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Physico-Chemical Characteristics and Study Valorization Ways of the Cotton Sector Waste in Benin to Biobased Building Materials

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Abstract: The economic importance of the cotton sector in West African countries has led to the development of this sector, which now generates a large quantity of waste. The objective of the present study is to investigate the possibilities of valorization of the by-products of the cotton sector into construction materials. The investigations near the actors of the cotton sector have made it possible to trace the itinerary of the cotton and to bring out fifteen (15) by-products from industries of which five (5) in the ginning mills, six (6) in the crushing mills and four (4) in the textile mills. The most important ones are cotton seed hulls, ginning clods and glue wastes which represent respectively 16%, 1.45% and 0.84% of the annual cotton production. Some physico-chemical characteristics allowed to evaluate the use of these by-products in construction materials. The higher calorific value and the protein content, which are respectively 19,536 J/g and 1.6%, make the hulls an alternative fuel and a feed for livestock. This by-product is fully utilized. As for the ginning clods, they are in the form of fibers. Due to their low apparent density of 25 kg/m^3, it is possible to use these clods in the manufacture of light construction materials. The glue wastes also contain 18% of starch, which makes it possible to consider its use in the production of thermal insulation panels inside the building. Although this study allows us to identify possible ways to valorize the by-products of the cotton sector, it remains to find the appropriate methods of their implementation.

Keywords: Cotton Waste, Ginning Clods, Cotton Seed Hulls, Physico-Chemical Characteristics, Biobased Material, Waste Valorization

1. Introduction

In West African countries, agriculture is an important sector of activity for economic and social development [1, 2]. In Benin, in 2019, it represents 36% of GDP, 90% of exports and more than 40% of jobs [3, 4]. Among the multiple sectors that make up Benin's agriculture, cotton is the main one. In 2019, the cotton sector represents 13% of GDP, 70% of exports, 60% of the industrial fabric, 40% of tax revenues and more than 40% of jobs in rural areas [3, 5, 6]. In Benin, cotton remains the main cash crop and thus forms the basis of the rural and agro-industrial economy [7]. Since 2011, Benin's production of seed cotton has been increasing (Figure 1) [8, 9]; this generates a large quantity of by-products that remain almost unused and also constitute a threat to the environment [10, 11] (Figure 2). It is therefore necessary to valorize the unexploited by-products of the cotton sector in order to protect the environment.

Moreover, the problem of global warming due to greenhouse gases is at the heart of the Sustainable Development Goals (SDGs). According to the Intergovernmental Panel on Climate Change (IPCC), energy production in the world represents the main source of GHG emissions [12] and the building sector is responsible for more than 30% [12-14]. Several works have shown that the energy consumption of a building depends considerably on its envelope (orientation, mass, material properties, height) [15-21], but mainly on the characteristics of the materials used [15, 16, 18]. Thus, we can act on the materials used in the construction of the building envelope to reduce their energy consumption, and consequently the associated GHG emissions.

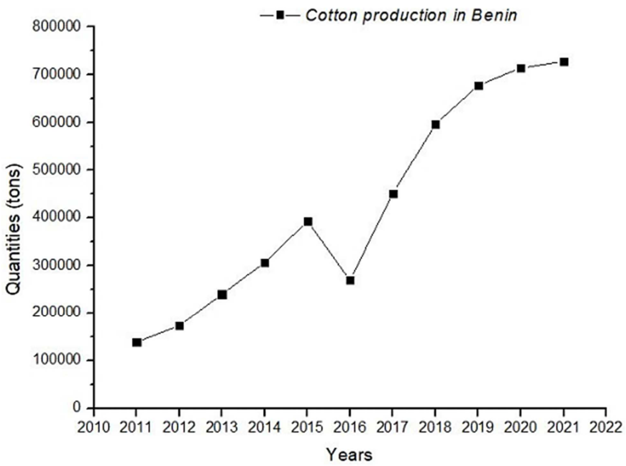

Figure 1. *Evolution of cotton production in Benin.*

a

b

Figure 2. *(a) discarded and burned ginning mill waste (b) discarded textile mill waste [11].*

Among the many existing materials, composites based on vegetable fibers (textiles, straw, hemp, …) present thermo-physical, acoustic, hygroscopic and mechanical characteristics necessary for the consumption of less energy consuming buildings. These materials have better properties than conventional materials (cement, sand and gravel) used in construction. They are also recyclable, renewable and sustainable [22-34].

In this context of global warming, improvement of comfort in buildings, protection of the environment, and despite the advantages offered by the use of materials based on plant fibers, there are no ways to valorize the waste from the cotton sector in Benin in the field of buildings. This work makes a synthesis on the cotton sector in Benin and studies the possibility of valorizing the by-products on the basis of their availability and their physicochemical characteristics.

2. Materials and Methodology

The study of the ways of valorisation of the by-products of the cotton sector was carried out on the basis of the availability and the physicochemical properties of the by-products. For that, it was made in three (3) stages:

1. Study of the cotton sector in order to identify all the by-products of the sector;
2. Estimation of the quantities of by-products in order to assess their availability;
3. Study of some characteristics of the available by-products in order to decide on their exploitability in the field of construction.

2.1. Study of the Cotton Industry in Benin

Semi-directive interviews with cotton sector actors provided information and data on the cotton processing itinerary, by-products and existing value-added methods for certain by-products. The participants in these interviews were cotton growers, cotton processors' associations, and the processing plants, which are the Compagnie de Textile du Bénin (CTB), the ginning plants of the SODECO group, the Société des Huileries du Bénin and the FLUDOR company.

2.2. Characterization of the Main by-Products

The important physico-chemical characteristics of the main by-products were determined by tests. Three laboratories were used for the tests: SCB-LAFARGE's laboratory, COLAS AFRIQUE's central laboratory in Cotonou and LERCA's laboratory at the University of Abomey-Calavi. The studied characteristics depend on the considered by-product and are: moisture content, water absorption capacity, calorific value, density, starch content and ash content.

2.2.1. Moisture Content

The moisture content was determined according to ISO 687 [35]. It allows to evaluate the quantity of water contained in raw by-products. The equipment used is composed of an electronic balance of precision 0.1 mg brand KERN (Figure 3-a), an oven (Figure 3-c), a crucible and a desiccator. The expression of the water content H is given by the expression (1):

$$H=\frac{m_2-m_3}{m_2-m_1}x100 \quad (1)$$

m_1: the mass of the crucible;
m_2: the mass of the sample and the crucible;
m_3: the mass of the dry sample and the crucible.

Figure 3. *(a) KERN precision balance (b) PROVITEQ precision balance - (c) XUE225 oven.*

2.2.2. Density and Water Absorption Capacity

The water absorption capacity was determined according to the NF EN 1097-6 standard [36]. The equipment is composed of a 0.01g precision balance (Figure 3-b), a ventilated oven with a thermostat (Figure 3-c), a pycnometer (Figure 4-a), a chronometer and a thermostated water bath. The expression of the water absorption capacity in 24 hours WA_{24} and that of the real density ρ_a are given by:

$$WA_{24}=\frac{100.(M_1-M_4)}{M_4} \quad (2)$$

$$\rho_a=\rho_w\frac{M_4}{M_4-(M_2-M_3)} \quad (3)$$

ρ_w the density of the test water;

M_1 the mass in air of the saturated and superficially dry sample;

M_2 the mass of the pycnometer containing the saturated sample and water;

M_3 the mass of the pycnometer filled with water only;

M_4 the mass in air of the oven-dried sample.

2.2.3. Ash Content

The ash content of the by-products was determined according to NF EN ISO 1171 [37]. It allows to determine the ash content at 815°C. For this purpose, the following were used: an electronic balance with a precision of 0.1 mg (Figure 3-a), a desiccator (Figure 4-b), an oven (Figure 4-c), crucibles and laboratory dishes. The ash content is determined through the expression (4):

$$A=\frac{m_3-m_1}{m_2-m_1}x100 \quad (4)$$

m_1: the mass of the crucible;
m_2: the mass of the sample and the crucible;
m_3: the mass of the ash and the crucible.

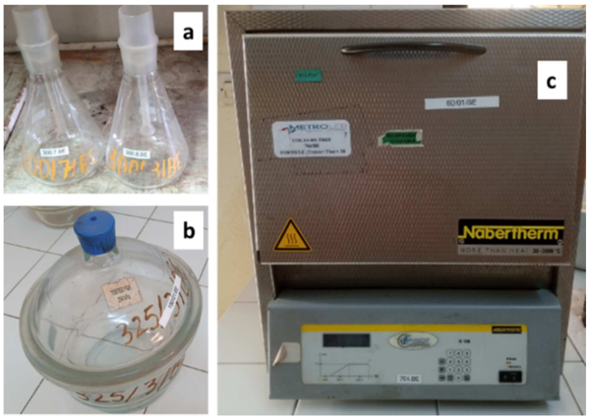

Figure 4. *(a) water pycnometer (b) desiccator (c) Nabertherm furnace.*

2.2.4. Bulk Density

The bulk density is the physical property of the material that allows us to evaluate its mass for a unit of volume. It takes into account the voids inside the material. It was determined in this study according to the standard NF EN ISO 17892-2 [38]. For this, the mass of a given volume of material is measured. The measurements were made on three (3) samples. The apparent density is given by the expression (5):

$$\rho=\frac{m}{V} \quad (5)$$

m: the mass of the material;
V: the volume of the container.

2.2.5. Calorific Values

Calorific value is the amount of energy contained in a unit of mass of a material. There are two types of calorific values: the lower calorific value (LCV) and the higher calorific value (HCV). They were determined in this study by the standard NF EN ISO 18125 [39]. The LCV is the energy theoretically recoverable by the user. It is the most interesting data to use. In this study, the HCV measurements were carried out in a calorimetric bomb type PARR 6100. The device was calibrated with a benzoic acid tablet.

The mass of water was thus determined (calorimetric bomb and calorimeter). The calorimeter box was then charged with oxygen at a pressure of 25 bars. The sample was placed in a dish of 25 mm diameter and 14 to 19 mm height before being introduced into the box immersed in the calorimeter tank. The combustion was electrically triggered by a wire. The water temperature was monitored every thirty

(30) seconds, before and after combustion until a linear cooling regime was reached. The calorific value (HCV in J/g) was calculated and displayed directly but it is the equation (6) that allows this calculation.

$$\text{HCV}=\frac{K_1 * E_{cal} * (t_m - t_i) - K_1 * (L - l) * E_{pt}}{M} \quad (6)$$

E_{cal} : calorimetric equivalent of the calorimeter, the bomb, their accessories and the water introduced into the bomb;

E_{pt} : calorific value of platinum 2.3 cal/cm;

K_1 : conversion factor of the calories in joules;

t_m : maximum temperature;

t_i : initial temperature;

L : initial length of the platinum filament;

l : remaining length of the platinum filament;

M : mass of the sample to be analyzed.

The HCV for the dry sample can be determined by equation (7).

$$HCV_{dry}=\text{HCV}\frac{100}{100-h} \quad (7)$$

The LCV for the dry sample is calculated according to equation (8) with equation (9).

$$LCV_{dry}=\text{HCV}_{dry} - 25.1 * h_2 \quad (8)$$

$$h_2 = 8937 * H * \frac{100-h}{100} + h \quad (9)$$

H: Hydrogen content by mass;

h: Moisture content.

2.2.6. Pure Starch Content

The pure starch content was determined for a liquid waste containing glue. It was determined in order to assess the potential of the waste to be used as a binder in a material. It was determined according to the ISO 10520 standard [40]. The method consists of two determination steps. The first is the hydrolysis of a portion of the sample with dilute hydrochloric acid, followed by clarification and filtration, then measurement of the optical rotation by polarimetry. A second portion of the sample is then treated with 40% *(V/V)* ethanol to extract sugars and low molecular weight polysaccharides. The filtrate is then subjected to the procedure of the first part. The difference between the two measurements obtained is multiplied by a factor and thus gives the starch content of the sample.

For this purpose, an electronic balance of precision 0.1 mg, 100mL volumetric flasks, a polarimeter, a boiling water bath and other laboratory glassware were used.

The starch content is given by the expression:

$$S = \frac{2000}{\alpha_D^{20}}\left[\frac{2,5\alpha_1}{m_1} - \frac{5\alpha_2}{m_2}\right]\frac{100}{w_1} \quad (10)$$

α_D^{20} : specific optical rotation of pure starch;

α_1 : total optical rotation in degrees;

α_2 : optical rotation of ethanol-soluble substances, in degrees;

m_1 : mass of the test sample of the first part;

m_2 : mass of the test sample of the second part;

w_1 : dry matter content of the test sample.

3. Results

3.1. Study of the Cotton Sector in Benin

3.1.1. Cotton Transformation Process

The processing of cotton begins after the harvest. The seed cotton is transformed in the ginning factories and then in the crushing and textile factories. At the output of the ginning factory, it is obtained cotton seed which represents 55% of the quantity of seed cotton and, cotton fiber which represents 42%. The cotton seeds are transformed in the crushing plant to obtain cotton oil and cotton cake, which represent respectively 10% and 20% of the quantity of seed cotton. At the textile mill, cotton ecru is obtained, which represents more than 41% of the original seed cotton. The other elements resulting from the process are considered as by-products. Figure 5 summarizes the general process of cotton transformation in Benin.

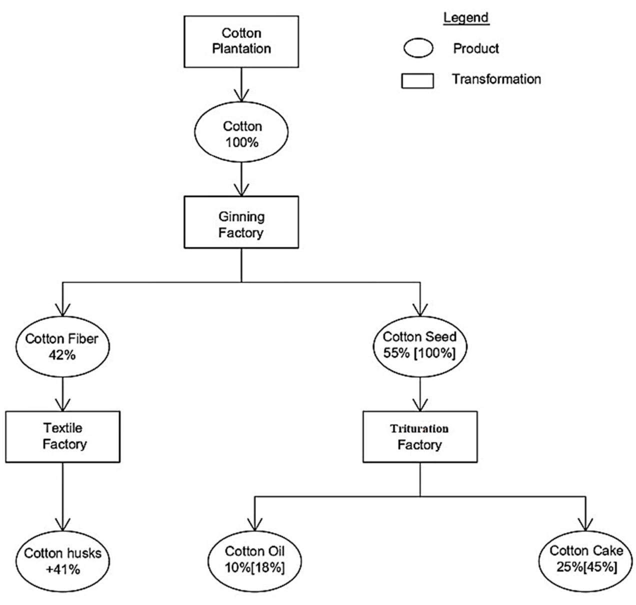

Figure 5. *General transformation process of cotton in Benin.*

In each processing sector, there are several stages and different by-products. In the ginning plant, there are five (5) by-products (Table 1) after 4 processing stages. Figure 6 shows the process of ginning seed cotton with the by-products obtained.

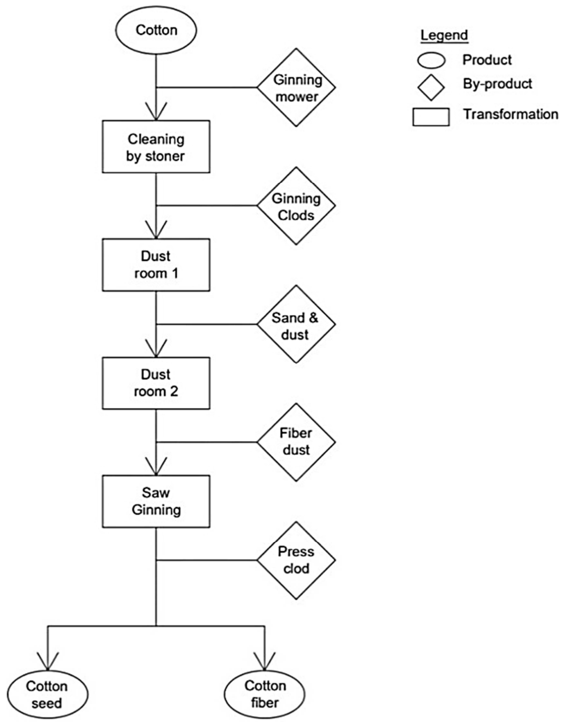

Figure 6. *Transformation process in the ginning plants.*

At the trituration plant, cottonseed oil and cottonseed cake are obtained after a long process of eight (8) steps resulting in six (6) by-products (Table 1). Figure 7 shows the stages of the cottonseed crushing process with the by-products obtained.

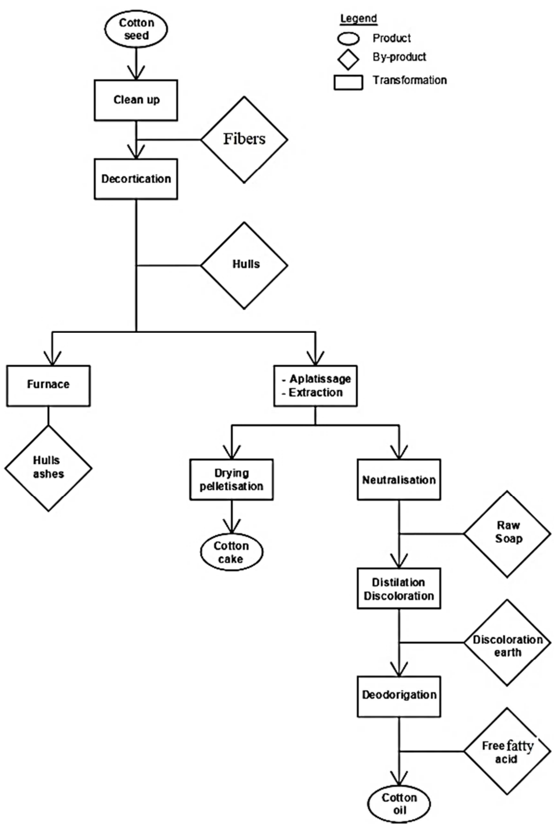

Figure 7. *Transformation process in the trituration plants.*

Lastly, the cotton fibers are processed into unbleached cotton in the textile mills. This transformation results in small quantities of four (4) by-products (Table 1). The diagram in Figure 8 shows the transformation process of cotton fibers with the by-products obtained.

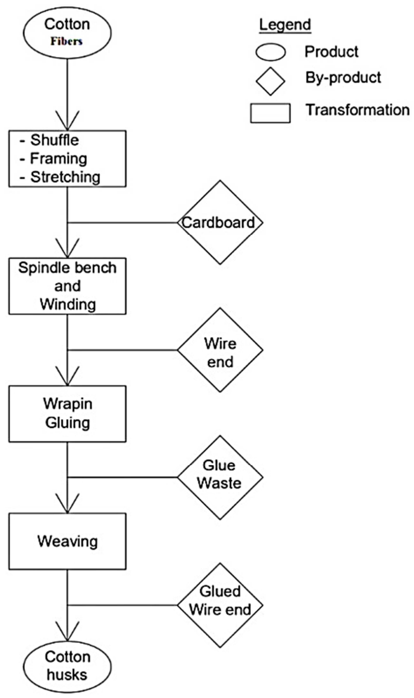

Figure 8. *Transformation process in textile plants.*

In short, during this processing chain, there are fifteen (15) by-products, including five (5) in the ginning mill, six (6) in the trituration mill and four (4) in the textile mill. Table 1 also shows the by-products and their sources.

3.1.2. Estimated Quantities of Waste

With the data collected in the processing plants of the sector, the quantity of each by-product was estimated according to the quantity of seed cotton. Thus, Table 1 presents these percentages for 100% seed cotton and an estimate for the 2020-2021 season.

Table 1. *Quantity of each by-product for 100% seed cotton.*

Processing plant	By-products	Quantity (%)	Quantity (tonnes)
Ginning mill	Destoning’s clods	0.450	3 276
	Sand and dust	0.400	2 912
	Fiber dust	0.120	873.6
	Press clods	0.500	3 640
	Ginning clods	1.450	10 556
Textile mill	Cardboard	0.010	72.8
	Glue waste	0.840	6115.2
	Glued thread’s bits	0.315	2293.2
	Thread’s bits	0.420	3057.6
Trituration mill	Fibers	0.550	4 004
	Hulls	16.00	116 480
	Hulls ashes	0.030	218.4
	Discoloration earth	0.080	582.4
	Raw soap	0.001	7.28
	Free fatty acid	0.008	58.24

From this table, it appears that the quantity of cottonseed hulls, estimated at 16% of production, is the most important of all other by-products. Thus, more than 116,000 tons of this by-product were generated in 2021. After hulls, there are ginning clods (1.45%) and glue waste (0.84%). Figure 9 shows the quantities of by-products (without hulls) for the last season and the average for the last three years.

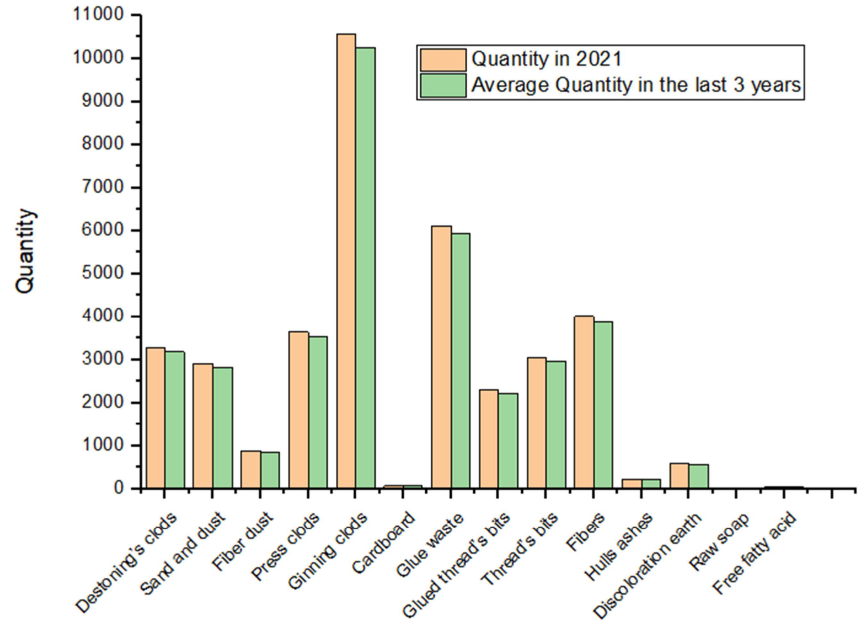

Figure 9. *Quantity of each by-product for the last three campaigns and the past campaign.*

This figure (Figure 9) allows us to classify the wastes according to their availability. It can be seen that after hull waste, ginning clods are the most important, followed by glue waste. In the rest of this study, only these three by-products are considered for characterization.

3.2. Characterization of the Main by-Products

3.2.1. Visual Aspect

All different, the collection of samples of each of the by-products have allowed to gather in figure 10 the pictures presenting some by-products. This figure helps to imagine or to identify by their natural forms not only the possible valuations of these by-products, but also the possible treatments to make them usable in the field of the building.

3.2.2. Physico-Chemical Characteristics

At the end of the tests, the physico-chemical characteristics of the main by-products tested are presented in Table 2.

The moisture content in the ginning clods is higher than in the hulls; this is due to the high-water absorption capacity of the ginning clods. These water contents depend on the climate (temperature, humidity, wind) and the storage conditions of the by-products before harvesting. In addition, both by-products have a high calorific value.

Table 2. *Physico-chemical characteristics of the by-products.*

	Hulls	Ginning clods	Glue waste
Moisture content	9.20%	15.73%	---
Water absorption capacity	34%	95%	---
Apparent density (kg/m^3)	52	25	---
Absolute density (kg/m^3)	1485	342	---
Ash content	3.30%	8.40%	---
LCV (J/g)	18301	16065	---
HCV (J/g)	19536	17271	---
Pure starch rate	---	---	18%

Figure 10. *Photo of by-product samples: (a) hulls, (b) ginning clods, (c) destoning's clods, (d) hulls ashes, (e) fiber waste, (f) sand and dust, (g) cotton stalks, (h) glued thread's bits, (i) thread's bits.*

4. Discussion

The main by-product of the cotton industry in Benin is the hull of the cottonseed (16%); it is used in several fields. Its lower calorific value at constant volume is 19,536 J/g, which makes it an excellent fuel. It is used in trituration factories (Société des Huileries du Bénin, Société FLUDOR) to feed the boiler and also in cement factories (Société des Ciment du Bénin SCB-LAFARGE). The works of Seyikpe [41] and Aranud [42] have highlighted the massive use of this by-product as Alternative Fuel. On the other hand, cottonseed hulls contain protein, about 1.6% according to the work of Soulama [43]. These hulls are used for animal feed [44–46]. This by-product is fully exploited by industries and farmers, as since 2018, cement factories are no longer able to get a normal supply of this by-product to use as an alternative fuel. Figure 11 illustrates the decrease in the amount (as a percentage of fuel) of cotton hulls used by the SCB-LAFARGE plant over the last ten years. This decrease is due to the difficulty in obtaining supplies of this material. It is easy to see that in 2021, this percentage will tend towards zero. This is due to the total valorisation of this by-product.

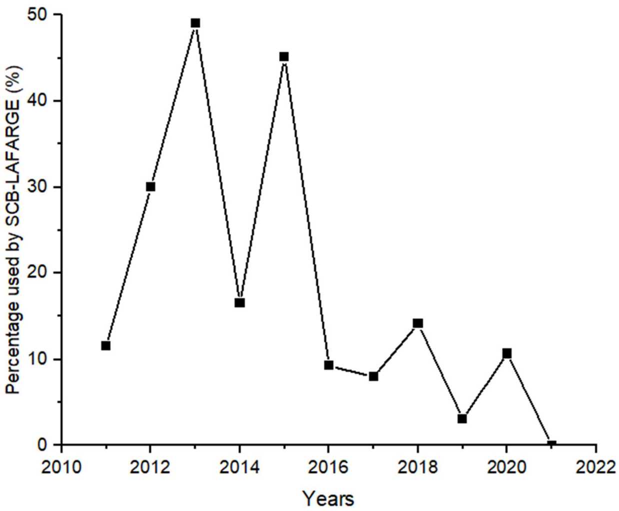

Figure 11. *Percentage of cottonseed hull used by SCB-LAFARGE in the last ten years.*

In addition to these uses as fuel or nutritional elements, cottonseed hulls could also be used in the production of construction materials such as thermal insulation panels [33]. Finally, since the hulls are covered with very thin fibers, these fibers can be separated from the hull and used as plant nanofibers. These nanofibers have many industrial applications.

The second by-product on the list is the ginning clods. It represents 1.45% of cotton production, or 10,556 tons for the 2020-2021 season. This quantity is relatively large. There is still no adequate use for this by-product; it is thrown away and then burned. Several scientific works have proved that cotton fibers can be used in the production of building materials, as reinforcement in cement matrix materials or thermal insulation panels [25-27, 30, 47]. The absolute density of the ginning clods is 342 kg/m^3; this by-product can reduce density and other characteristics in building materials. Therefore, a use in construction materials is possible for these wastes. Several researchers have done similar work [25].

The third is glue waste. This is a by-product from the gluing stage of cotton threads. It is obtained from a mixture of starch flour and water. This waste glue, not recycled, is thrown into a pit to be decomposed later by microorganisms. Chemical analysis performed on this by-product shows that it contains 18% starch which is a compound well known for its potential to serve as a binder in the production of eco-building materials [48-50]. For example, in the work of Hounkpatin et al. [51] and Ferrandez-Garcia et al. [52], starch glue has been used as a binder to manufacture thermal insulation panels. Given its starch content and the potential of starch as a binder, this by-product can be used as a binder in the production of thermal insulation boards or fiber boards.

5. Conclusion

In spite of the quantity of waste generated by the cotton sector, there is not yet a policy of their valorization. This study made it possible to make a synthesis of the various types of by-products of the cotton sector, their quantities and also some physical and chemical characteristics. With the exception of seed hulls, which are in high demand and are used for energy purposes, it is possible to consider the use of ginning clods and glue waste in the production of construction materials.

In this study, the different ways of valorization of the by-products have been evaluated by the possibility of their use as filler, binder or reinforcement in construction materials or insulation materials in buildings. These by-products would have other uses in other areas. However, this study does not give more details on the methods of implementation of materials with by-products, the characteristics that these materials would have and many other data that would allow to judge acceptable or not the materials based on these by-products.

References

[1] Abraham, M., Pingali, P.: Transforming Smallholder Agriculture to Achieve the SDGs. In: Gomez, P. S., Riesgo, L., Louhichi, K. (eds.) The Role of Smallholder Farms in Food and Nutrition Security, pp. 173-209. Springer International Publishing (2020). https://doi.org/10.1007/978-3-030-42148-9_9

[2] Osabohien, R., Matthew, O., Gershon, O., Ogunbiyi, T., Nwosu, E.: Agriculture Development, Employment Generation and Poverty Reduction in West Africa. Open Agric J. (2019). https://doi.org/10.2174/1874331501913010082

[3] Ministère de l'Agriculture de l'Elevage et de la Pêche.: Stratégie Nationale Pour l'e-Agriculture Au Bénin 2020-2024 [National Strategy for e-Agriculture in Benin 2020-2024]. MAEP. http://assets.fsnforum.fao.org.s3-eu-west-1.amazonaws.com/public/discussions/contributions/Stratégie nationale e-Agriculture Benin 25-08-2019.pdf (2019). Accessed 14 september 2021.

[4] Alidou, M. N., Ceylan, R. F., Ilbasmj, E.: Trade and revealed comparative advantage measures: a case of main export crops in Benin republic. Kastamonu Üniversity J Fac Econ Adm Sci. 18 (1), 382-397 (2017).

[5] Bonou-zin, R. D. C., Allali, K., Fadlaoui, A.: Environmental Efficiency of Organic and Conventional Cotton in Benin. Sustainability (2019). https://doi.org/10.3390/su11113044

[6] Maboudou, A. G., Niehof, A.: Responses of Rural Households to the Cotton Crisis in Benin. Sustainability (2020). https://doi.org/10.3390/su12104207

[7] Adam, S., Edorh, P., Totin, H., et al. Pesticides et métaux lourds dans l'eau de boisson, les sols et les sédiments de la ceinture cotonnière de Gogounou [Pesticides and heavy metals in drinking water, soils and sediments in the cotton belt of Gogounou], Kandi et Banikoara (Bénin). Int J Biol Chem Sci. (2011). https://doi.org/10.4314/ijbcs.v4i4.63054

[8] Gouvernement de la Republique du Bénin.: Évolution de la production du coton ces 10 dernières années au Bénin [Evolution of cotton production over the last 10 years in Benin]. Gouvernement de la République du Bénin. https://www.gouv.bj/actualite/1243/evolution-production-coton-10-dernieres-annees-benin/ (2021). Accessed 12 september 2021.

[9] FAO.: Cultures et produits animaux [Crops and animal products]. FAO. http://www.fao.org/faostat/fr/#data/QCL (2021). Accessed 25 october 2021.

[10] CHOGOU, S. K.: Itinéraires techniques et pratiques paysannes dans les zones cotonnières du nord du Bénin [Technical itineraries and farmers' practices in the cotton zones of northern Benin]. Colloque International Umr Sagert. 1, 25-27 (2003).

[11] Clarence, S. G., Raimi, O. I. A. A., Claude, V. E.: Valorisation of By-Products of the Cotton Sector in Benin: Design and Manufacturing of a Defibrator and a Thermopress for the Production of Insulation Panels. Int J Adv Res. (2021). https://doi.org/10.21474/ijar01/12504

[12] Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC).: Réchauffement Planétaire de 1,5°C [Global warming of 1.5°C]. IPCC. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/09/SR15_Summary_Volume_french.pdf. (2020). Accessed 25 october 2021.

[13] Direction de la Stratégie Groupe Engie.: Un Monde d'Energie [A World of Energy]. Engie. https://www.engie.com/sites/default/files/assets/documents/2020-01/un-monde-denergie-edition-2019-engie1_compressed_0.pdf (2019). Accessed 05 janvier 2022.

[14] Lee, J., Kim, J., Song, D., Kim, J., Jang, C.: Impact of external insulation and internal thermal density upon energy consumption of buildings in a temperate climate with four distinct seasons. Renew Sustain Energy Rev. (2017). https://doi.org/10.1016/j.rser.2016.11.087

[15] Zwanzig SD, Lian Y, Brehob EG. Numerical simulation of phase change material composite wallboard in a multi-layered building envelope. Energy Convers Manag. 2013; 69: 27-40. https://doi.org/10.1016/j.enconman.2013.02.003

[16] Sadineni SB, Madala S, Boehm RF. Passive building energy savings: A review of building envelope components. Renew Sustain Energy Rev. 2011; 15 (8): 3617-3631. https://doi.org/10.1016/j.rser.2011.07.014

[17] Mirrahimi S, Mohamed MF, Haw LC, Ibrahim NLN, Yusoff WFM, Aflaki A. The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot-humid climate. Renew Sustain Energy Rev. 2016; 53: 1508-1519. https://doi.org/10.1016/j.rser.2015.09.055

[18] Fang Z, Li N, Li B, Luo G, Huang Y. The effect of building envelope insulation on cooling energy consumption in summer. Energy Build. 2014; 77: 197-205. https://doi.org/10.1016/j.enbuild.2014.03.030

[19] Zhu J, Chew DAS, Lv S, Wu W. Optimization method for building envelope design to minimize carbon emissions of building operational energy consumption using orthogonal experimental design (OED). Habitat Int. 2013; 37: 148-154. https://doi.org/10.1016/j.habitatint.2011.12.006

[20] Sozer H. Improving energy efficiency through the design of the building envelope. Build Environ. 2010; 45 (12): 2581-2593. https://doi.org/10.1016/j.buildenv.2010.05.004

[21] Košir M, Gostiša T, Kristl Ž. Influence of architectural building envelope characteristics on energy performance in Central European climatic conditions. J Build Eng. 2018; 15: 278-288. https://doi.org/10.1016/j.jobe.2017.11.023

[22] Aditya L, Mahlia TMI, Rismanchi B, et al. A review on insulation materials for energy conservation in buildings. Renew Sustain Energy Rev. 2017; 73: 1352-1365. https://doi.org/10.1016/j.rser.2017.02.034

[23] Ahmad A, Maslehuddin M, Al-Hadhrami LM. In situ measurement of thermal transmittance and thermal resistance of hollow reinforced precast concrete walls. Energy Build. 2014; 84: 132-141. https://doi.org/10.1016/j.enbuild.2014.07.048

[24] Ahmadi R, Souri B, Ebrahimi M. Evaluation of wheat straw to insulate fired clay hollow bricks as a construction material. J Clean Prod. 2020; 254: 120043. https://doi.org/10.1016/j.jclepro.2020.120043

[25] Alomayri T, Shaikh FUA, Low IM. Characterisation of cotton fibre-reinforced geopolymer composites. Compos Part B Eng. 2013; 50: 1-6. https://doi.org/.1016/j.compositesb.2013.01.013

[26] Binici H, Eken M, Dolaz M, Aksogan O, Kara M. An environmentally friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres. Constr Build Mater. 2014; 51: 24-33. https://doi.org/10.1016/j.conbuildmat.2013.10.038

[27] Briga-Sá A, Nascimento D, Teixeira N, et al. Textile waste as an alternative thermal insulation building material solution. Constr Build Mater. 2013; 38: 155-160. https://doi.org/10.1016/j.conbuildmat.2012.08.037

[28] Chikhi M, Agoudjil B, Boudenne A, Gherabli A. Experimental investigation of new biocomposite with low cost for thermal insulation. Energy Build. 2013; 66: 267-273. https://doi.org/10.1016/j.enbuild.2013.07.019

[29] Dieckmann E, Eleftheriou K, Audic T, Lee KY, Sheldrick L, Cheeseman C. New sustainable materials from waste feathers: Properties of hot-pressed feather/cotton/bi-component fibre boards. Sustain Mater Technol. 2019; 20. https://doi.org/10.1016/j.susmat.2019.e00107

[30] Koh CH (Alex), Kraniotis D. A review of material properties and performance of straw bale as building material. Constr Build Mater. 2020; 259: 120385. https://doi.org/10.1016/j.conbuildmat.2020.120385

[31] Ranjbar N, Zhang M. Fiber-reinforced geopolymer composites: A review. Cem Concr Compos. 2020; 107. https://doi.org/10.1016/j.cemconcomp.2019.103498

[32] Serra A, Tarrés Q, Llop M, Reixach R, Mutjé P, Espinach FX. Recycling dyed cotton textile byproduct fibers as polypropylene reinforcement. Text Res J. 2018; 89 (11): 2113-2125. https://doi.org/10.1177/0040517518786278

[33] Soulama S. Caractérisation mécanique et thermique de biocomposites à matrice polystyrène recyclé renforcée par des coques de cotonnier (Gossypium Hitsutum L.) ou des particules de bois de Kénaf (Hibiscus Cannabinus L.) [Mechanical and thermal characterization of biocomposites with recycled polystyrene matrix reinforced with cotton husks (Gossypium Hitsutum L.) or Kenaf wood particles (Hibiscus Cannabinus L.)]. Published online 2014. http://www.theses.fr/2014BELF0243/document

[34] Wei K, Lv C, Chen M, Zhou X, Dai Z, Shen D. Development and performance evaluation of a new thermal insulation material from rice straw using high frequency hot-pressing. Energy Build. 2015; 87: 116-122. https://doi.org/10.1016/j.enbuild.2014.11.026

[35] ISO. ISO 687 Solid Mineral Fuels - Coke - Determination of Moisture in the General Analysis Test Sample.; 2010: 9.

[36] CEN. NF EN 1097-6 : Essais Pour Déterminer Les Caractéristiques Mécaniques et Physiques Des Granulats [Testing to Determine the Mechanical and Physical Characteristics of Aggregates].; 2001: 58.

[37] ISO. ISO 1171 Solid Mineral Fuels - Determination of Ash.; 2010: 9.

[38] ISO. NF EN ISO 17892-2: Reconnaissance et Essais Géotechniques - Essais de Laboratoire Sur Les Sols - Partie 2 : Détermination de La Masse Volumique d'un Sol Fin [Geotechnical Testing and Recognition - Soil Laboratory Tests - Part 2: Determination of Fine Soil Volumetric Mass].; 2014.

[39] ISO. NF EN ISO 18125: Biocombustibles Solides - Détermination Du Pouvoir Calorifique [Solid Biofuels - Calorific Value Determination]; 2017.

[40] ISO. IS0 10520 : Native Starch - Determination of Starch Content - Ewers Polarimetric Method.; 2015: 9.

[41] SEYIKPE H. Etude des combustibles alternatifs utilises en industrie cimentière : cas de la SCB-LAFARGE d'Onigbolo [Study of alternative fuels used in the cement industry: case of SCB-LAFARGE of Onigbolo]. Published online 2021. https://biblionumeric.epac-uac.org:9443/jspui/bitstream/123456789/2835/1/Mémoire SEYIKPE S. Hermas_compressed.pdf

[42] ARNAUD YBA. Injection des alternatifs fuels à l'amont du four [Injection des alternatifs fuels à l'amont du four]. Published online 2018. https://biblionumeric.epac-uac.org:9443/jspui/handle/123456789/696

[43] Soulama S, Atcholi KE, Almusawi AM. Contribution à l'étude de l'influence des paramètres d'élaboration et optimisation du procédé de mise en œuvre de bio-composites en coques de cotonnier et polystyrène recyclé [Contribution to the study of the influence of the parameters of elaboration and optimization of the process of implementation of bio-composites in shells of cotton and recycled polystyrene]. 2015; 11 (1): 35-58. http://www.afriquescience.info/document.php?id=4207

[44] Robinson EH, Li MH. Use of Plant Proteins in Catfish Feeds: Replacement of Soybean Meal with Cottonseed Meal and Replacement of Fish Meal with Soybean Meal and Cottonseed Meal. J World Aquac Soc. 1994; 25 (2): 271-276 https://doi.org/10.1111/j.1749-7345.1994.tb00190.x

[45] Alford BB, Liepa GU, Vanbeber AD. Cottonseed protein: What does the future hold? Plant Foods Hum Nutr. 1996; 49 (1): 1-11. https://doi.org/10.1007/BF01092517

[46] Kumar M, Tomar M, Punia S, et al. Cottonseed: A sustainable contributor to global protein requirements. Trends Food Sci Technol. 2021; 111: 100-113. https://doi.org/10.1016/j.tifs.2021.02.058

[47] Goga G, Chauhan BS, Mahla SK, Cho HM, Dhir A, Lim HC. Properties and characteristics of various materials used as Biofuels: A review. Mater Today Proc. 2018; 5 (14): 28438-28445. https://doi.org/10.1016/j.matpr.2018.10.130

[48] Bumanis G, Vitola L, Pundiene I, Sinka M, Bajare D. Gypsum, Geopolymers, and Starch—Alternative Binders for Bio-Based Building Materials: A Review and Life-Cycle Assessment. Sustainability. 2020; 12 (14). https://doi.org/10.3390/su12145666

[49] Kulshreshtha Y, Schlangen E, Jonkers HM, Vardon PJ, van Paassen LA. CoRncrete: A corn starch based building material. Constr Build Mater. 2017; 154: 411-423. https://doi.org/10.1016/j.conbuildmat.2017.07.184

[50] Le AT, Gacoin A, Li A, Mai TH, Rebay M, Delmas Y. Experimental investigation on the mechanical performance of starch–hemp composite materials. Constr Build Mater. 2014; 61: 106-113. https://doi.org/10.1016/j.conbuildmat.2014.01.084

[51] Wilfried Hounkpatin H, Kouamy Chégnimonhan V, Allognon-Houessou E, Bruno Kounouhewa B. Thermal Insulation Panel Based on Vegetable Typha Domingensis and Starch: Formulation and Physico-chemical Characterization. Int J Sustain Green Energy. 2020; 9 (2): 29. https://doi.org/10.11648/j.ijrse.20200902.12

[52] Ferrandez-García MT, Ferrandez-Garcia CE, Garcia-Ortuño T, Ferrandez-Garcia A, Ferrandez-Villena M. Study of Waste Jute Fibre Panels (Corchorus capsularis L.) Agglomerated with Portland Cement and Starch. Polymers (Basel). 2020; 12 (3). https://doi.org/10.3390/polym12030599