88.04 to 89.15%, from 0.83 to 1.14%, from 3.81 to 15.5%, from 22.58 to 60.32%, from 2.52 to 33.82%, from 3.82 to 32.95%, from 5.20 to 10.67%. The analysis of these values shows that these plant organs have adhesive properties that make them potential natural binders that can be used in the formulation of particleboard with natural binders. The values of the cellulose and lignin content respectively from 22.58 to 60.32% with an average of 41.45% and from 3.82 to 32.95% with an average of 18.38% testify to their binding properties.

P. biglobosa pods have the best lignin content 32.95% and an above-average cellulose content of 49.76%. The bark of G. Venusta Fresen has the highest cellulose content of 60.32% and the lowest lignin content of 3.82%.

In addition, some authors have proceeded with the extraction of materials rich in tannins and mucilages. The values obtained are summarised in table N°3.

Table N°3 : Composition of plant organ extracts rich in retained tannins and mucilage *(Nenonene, 2009)*.

Composition of the extracts	***Extracts***				
	Cosse de P. Biglobosa	***Ecorce de P. Dulce***	***Gaine Foliaire de S. Cautadum***	***Calice B. Costatum***	***Ecorce de G. Venusta***
Moisture content (%)	*27*	*20*	*11*	*15*	*11*
Mineral materials (%MS)	*20*	*6*	*29*	*6*	*26*
Tannin content (%MS)	*45*	*35*	*24*	-	-
Pectin substance content (%MS)	-	-	-	*15*	*11*

The levels of tannin and pectin respectively from 24 to 45% for the pods of P. Biglobossa, the barks of P. Dulce and the leaf sheaths of S. Cautadum and from 11 to 15% for the calyxes of B. Coastatum and the barks of G. Venusta give more information on the stickiness of these plant materials which the bibliography reports as natural binders.

2.2.3. Thermal and mechanical characterisation

Thermally, thermogravimetric analysis (ATG) and differential enthalpy analysis (AED) are also determined for the thermal characterisation of the various natural binders.

Nenonene, 2009, studied the ATG thermograms of the pyrolysis (figures a to c) of samples of tannin-bearing plant material such as P. biglobosa pods, P. dulce bark and S. caudatum leaf seeds. The analysis of these curves shows four phases, under air, although the fourth is not always well marked. On the other hand, under nitrogen, only three phases are remarkable. During the first phase, i.e. 50 to 240°C, the loss of mass observed is greater than the loss of water from the material, thus indicating that during this phase, in addition to the elimination of residual humidity, some compounds have been "destroyed". During the second phase, a 50 to 65% fall in the mass of the plant material is observed, which is explained by the destruction of the non-structural hemicellulose, and the third is characterised by a regular and gradual fall to a limit value corresponding to the mass of the raw ash. The fourth phase expresses the specific destruction of structural hemicelluloses and lignin.

The thermograms of the AED analyses (Figure d) support this assertion by showing structural modifications which appear much earlier (120- 135°C) with a more marked exothermic phase after 180°C, thus reflecting relatively significant destructuring.

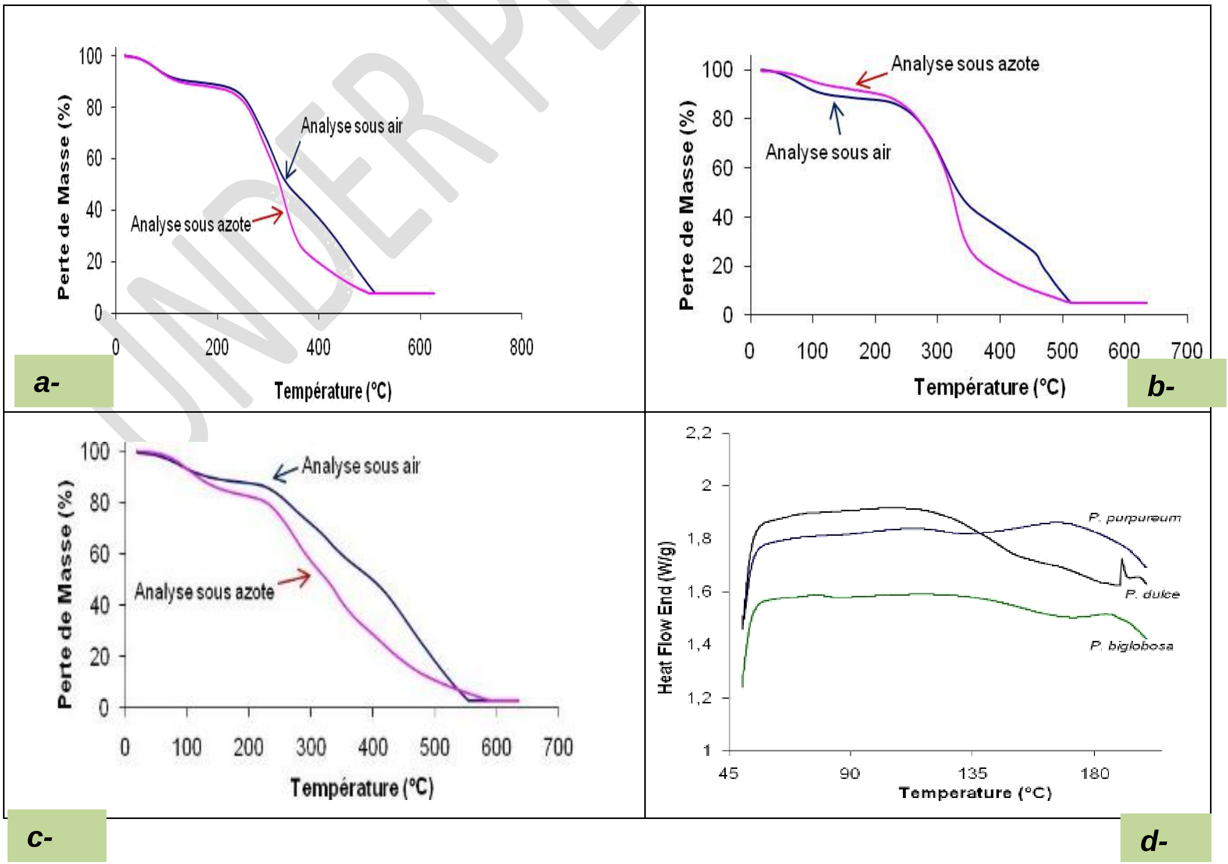
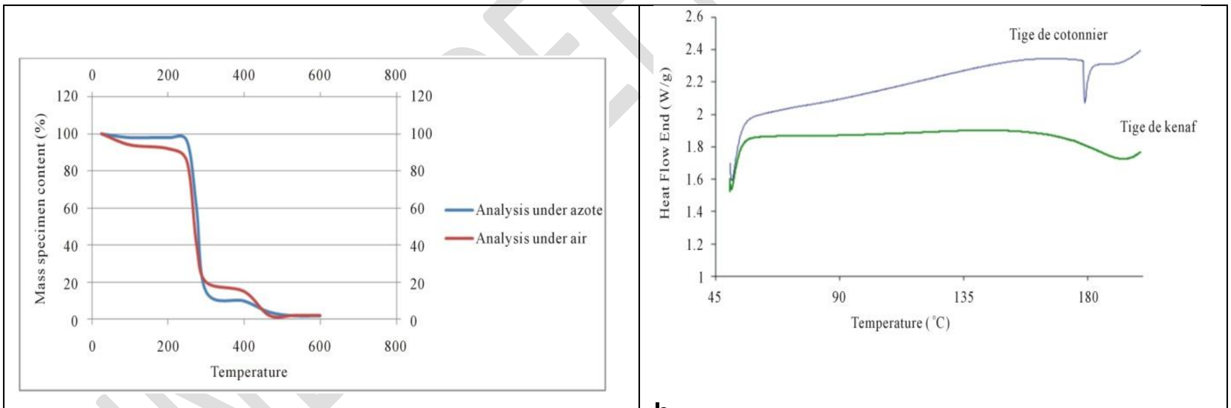


Figure 1 ***(Nenonene, 2009)*** **:** Mass loss curves in thermogravimetric analysis under air and nitrogen of **a**-: the bark of Parkia biglobosa; **b**-: the bark of Pithecellobium dulce; **c**-: the sheath of Sorghum Cautadum ; **d**- Differential calorimetry curves of tannin plants

The author concludes from the above, that the thermopressing temperatures of the particle boards could be chosen in the first phase of pyrolysis especially in the temperature range between 110 and 240 °C which corresponds to the beginning of the structural modifications of the organs.

However, in this relatively large range, the search for an optimal value can be envisaged on the cotton stem fibres and on each of these binders, since the bibliography reports an improvement in the mechanical characteristics of the particleboards elaborated when the thermopressing temperature goes from 140°C to 180°C. Soulama, 2014, reports that thermogravimetric analysis of cotton stem fibres shows that this material does not present any danger of destruction up to 250°C and that differential calorimetry analysis indicates that the thermopressing temperature of 180°C - 190°C is well suited to the structural transformation capacities of the stems for the elaboration of composite panels. The curves below illustrate these results.



a-:

b-

Figure 2: a. Mass loss curves of cotton stalk fibres in thermogravimetric analysis under air and nitrogen ***(Nenonene, 2009) ;*** **b.** Differential calorimetry curves of cotton stalks (***Soulama, 2014)***

From all of the above, the temperature of 180°C appears to be the right one to ensure the optimal transformation of the cotton stalk fibres and the natural binders studied.

3. Development of composite materials based on cotton stalk fibres/natural binder and physico-chemical, mechanical and thermal characterization

3.1. Methods of synthesis of composite materials

The development of particleboard based on lignocellulosic stem fibres and natural binders has been addressed by several researchers. Most of the procedures developed revolve around four (04) main phases: fractioning, which consists of drying and grinding the selected plant materials, impregnation, which consists of mixing the plant product obtained with the natural binder powder or extract, formatting, which consists of shaping the kneaded product in a mould, followed by thermo-pressing for a set period of time and at a precise temperature, and finally the finishing operation, during which the mould is removed from the mould and the surfaces treated, *Ahouannou et al., 2019, Soulama S. et al., 2015, Kokou Esso Tchombi et al., 2015, Bajwa et al., 2011, Xiao-yan Zhou et al., 2010*.

Ahouannou et al., 2019, started from the powder of the Grewia Venusta bark and the fibres of cotton stalks, which he proposes to knead, mould (in the mould preheated to a temperature of 150°C, with a constant pressure), remove from the mould after pressing the dough and then dry the sample. Indeed, it is risky to specify that the temperature of the sample remains constant during the pressing process, since no scientific regulation is taken to ensure that the desired temperature is maintained. The author has not dealt with the chemical characterisation (cellulose, hemicellulose and lignin content) of the vegetable matter as well as the mechanical characterisation of the particle boards obtained.

He used the powder from the bark of the G. Venusta in proportions of 60, 65 and 70% to elaborate different materials. Analysis of the characterisation results shows that the increase in the proportion of binder (from 60% to 70%) leads to a decrease in the density (from 477.09 kg/m3 to 433.4 kg/m3) and thermal conductivity (from 0.104 to 0.085 $W.m^{-1}.K^{-1}$) of the samples based on cotton stem particles.

Tchombi and al., 2015 and Nenonene 2009 developed particleboards based on Kenaf stem fibres with, among other natural binders, lyophilised mucilaginous extracts of G. Venusta bark in a proportion of 10%.

Soulama, 2014, at the end of its study of the state of the art, has identified four (04) main parameters on which the quality of the particleboard produced by thermo-pressing depends. These parameters influence the thermo-physical and mechanical characteristics of the panels. They are :

- Moisture content in the knead ;
- The pressing temperature;
- The level of binder in the knead;
- The pressing time of the knead to obtain the sample panels.

He adopted the same method for the elaboration of the particle boards, highlighting the impact of the identified parameters on each of the stages (fractioning, impregnation, formatting, thermo-pressing). He differentiated the setting up of the kneading by twin-screw extrusion from the injection moulding method.

Xiao-yan Zhou and al., 2010 used the same methodology across the four stages, to develop particleboard made from cotton stalk fibres without any binder or additives. He has shown the presence of adhesive material in the cotton stalk fibres which allowed this development and thus justifies its use by many authors in the bibliography.

The analysis of his work highlights certain limits such as the non-inclusion of the variation in pressing temperature and the possibilities of treating plant matter to improve its characteristics.

The tannin or pectin extract of the natural binder is mixed with the fibres from the grinding of the reinforcing material. It is then thermo-pressed before demoulding and finishing (Nenonene, 2009). It should be noted that the use of binder extracts has led to lower rates (10 to 15%) than powder (60 to 75%). This has a significant influence on the density, mechanical characteristics and thermal efficiency of the materials processed. The limits of his work can be seen in the absence of thermo-acoustic characterisation and the resistance to environmental aggression of the particle boards in order to achieve a more complete characterisation.

The following photos show the main materials used as well as test specimens made by some researchers, for example *Nenonene, 2009 and Ahouannou et al., 2019.*

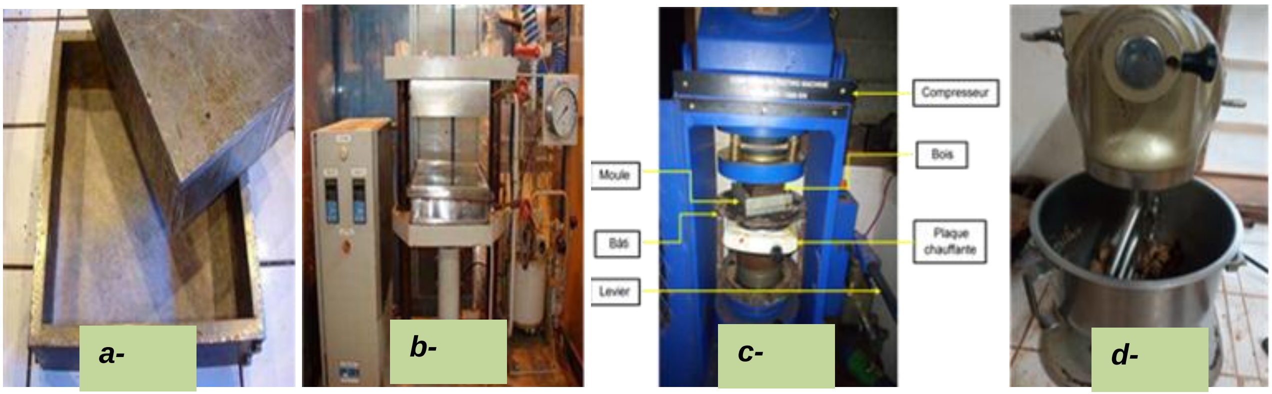


Photo 8 : Views of some materials and equipment a- Mould ; b- Thermopress ; c- Mechanical press equipped with a hot plate; d- Mixer ***(Nenonene, 2009 ; Ahouannou and al., 2019)***

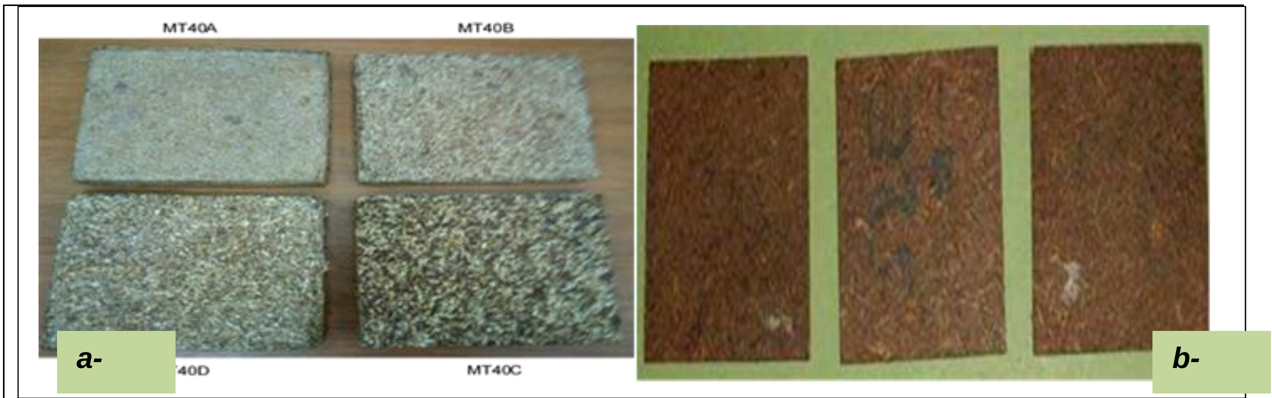


Photo 9: View of : **a-** Chipboard test tubes (cotton stem fibre/ G. venusta powder) ***Ahouannou, 2019*** ;

b- Extruded chipboard test tubes (kenaf stem particles and P. biglobosa pod powder*).* ***Nenonene, 2009***

2.3. Caractérisations physico-chimiques, mécaniques et thermiques des matériaux composites à base de FTC ?

The last decade has been marked by significant work on the development of new materials in the engineering science sector. In the different types of fibres exploited, those from cotton stalks have also been used. Table N°4 reports the results of the bibliography on the physico-chemical, mechanical and thermal characteristics of composites based on cotton stalk fibres and various binders from biomass.

Table n°4 : ***Physico-chemical, mechanical and thermal characteristics of FTC-based composites***

Characteristics panels of particles	**X-Y Zhou et Al., 2010** Stem Fibres of Cotton/binder	**Bajwa et al., 2011** Properties of composites thermoplastics based on cotton and guayale residues as filler fibres	**Soulama, 2014** Mechanical and thermal characterisation of biocomposites with recycled polystyrene matrix reinforced with cotton hulls (Gossypium hirsutum L.), or kenaf wood particles (Hibiscus Cannabinus L.).	**Soulama, S et al., 2015** Optimisation of the production process and physical parameters of the particleboard from cotton stalks (Gossipium hirsutum) and of the Kenaf (Hibiscus cannabinus L.)
Density or mass volume (kg/m^3)	150-250-350-450	-	590,1 - 713,5	660,225
Swelling in tickness	-	1,00-3,00	-	-
Thermal conductivity (W/m°K)	0,058-0,081	0,015-0,027	0,077 - 0,148	0,067
Elastic flexural modulus (MOE) (MPa)	25-82	1017,84	493,60 - 1805,40	1757,49
Tensile strength (MOR)	0,100-0,650	11,82	6,14 - 17,09	15,52
Internal Bond Strength (IB) (MPa)	0,060-0,175	-	-	-

Xiao-Yan Zhou and al., 2010 studied the impacts of variation in density (density), moisture and pressing time on the thermal conductivity and mechanical characteristics of resin and additive-free, resin-free, cotton-based fibreboard. The results showed that panels with a density of 150-450 kg / m^3 have thermal conductivity values ranging from 0.0585 to 0.0815 W/m°K, which are close to other types of panels with the same density range. Thermal conductivity values have a strong linear correlation with density.

They increase with increasing density. Indeed, the increase in density means a decrease in voids, whereas voids have a low thermal conductivity compared to solids. This easily justifies the increase in thermal conductivity due to the increase in the material corroding the increase in density.

The internal bond strength (IBS) has a value which already meets the requirements of the standards for relatively low densities. This value improves significantly with increasing fibre and pressing time.

The same trend has been observed for tensile strength (MOR) and elastic flexural modulus (MOE). In addition, the increase in pressing time to 25s/mm pressed thickness from 20/mm improves the ORM by approximately 26%. As a result, the MOR and the MOE are not significantly affected by the pressing time from 25 s to 30 s/mm.

Soulama, 2014 reported the influence of certain parameters on the characteristics of the panels. The flexural modulus of elasticity or Young's modulus of elasticity (YMO) and modulus at break (MOR) increase with increasing water content and reach maximum values of 1490 MPa and 14 MPa respectively for kneading water contents of 27% and 33%. Finally, for kneading water contents below 14%, the ORM values are all below 550 MPa and therefore do not comply with the AINSI A 208.1 1999 standard. He notes that the water content does not have a major impact on the density of the particleboard. Furthermore, the increase in thermo-pressing temperature from 120°C to 140°C has a beneficial effect on the density and on all the mechanical characteristics evaluated with, however, a slight increase in the swelling rate in thickness. For binder rates ranging from 5% to 12.5%, an increase in MOE and MOR is observed, reaching values of 1950.78 MPa and 17.01 MPa respectively. Above 12.5% binder content, there is a decrease in MOE and MOR. However, the 12.5% binder content appears to be the optimum for obtaining maximum MOE and MOR values.

The pressing time is strongly related to the water content of the dough, the temperature of the thermopress and the binder content.

He reports that setting the water content in the knead to 17% and the binder content to 12.5% requires a pressing temperature of 140°C and a pressing time of at least 20 minutes to meet the requirements of the standard and for economic reasons.

At a pressing temperature of 140°C, panels are obtained which comply with MOE, MOR values in accordance with the prescribed standards. The thermal conductivity of the panels made of cotton stems then varies between 0.0889 and 0.1036.

Soulama S. et al., 2015 in their article on the optimisation of the production process and physical parameters of cotton stalk particleboard (Gossipium hirsutum) and Kenaf (Hibiscus cannabinus L.), analysed different parameters affecting the panels in order to retain values that allow optimisation of the characteristics.

In summary, it should be remembered that the water content, pressing time and temperature, and the binder content are parameters that have a significant influence on the mechanical and thermal characteristics of the particleboard panels. The binder content is related to the rate of reinforcement in the kneading mass. Their study has made it possible to identify the optimum values for each parameter in order to obtain characteristics that comply with the standards.

3.3 . Production Processes and Prototype of Cotton Stem Fibreboards / Natural Binder

Within the framework of the implementation of particleboard, several researchers have established a precise process for producing large panel prototypes ready for use in industry. The process chosen for manufacture is generally the compromise that allows the optimum values of the various parameters that influence the characteristics of the samples obtained to be obtained. At this level, the water content of the kneaded material, the pressing time and temperature, and the binder content are fixed.

Soulama, 2014, in his work used the shells (the name shells used here by the author takes into account in addition to the shells the stem fibres) of cotton with a binder that is recycled polyester. After having prepared the raw materials, he used an extruder to mix the polymers with the fibres from the cotton plant hulls and then a granulator to transform the extrudate into granules. Three types of mixture were produced, i.e. 20% R- 80% M, 15% R- 85% M then 10% R- 90% M. He then used an injection moulding machine set at 180°C under a pressure of 2500 bars to mould the samples and specimens of dimensions 300 mm x 300 mm.

Photo N°10 : Vew of Extrusion assembly **(Soumala, 2014)**

Photo N°11 : Vew of Injection moulding machine (Soumala, 2014)

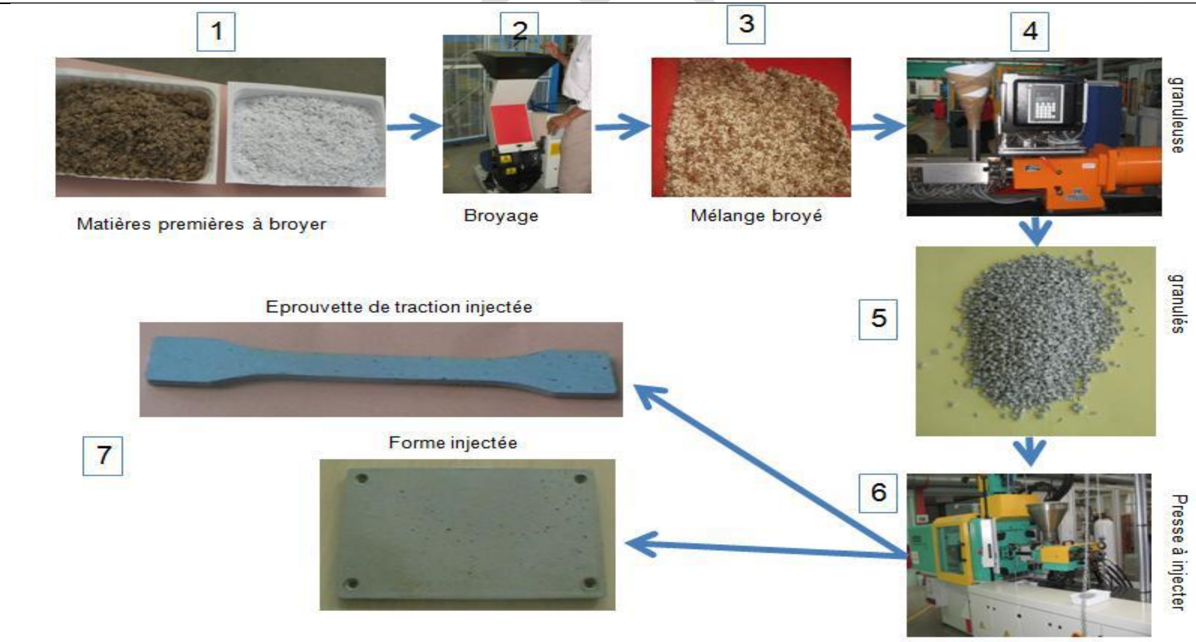


Photo N°12 : Different stages of the biosourced material manufacturing process **(Soumala, 2014** and ***Kelch et al.,2018*** **)**

Despite the interesting results of *Soulama, 2014*, this work has many limitations:

- The use of a binder of mineral origin which does not have the same biodegradable capacity as particleboard, whose two raw materials are all vegetable;
- The non-treatment of the fibres from the stems of cotton hulls in order to evaluate the possibility of improving the mechanical properties;
- Using the hull in powder form (small granulometry), in order to vary the granulometry of the components and improve certain characteristics ;
- Finally, limiting the fibre content to 20%, which also limits the mechanical characteristics even if those obtained already comply with the standards.

Xiao-Yan Zou et al., 2010, after calibrating the fibres of cotton stalks, proceeded to the moulding of panel samples with boxes of 300 mm x 300 mm internal dimensions and a thickness of 25 mm. The mats are subjected to an electromagnetic (EM) radiation press, whose interaction with the humidity in the kneading machine allows the resin contained in the stems to harden. The main specificity of his work lies in the formulation and development of panels with no added binder, which are not similar to fibre-binder composites, and the pressure at high electromagnetic frequency (0.95 to 2.45 GHz).

Atcholi et al, 2014 have developed panels using binders such as Grewia venusta bark and Bombax costatum chalices. They extracted mucilage and pectin from the vegetable raw materials and then hydrolysed them for kneading.

3. Conclusion and prospects

A critical analysis of the reported work reveals that lignin and cellulose are present in the plant matter of cotton stem fibres in proportions of 20-26% and 3.82-32.95% respectively, and in natural binders of 32-46% and 22.58-60.32%; this is evidence of the presence of mucilages and fibres. For a better structuring of these composites, the thermo-pressing temperatures obtained in previous work are in the range of 110-240°C. It has been reported that an increase in the binder powder quantity by 15% or in the fibre size from 0.063-0.63 mm to 1.25-2 mm results in a decrease in density by 10 and 30% and in thermal conductivity by 20 and 30% respectively. The mechanical characteristics (MOR, MOE and IB) decrease with increasing pressing time (5 to 25 min) and temperature (140 to 200°C) as well as the granular class.

From this study, it should be noted that particleboard can be made from vegetable fibres and natural binders. These materials formulated by different actors on the basis of frozen extract

(10% of the kneading) or powders resulting from the grinding (60 to 70% of the kneading) of the binder under a temperature of 140°C with a pressing time of 5 min give results as much better than those formulated with UF binders and bone glue. This work brings the advantage of biomass recovery, better management of agricultural waste and also the reduction of formaldehyde, which is toxic to human health.

Despite these contributions of the last decade, most of the work has limitations that deserve to be addressed with a view to improving the thermophysical and mechanical characteristics of the new panels, and finally to take into account the environmental aspects of the issue.

In fact, the limitation of the MOE of the panels with G. Venusta's binder, which remains below the value of the ANSI 218.1 standard (*Tchombi et al., 2015*) ; the thermo-acoustic characterisation and resistance to environmental aggression not addressed in the work of *Nenonene, 2009*; the definition of the chemical composition of the polymer matrix to obtain better polymerisation and thermo-press moulding not taken into account by *Safia SAHRI, 2012*; the release of the formaldehyde compound and the sensitivity of the panels to humidity [not studied by *Soumala,2014* and *Soumala et al., 2015* are all milestones identified in this state of the art on the development and manufacture of composite materials based on plant reinforcements and binders are also of significant relevance.

Moreover, the valorisation of the biomass of Benin through the elaboration of particle boards based on cotton stalk fibres and the bark of Grewia Venusta constitutes a new path on which we plan to experiment in order to find approaches to respond to many of the limitations reported in the present study. This path will lead us to develop a new material, because although both plant materials are used on both sides in the elaboration of lignocellulosic composites, their formulation has not yet been thoroughly examined in the literature.

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