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Article

Utilization of Bamboo Shoots as a Renewable Local Available Source of Adsorbent (silica gel)

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Abstract: The availability of an economic source of amorphous silica has been a challenge in Nigeria over the years. In this study, characterization of silicon dioxide (SiO_2) and its extraction from bamboo shoot were carried out. Dried bamboo shoots were calcinatd at 600 ºC for 5 hr using a muffle furnace to obtain bamboo ash (BSA). Silica gel was produced by digesting BSA with sodium hydroxide solution to form sodium trioxosilicate (IV) solution. The solution was treated with hydrochloric acid solution to form silica gel at pH 7.0 and then, dried. The yield of 40.60% silica obtained had attrition, moisture content, porosity and bulk density of 50.90%, 2.53%, 1.06 and 1.05 g/m^3, respectively. Characterization using FT-IR technique has indicated the presence of silanol (Si-OH) and siloxane (Si-O-Si) functional groups in high frequency stretching and low frequency bending of the silica. Besides, Scanning Electron Microscope (SEM) analysis revealed amorphous structure of SiO_2 prepared from BSA. Thus bamboo shoot can serve as an economical source of amorphous silica.

Keywords: Bamboo shoot, Characterization, FT-IR, SEM and Silica gel

1. Introduction

Bamboo is a giant woody perennial monocotyledonous plant that belongs to the family-Gramineae and subfamily-Bambuseae. It is widely distributed because it can grow on land unsuitable for other agricultural crops. It is abundantly found in Asia, South America, and Africa; with over 1200 species and 70 genera in natural forests and vast plantations areas. Africa, Asia and Latin America used it extensively for housing construction, forestry, agro-forestry, agricultural activities and utensils, (Mayowa and Joshua, 2018; Okwori and Chado, 2013). Asia countries such as China and Japan utilized the juvenile shoots as edible food because of high minerals content, except fat, (Nongdam and Leimapokpam, 2014). Besides its nutritional values, it has significant health benefits. The ancient traditional pharmaceuticals, control diabetes and cholesterol level with prepared bamboo salt extracts, (Hossain et al., 2015). It was found that different parts of the plant contain hemi-cellulose, cynogenetic glycosides, resins, waxes, and many others. The bud joint is said to contain silicious substance, which is white camphor like crystalline in appearance; sweet in taste and slightly sticky to the tongue, (Hossain et al., 2015; Sangeetha et al., 2015).The ash content of bamboo contains inorganic minerals primarily silica, calcium, potassium, manganese and magnesium. Silica content is found to be higher in the epidermis, very little in the nodes and absent in the internodes, (Okwori and Chado, 2013).

As spotted earlier, Asia and other developed countries used bamboo extensively for the development of their economy. Contrary, in Nigeria, the uses are limited due to certain impediments. Rather it is an alternative raw material for textile production. Most States used it as scaffold materials and decking of storey buildings; fencing/thatched houses roofing, and staking materials for yam plantations. Literature showed that there is little contribution of bamboo towards income generation specifically in the area of study, (Okwori and Chado, 2013; Ogunwusi, 2013; Nwaihu et al., 2015). Therefore, the purpose of this research work is hinged on diversifying the use of bamboos as an alternative source of silica gel, since they are abundant and commonly found.

2. Materials and Methods

2.1. Materials

Sodium hydroxide purchased from Merck, hydrochloric acid from QualiKems, and distilled water were utilized.

2.1.1. Methods

The Bamboo shoots obtained were peeled and washed to remove dust and other impurities. These were pounded and dried under the sun for 3 days. It was burned at 600 ºC for 5 h using a muffle furnace to obtain BSA. To obtain silica gel, 10 g of ash obtained from calcinations was digested with 100 mL portions of 1 M sodium hydroxide solution and heated at 80 ºC for 1 h with constant stirring. The solution was allowed to cool at ambient temperature and filtered through Whatman filter paper no.42 to remove solid residue. The filtrate was treated with 1 M hydrochloric acid solution drop wise with constant stirring until the pH of the solution was adjusted to 7.0. The silica formed was aged for 24 h and centrifuged at 4000 rpm for 10 minutes, clear supernatant was then discarded. Distilled water was added to the gels to break it and make slurry. Slurries were washed severally (5 times) and transferred into a beaker, dried at 80 ºC for 12 h to produce xerogels. The sample was stored in airtight plastic bag.

The conversion of silicon dioxide to sodium trioxiosilicate (IV) is shown in equation 1, whereas production of silica gel is shown in equation 2.

$$SiO_2 + 2NaOH(aq) \longrightarrow Na_2SiO_3(aq) + H_2O \qquad (1)$$

Sodium silicate upon treatment with HCl forms silica gel:

$$Na_2SiO_3(aq) + HCl(aq) \longrightarrow SiO_2(s) + NaCl(aq) + H_2O \qquad (2)$$

Fig. 1. Plates (a) Raw bamboo shoots (b) Cleaned and sliced bamboo shoots (c) Pounded and dried bamboo shoot (d) BSA (e) Crystal formation (f) Extracted silica gel

2.2. Determination of Physicochemical Properties of Adsorbent

2.2.1. Determination of percentage yield

The percentage yield of the adsorbent (extracted silica) was calculated using the formula:

$$\% \text{ Yield} = \frac{\text{Actual Yield (g)}}{\text{Sample (g)}} \times 100 \quad (3)$$

2.2.2. Determination of attrition

Two grams (2 g) of adsorbent was placed in a 250 mL conical flask containing 50 mL of distilled water and stirred for 2 h using magnetic stirrer. The mixture was filtered with the aid of plastic funnel and filter paper. The residue filtered off was dried, weighed and percentage attrition was determined as:

$$\% \text{ Attrition} = \frac{A_1 - A_2}{A_1} \times 100 \quad (4)$$

Where A_1 = Initial mass of the adsorbent A_2 = Final mass of the adsorbent

2.2.3. Determination of Moisture Content (M %)

An empty crucible was washed, oven dried and cooled in a desiccators. Its mass was then recorded as M_1. Two grams (2 g) of the adsorbent sample was weighed into the clean dried empty crucible, it was weighed and the mass M_2 was recorded. The crucible and its content was then placed in an oven for drying at 105 ºC for 3 h. This was repeated until a constant mass, M_3 was obtained. The percentage mass (M %) lost was calculated as follows:

$$M (\%) = \frac{M_2 - M_3}{M_2 - M_1} \times 100 \quad (5)$$

2.2.4. Determination of porosity

Two grams (2 g) portion of the adsorbent was weighed and dispersed in 50 mL (V_w) distilled water in a graduated tube. The mixture was centrifuged for 15 minutes at 5000 rmp. The resulting volume was recorded as V_T. Porosity was calculated from the equation below:

$$\text{Porosity} = \frac{V_w}{V_T} \quad (6)$$

Where V_w = volume of water taken, V_T = volume resulting after dispersion of sample

2.2.5. Bulk density

This was determined by weighing 2 g portion of the adsorbent into a dried graduated 10 mL measuring cylinder. The cylinder was tapped on a bench until the volume of the mixture has stopped decreasing. The mass (M_1) and volume (V_1) were recorded and the density was calculated as shown below:

$$\text{Bulk density} = \frac{M_1}{V_1} \quad 7$$

Where M_1 = mass of the sample (g), V_1 = volume of the sample (mL)

2.3. Characterization

2.3.1. FT-IR measurement

IR spectrum was recorded as Nujol mulls using KBr pellets on FT-IR spectrophotometer Shimadzu (FT-IR 8400S). Two milligrams (2 mg) of the sample was weighed into a small agate mortar and a drop of nujol was added and ground. The mull obtained was suspended on the cell of the spectrophotometer and scanned between 4000-400 cm^{-1} at 32 runs per minute.

2.3.2. SEM measurement

The morphology of the prepared silica powders were investigated by SEM (Quanta 400, FEI, USA). The sample was coated with a very thin film of gold (Au) using a sputter coater (SPI, 12150 AX, USA) and prior to SEM analysis.

3. Results and Discussions

3.1. Physicochemical Properties of the Prepared Silica Gel

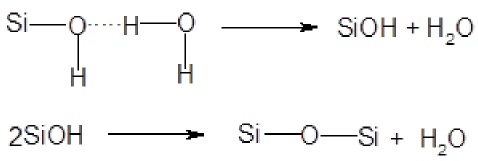
The percentage yield of silica gel extracted from bamboo shoot, digested with 1 M NaOH solution was found to be 40.60% (table 1). The moderate yield is an indication that bamboo shoots contain relative amount of silica and can serves as an economical material for the production of silica gel, (Addis, 2018). However, researchers have shown that factors such as concentration and volume of alkaline solvent as well as extraction temperature and time can affect the yield of silica gel. According to literatures, the more the solvent, the higher the surface area for the distribution of solvent to bamboo ash. This mean the formation of Na_2SiO_3 will increase as well as the yield of silica gel, (Addis, 2018; Setyawan et al., 2019).

Table 1: Some physicochemical properties of the prepared silica gel

Parameter	Value
Percentage yield	40.60%
Attrition	50.90%
Moisture content	2.53
Porosity	1.06
Bulky density	1.05g/m^3

Attrition is an important parameter of an adsorbent to maintain its physical integrity and withstand frictional forces. Researchers had shown that for an adsorbent, especially the one of low-cost to be utilized for economical purposes, it must have high abrasive forces either in batch or column applications if not only impressive adsorption properties. The consequence is that, adsorbent of low abrasion resistance loss its particle integrity and formed dust particles; hence, the rate of filtration is reduced and amount of adsorbent, (Adie et al., 2013). Percentage attrition of the prepared silica gel was determined as 50.90%, an indication that, the value is of good mechanical strength, meaning low ability of degradable during usage.

The moisture content is the mount of solvent an adsorbent contains. This parameter can be affected by certain factors. Moisture content is non-proportional to solvent concentration. That is, the lower the solvent concentration, the higher the moisture content. It can also be affected by the breaking of hydrogen bond that exist between water and silanol groups, consequently, the silanol group condensed to release water in the process as shown in the equations below. A good adsorbent must have low moisture content because high value can reduce adsorption strength, (Setyawan et al., 2019). The moisture content value of the prepared silica was found to be 2.53 %, little above the literature datum for commercial silica, maximum: 2%, (Setyawan et al., 2019). Increase in the value of moisture content may be attributed to one of the above mentioned factors. Equation (8) and (9) show the release of water from silica



(8)

(9)

Porosity of the silica was found as 1.06, an indication that the substance has adsorption applications. This is because characteristics of adsorbent are measure of the particle size and geometry of its void, (Kukwa et al., 2016).

Bulk density portrait the quality of an adsorbent. High values of bulk density implies good quality adsorbents, (Hasany and Chaudhary, 1996). The silica extracted has a bulk density value of $1.05 g/m^3$, this is relatively high which portend good quality adsorbent.

3.2. Infrared Spectral Analysis

The FT-IR spectrum of silica (extracted at 600°C) is shown in Fig. 2.

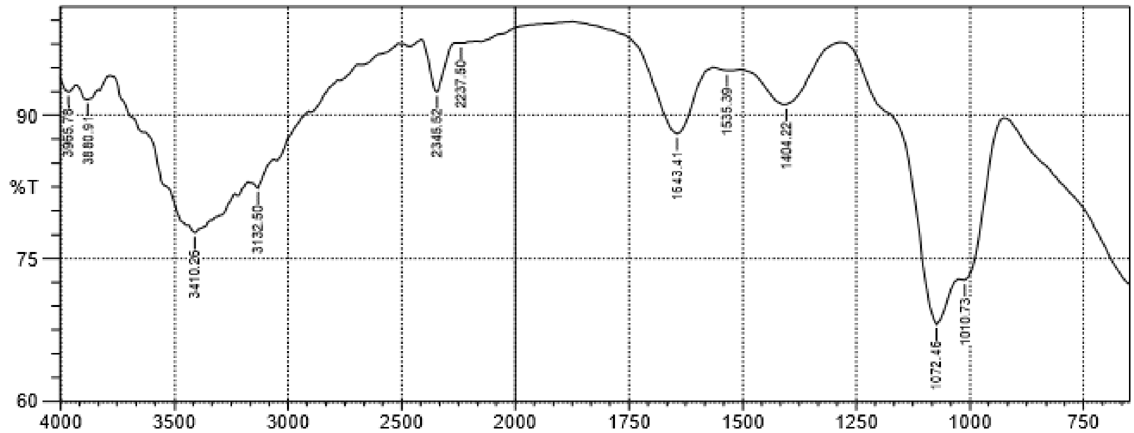


Fig. 2: FT-IR result for silica

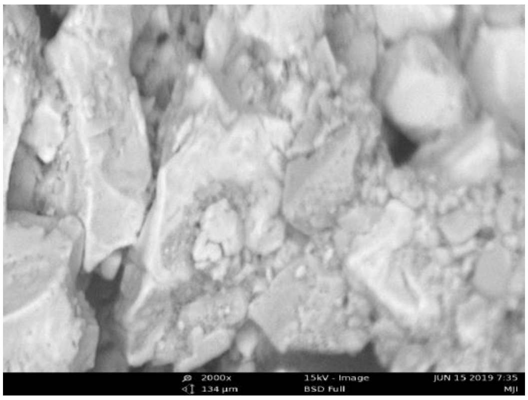
Two main characteristic peaks were observed around 3410 cm^{-1} and 1072 cm^{-1}. A strong and broad band observed at 3410 cm^{-1} is ascribed to O-H stretching group of silanol, Si-OH while the weak band at 1643 cm^{-1} assigned to the vibration bending mode (H-O-H) of incorporated water molecule. Another strong band at 1072 cm^{-1} is attributed to asymmetric vibrational mode of siloxane, Si-O-Si. This vibrational frequency clearly shows that the bamboo shoot (ash) contain silica. The spectral bands of Si-O-Si had also been reported by many other researchers, (Khushbu et al., 2016; Ananthi et al., 2016; Mupa et al., 2015; Yiase et al., 2018).

3.3. Scanning Electron Microscope (SEM)

The Scanning Electron Microscope (SEM) revealed the surface morphology of adsorbent derived from bamboo shoot ash. Images were obtained at 1000x, 1500x and 2000x magnifications as depicted in Fig.3 (a), (b) and (c), respectively. It can be observed that the extracted silica from BSA calcinated at 600 ^{o}C were of average particle size and irregular structure, that is amorphous, (Chanadee and Chaiyarat, 2016). Amorphous silica serve as good fertilizer because plant roots readily assimilate for more reactive and efficiency to burst their productivity, (Setyawan et al., 2019). The aggregate of the substance prepared is surrounded by number of pores as shown (Fig.3) giving the impression of porous, thus confirming images of the adsorbent.

(a)

(b)



(c)

Fig. 3. Micrographs of bamboo shoot silica at (a) 1000× (b) 1500× and (c) 2000× magnification

4. Conclusion

The yield of silica (40.60%) obtained from 10 g BSA using 1 M NaOH analytical reagent has proved bamboo shoot to serve as an economical source of silica, since the plant is naturally renewable. The FTIR data had shown that the extracted silica contain silanol and siloxane groups. In addition, SEM analysis revealed amorphous nature of the silica extracted.

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