Utilization of Guinea corn (Sorghum vulgare) Husk for Preparation of Bio-based Silica and its Characterization Studies

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Abstract—Bio-based silica was prepared from Guinea corn Husk within the context of sustainable chemistry. The Guinea corn Husk was leached in dilute HCl, washed, dried and calcined at 650 °C for 4hr. The resultant ash was digested in 2M NaOH solution, precipitated by adding H₂SO₄ and then washed to remove sulphate by-product. The siliceous materials were characterized using SEM-EDX, FTIR and XRD to investigate its composition and morphology, functional groups and the phase respectively. The elemental investigation revealed Si as major element in the ash. The presence of Si-O-Si (siloxane) and Si-OH (silanol) were confirmed by FTIR of the silica. The SEM micrograph of the silica also showed agglomeration of regular spherical particles in the morphology. The XRD pattern of the siliceous material indicated an amorphous form of the product. Guinea corn Husk as an agricultural waste can be a sustainable means for silica and other siliceous materials.

Keywords— Agricultural waste, Bio-based, Guinea corn Husk, Silica, Sustainable chemistry.

I. INTRODUCTION

The concerns of sustainable chemistry have lead to the production of bio-based materials. Bio-based materials refer to products that mainly consist of a substance (or substances) derived from biomass and either occur naturally or are synthesized, or it may refer to products made by processes that use biomass (Curran, 2010). Sustainable chemistry has one of its objectives to be the use of renewable feed stocks and byproduct in the production processes (Kargarole and Gur, 2016). Sustainable means are used to find alternatives to conventional chemical syntheses and transformations (Varma, 2014). Scalalet et al., (2015) posited that this sustainable means play a significant role in effectively addressing the global challenges, such as economy, climate change, limited natural resources, dependency on decreasing fossil resources.

Agriculture practice is a means of sustainable development as it contributes majorly to the economy of some countries in the world (Chongela, 2015). Recently more attention is given to agricultural production in most developing countries. In Nigeria, part of the efforts of the government to diversify economy of the nation from non-renewable oil is by boosting agricultural production (Anyawu et al., 2013). Waste from agricultural practices have been investigated and reported to have a greater potential for bioresource like bioenergy (Simonyan and Fasina, 2013) and biogas (Ngumah et al., 2013).

Guinea corn Husk (GcH) is an agricultural waste from milling of Guinea corn (Sorghum vulgare). Guinea corn is an important food crop grown abundantly in northern part of Niger and Benue Rivers in Nigeria (Ndububa and Nurudeen, 2015). Akinloye et al. (2014) reported that about 1.5 million tones of guinea corn husk is generated annually which has potential to increase as the economy is diversified to agriculture. Guinea corn Husk has been utilized in the production of bioethanol (Oyeleke and Jibrin, 2009) and its ash as partial replacement in Ordinary Portland Cement in concrete (Ndububa and Nurudeen, 2015) with major constituent of SiO₂.

Silica, SiO₂ is present in abundance on earth crust and plant root tissues (Ghorbani et al., 2013). It exists in amorphous and crystalline structures consisting of inter-linked SiO₂ unit in a tetrahedral arrangement (Nandanwar, 2013; Le et al., 2013). It is an important basic raw material in many industrial finished products such as electronics, ceramic, pharmaceutics, detergents, adhesives and polymer materials. It also has many technological applications as thixotropic agents, thermal insulators, composite fillers, e.t.c. (Ghorbani et al., 2013; Sun and Gong, 2001). Some biomass materials have been reportedly used for synthesis...
of silica among which are rice husks (Wang, 2012; Le et al., 2014), wheat husks (Shaik and Shaik 2013), coconut shells (Sivasubramanian and Sravanthi, 2015), sedge (Ghorbani et al., 2013), cow dungs (Rani, et al., 2014).

Consequence of the expansion in agricultural production is an increase in the level of agricultural waste. These agricultural wastes encompass waste from unutilized (excess) and biomass residue from processing of agricultural products (Edewor-Ikuponiyi and Amuda, 2013). Often, these wastes pose threat to the environment, resulting in bad odour and also affecting the quality of groundwater. However, agricultural wastes embedded with various useful constituent which can be harnessed as raw materials for further production of materials.

Attention of researchers is now shifted to the utilization of biomass material towards a sustainable development of final products (Edewor-Ikuponiyi and Amuda, 2013). In a related investigation on the same guinea corn husk by Nurudeen et al., 2014), sedge (Ghorbani et al., 2013), wheat husks (Shaik and Shaik 2013), coconut shells (Sivasubramanian and Sravanthi, 2015), cow dungs (Rani, et al., 2014).

II. MATERIALS AND METHODS

2.1 Materials

Guinea corn Husk (GcH) was sourced locally from farmer as an agricultural waste and was used as a feedstock for the preparation of silica. Chemical reagents used including sodium hydroxide, sulphuric acid, hydrochloric acid and barium chloride are of analytical grade and were used as purchased.

2.2 Methods

2.2.1 Preparation of Silica from Guinea corn Husk

The preparation was done using slightly modified method reported by Sivasubramanian and Sravanthi, (2015). The guinea corn Husk (GcH) was washed thrice with de-ionized water to remove some foreign particles from it after which it was air dried. The air dried GcH was pre-treated by leaching in 0.1 M HCl for 2 hr and washed with de-ionized water to remove some other metallic oxides. The pre-treated GcH was calcined in muffle furnace at 650 °C for 4 hr to produce Guinea corn Husk Ash (GcHA). Silica extraction was done by adding 2 M NaOH solution to the ash and stirred on magnetic stirrer plate at a constant temperature of 100 °C for 8 hr. Afterwards, the mixture was filtered and the sodium hydroxide extract in form of sodium silicate (eqn. 1) was further used for the preparation of silica. The sodium silicate was reacted with 2.5 N H2SO4 to precipitate pure silica (SiO2) (eqn. 2). The white siliceous precipitate formed was aged in an autoclave for 5 hr, filtered and washed severally with de-ionized water to remove sulphate impurities.

\[
\text{SiO}_2 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SiO}_3 + \text{H}_2\text{O} \quad (1)
\]

\[
\text{Na}_2\text{SiO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{SiO}_2 + \text{Na}_2\text{SO}_4 + \text{H}_2\text{O} \quad (2)
\]

2.2.3 Characterization Studies

The elemental compositions of the guinea corn husk ash (GcHA) were determined by X-Ray Fluorescence (XRF) and Energy Dispersive X-ray Spectroscopy (EDX). The bio-based silica prepared from the GcHA was characterized for its surface functional groups, morphological properties with elemental compositions and to assess the phase, the degree of crystallinity using FTIR and SEM-EDX and XRD respectively.

III. RESULTS AND DISCUSSIONS

Guinea corn Husk Ash and Silica

The composition of the acid-leached Guinea corn Husk Ash (GcHA) determined by XRF is presented in Table 1. The results showed that the ash contains 93.83% of SiO2 as the major component; Al2O3 and CaO were present as minor components while K2O, Fe2O3 and P2O5 as trace components. This indicates that guinea corn husk (GcH) is a good precursor for silica comparing with value reported for rice husk ash (99.08%) by Le et al., (2013). In a related investigation on the same guinea corn husk by Nurudeen and Ndububa, (2015), 78.17% of SiO2 was reported. However, 93.83% obtained from this study is likely due to the pre-treatment in HCl which reduced the content of other metallic oxides.

| Element   | Al2O3 | SiO2  | K2O  | CaO  | Fe2O3 | P2O5 |
|-----------|-------|-------|------|------|-------|------|
| % Weight  |       |       |      |      |       |      |
|           | 1.182 | 93.83 | 0.069 | 1.897 | 0.146 | 0.247 |
The comparison of elemental compositions of the guinea corn husk ash (GcHA) and the prepared silica as revealed by Energy Dispersive X-ray spectroscopy (EDX), (Figs. 1 and 2) with XRF results showed that the results were in close agreement. It is observed that silicon with the highest intensity is the major element present in the ash. This agrees with the XRF analysis result reported in Table 1. Consequence to this result, it is evident that silica can be prepared from GcHA. The guinea corn husk ash (GcHA) contains majorly silicon with little impurities of other elements. The intensity of the silicon (Si) in the prepared silica appears to be stronger (Fig. 2) than that of GcHA (Fig. 1). The disappearance of some minor elements like magnesium, potassium and calcium in the silica (Fig. 2) which were earlier present in GcHA (Fig. 1) suggested more purity of the silica. Therefore, purer silica has been extracted from the ash using sodium hydroxide (Shaik and Shaik, 2013). However, the presence of carbon and sulphur are likely to be contaminant during the analysis.

The FTIR spectroscopic study revealed the two major functional groups of silica, silanol (Si-OH) and siloxane (Si-O-Si) (Fig. 3). The summary of the observed functional groups is presented in Table 2. The broad absorption band at between 3433 cm\(^{-1}\) is assigned to –OH of silanol and absorbed water (Rani et al., 2014). The peaks at 954, 795 and 463 cm\(^{-1}\) correspond to asymmetry, symmetry and bending mode of SiO\(_2\) respectively (Le et al., 2013). The siloxane group of the silica is attributed to 1083 cm\(^{-1}\) (Chee and Yaacob, 2010). The surface functional group from FTIR analysis confirmed the material to be silica.
Table 2: FTIR peaks of silica and the assigned bond

| Assigned bond                | Wave number (cm⁻¹) |
|-----------------------------|--------------------|
| O-H                         | 3433               |
| Si-O-Si                     | 1083               |
| SiO₂ asymmetry mode         | 954                |
| SiO₂ asymmetry mode         | 795                |
| SiO₂ bending mode           | 463                |

The morphology studied by Scanning Electron Microscopy (SEM) is shown in Figs. 4 and 5 for the GcHA and extracted silica respectively. The micrograph (Fig. 4) revealed flake like and irregular particles. These irregular particles of the ash morphology suggested different components of the ash. The Fig. 5 however shows agglomeration of regular and spherical shape particles but rough surface. This indicates assembly of similar particles of silicate ions as compare with the morphology of the ash which was irregular. Ndubuda and Nurudeen, (2015) reported the direct use of such ash in partial replacement of cement in concrete. It evident that higher quality and purity of silica can be extracted from ash contained silica by treatment with aqueous sodium hydroxide followed by precipitation using acid (Shaik and Shaik, 2013).
The XRD pattern of the silica is presented in Fig. 6. From the figure, it can be said that the silica is an amorphous since the characteristic peak at 2θ cannot be seen (Le et al., 2013; Geetha et al., 2016).

IV. CONCLUSION

This study has successfully demonstrated the use of guinea corn husks, an agricultural waste for the preparation of silica. The characterization studies using FTIR and SEM-EDX confirmed the prepared material to be silica. Also XRD pattern indicated the amorphous form of silica. Therefore, it is found that amorphous silica, an important material which has numerous applications can be prepared in accordance with sustainable chemistry.

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