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BANANA PSEUDO-STEM HITS VARIOUS SPOTS IN WASTE MANAGEMENT

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ABSTRACT

Banana is one of the most well-known and useful plants in the world. Almost all the parts of this plant, that are, fruit, leaves, flower bud, trunk, and pseudo-stem, can be utilized. The exploitation of banana pseudo stem as a source for bioethanol production from the sugars released due to different chemical and biological pretreatments, fiber extraction with the help of pectinases, production of activated carbon as electrode materials for supercapacitors and biosynthesis of metallic nanoparticles. Several potential applications of the pseudo stem are mentioned, such as the use of this fiber to fabricate rope, placemats, paper cardboard, string thread, tea bags, high-quality textile materials, absorbent, polymer/fiber composites, etc discussed in this paper

Keywords: Banana, pseudo stem, applications, fiber

Introduction

Banana is the second largest produced fruit after citrus, contributing about 16% of the world's total fruit production. India is amongst the largest banana (*Musa acuminata*) producing countries and thus banana pseudo stem is commonly available agricultural waste to be used as a lignocellulosic substrate. The pseudo-stem is the main part of the banana plant tree and serves three main physiological functions: to hold the glass, transport water and minerals, and store food reserves. The banana pseudo-stem has also been considered for use as pulp and paper raw material, fiber for textiles, and filler or structural reinforcement in composite materials. Additionally, all parts of the banana plant have some medical added value, such as the flower can be cooked and consumed by diabetics, bronchitis, dysentery, and ulcer patients. The banana pseudo-stem sap can be orally taken or externally applied for stings and bites. The most widely known banana plant species for its fiber is Abaca (*Musa textiles*). Its fiber is highly important among the leaf fiber group, whereas the most common banana that is consumed by humans is a member of the *Musa acuminata* species (Ahmad and Danush, 2018).

The pseudo-stem of the banana plant is the stem of the banana plant that provides and transports nutrients from the soil to the fruits. This pseudo-stem will be cut and become waste biomass after the banana fruit is ripe and harvested because the banana plant is unusable for the next harvest. For every ton of banana fruit harvested, about 100 kg of the fruit is rejected (i.e., rotten fruit) and approximately 4 tons of biomass wastes (e.g., leaf, pseudo-stem, rotten fruit, peel, fruit-bunch-stem, rhizome, etc.) are produced. This means, that for every cycle of banana fruit production, four times of biomass wastes are also produced. Based on other literature, it can be estimated that one hectare of banana farms could produce approximately 220 tons of biomass wastes. These wastes are usually disposed of by the farmer into lakes and rivers or simply burned. The banana tree wastes if not properly managed can cause problems to the environment, because if they are dumped in wet conditions or burned can produce greenhouse gases, which can cause a problem to the environment. Proper research is required to combat the problem of waste.

Banana Pseudo-stem

Chemical Composition of Banana Stem/Pseudo-stem

The composition of banana stems differs largely in the pseudo-stem's outer bark and inner core. The inner parts of the pseudo-stem contain no elementary fibers and fibers consist of pipes rather than fiber bundles, which is considered to positively affect water transportation in the stem. The lignin content in fibers from the inner part of the banana stem equals only 50.9% of the content in fibers from the banana bark. According to Mophapaltra et al. (2010), the core of the banana pseudo-stem is rich in polysaccharides with traces of other elements and has a very low content of lignin. The content of glucose and cellulose was found to be in the ratio of 42.0-74.0 and 34.0-63.9% of DS, respectively, and lignin in the ratio of 5.1-22.3% of DS, in banana pseudo-stem, and 3.3-4.6% of DS, in the inner parts of the banana pseudo-stem. N-tot, P-tot, and K-tot contents were found to be around 0.3-2.8, 0.2-0.5, and 4.0-4.6% of DS, respectively. C/N-ratios were reported in levels of 21-66 (Bernstad *et al.,* 2012)

Potential applications of banana stem

Banana pseudo-stem usually becomes biomass waste once the harvest time of banana fruit is finished. Its disposal has become a major problem due to the amount of waste. Therefore, researchers have started to extract the fibers and other components from the stem and used them to produce various value-added products. One of the most common banana pseudostem fiber products produced today is rope and cordage. Banana pseudo stem is categorized into central core (10-15%), fiber (1.5-2%) and waste material after fiber extraction (10-15%) which is further divided as sap (35-40%) and scutcher (40-45%). Pickles, candy and soft drinks were prepared from a central core. Fibers were utilized in the textile industry, microcrystalline cellulose, paper preparation (currency note paper) and handicrafts. Compost and vermicompost were prepared from scutcher and mordant for fixing a colour and organic liquid fertilizers were prepared from sap (Subagyo and Chafidz, 2018).

Production of activated carbon as electrode materials for supercapacitors

The production of activated carbon electrodes from a banana stem for supercapacitor cell applications has been successfully performed by Taer *et al.* (2018). The preparation process was conducted using a chemical activation agent such as KOH or ZnCl2 at a large concentration of 10-50 percent of the carbon mass. The production of activated carbon from banana stems uses a combination of chemical and physical activation. This preparation of the carbon electrode begins by processing banana stems using previously reported methods (Taer *et al.,* 2018).

Banana stems were pre-carbonized at a low temperature of 250 ˚C for 2.5 hours, followed by a grinding and sieving process, resulting in a green carbon powder with particle sizes of 39-52 μm. The next step, chemical activation, was performed using KOH at various concentrations, i.e., 0.0 M, 0.3 M, 0.5 M, and 0.7 M. All samples were formed into a green carbon monolith by compression pressure, and thus all carbon pellet samples were from integrated carbonization and activation methods, as previously reported (Taer *et al.,* 2018). The samples were carbonized at a temperature of 600 °C using a furnace tube in a nitrogen gas environment with a constant flow rate of 1.5 L /min, followed by physical activation using CO2 gas at a temperature of 850 ˚C and a scan rate of 10 ˚C/min. The carbonization and physical activation processes convert the green monolithic sample into activated carbon (AC) and the samples were polished and washed to neutral pH to increase the sample purity. The mass, diameter, thickness, crystallinity, morphology and chemical composition of the activated carbon monolithic samples were measured. The electrochemical property measurements were performed using fabricated supercapacitor cells, i.e., a sandwich type that consists of body cells, current collectors, electrodes, a separator and electrolytes (Gonzalez *et al.,* 2016). The body cells and current collectors were made from acrylic and 316 stainless steel tape. Electrochemical measurements were performed using a Physic CV UR Rad-Er 5841 instrument calibrated with a 1280 solartron device. Electrochemical measurement was conducted at a scan rate of 1 mV/s and a potential window of 0 to 500 mV controlled using CVV6 cyclic voltammetry software. The electrochemical characteristics of an AC-Ks-based supercapacitor cell were examined via the specific capacitance calculated using the standard equation (Li *et al.,* 2010; Taer *et al.,* 2018).

The binderless activated carbon electrode from a banana stem exhibits an excellent combination of physical and electrochemical properties. The use of a low concentration of KOH activation agent of 0.0-0.7 M, followed by physical activation at a temperature of 850 ˚C for 2 hours using CO2 gas, has succeeded in producing an activated carbon electrode without the addition of adhesive material. The physical properties of the carbon electrode are strongly related to the specific capacitance of the supercapacitor cell.

Biosynthesis of metallic nanoparticles (MNPs)

Banana stem has many bioactive compounds including alkaloids, glycosides, saponins, tannins, flavonoids, and phenols which may well reduce and stabilize the MNPs. The fresh waste banana stem (WBS) was cut into pieces with a size of 1–2 mm. The WBS pieces (500 g) were refluxed with distilled water (1000 mL) for 2 h. The solution was filtered and the pale yellow extract was stored in the refrigerator at 2–4 °C. The salt solutions of Ag^{+} or Au^{3+} ions were added into the WBS extract under stirring at 1000 rpm in dark conditions.

The MNPs formation was confirmed by a change in the colour. For optimization of reaction conditions, parameters including concentration of metallic ion (0.5–2.0 mM), reaction temperature (30-90 °C), and reaction time (30-90 min) were investigated by UV-vis measurement. The absorption spectrum of the aqueous extract showed peaks at a region of 298 nm.

The formation of WBS-AgNPs and WBS-AuNPs was recognized with an increase of intensity at surface plasmon resonance (SPR) peaks of about 415 nm and 525–630 nm, respectively. To investigate characterizations and applications, MNPs were synthesized under the optimized conditions. The MNPs catalyst was obtained by centrifugation at 4000 rpm for 30 min and washed thrice with water and then ethanol to remove the impurities. The powder of MNPs was dried at 90 _C overnight. For evaluation of antibacterial activity, solutions of

WBS-AgNPs and WBS-AuNPs were tested against a gram-positive bacterium strain (*Bacillus subtilis*) and a gram-negative bacterium strain (*Escherichia coli*) by using the disk diffusion method.

The metallic nanoparticles and their applications in wastewater treatment and pharmaceutical field. The procedure not only was an eco-friendly, inexpensive, simple and rapid method without the requirement of any toxic chemicals but also utilized successfully waste source in the agricultural field. The bioactive molecules in waste banana stem extract played a role as capping and reducing agents for the transformation of metallic ions into the nanoparticles. The biosynthesized AgNPs and AuNPs were crystalline and spherical with mean sizes of 7–13 nm and 11–14 nm, respectively. The AgNPs showed very strong bioactivity against two tested bacterial strains. Doan *et al.* (2020) described that the biosynthesized nanoparticles may be used for development in biomedical and environmental applications.

Fiber extraction

Generally fiber extraction is done by using the Raspador machine, besides observing and understanding the routine process of fiber extraction using the Raspador machine, enzyme soaking of the banana stem under optimized conditions and later extracted fibers with the help of the Raspador machine were found to be good. A pre-treatment of the green stem and trunk of the banana plant with pectinases was found to be useful for the fiber extraction process because the fiber quality and yield obtained from the banana trunk as well as the banana stem was better with enzyme soaking than at the zero hours' stage which was equivalent to the conventional fiber extraction process. The quality of fiber extracted from the banana trunk was better than the banana stem. The fiber yield varied with different periods of retention. In the case of the banana stem, retention of 12 and 36 hours was found to be useful from the viewpoint of fiber yield but 36 hours of retention could produce the best quality fiber from the banana stem. Chauhan *et al.* (2013), have also reported an increase in fiber yield and fiber quality through a prior treatment of *Calotropis procera* (Ankra twigs) with pectinase enzyme.

Adoption of the enzymatic route shall help in enabling the handmade paper manufacturers to utilize the machine extracted banana fiber that is available at a cheaper price than the hand extracted banana fiber to produce good quality handmade paper thereby improving their profitability. Further studies may be required to make the process of fiber extraction more cost-effective through the enzymatic route.

Paper preparation

Contains cellulosic fibers that can be exploited in a paper mill, these fibers being the object of study of this work to obtain pulp and subsequent evaluation of its suitability and paper, by applying chemical and mechanical pulping processes. The methodology consisted of applying two chemical processes to soda and kraft. The latter being characterized by the combination of a boiling temperature and atmospheric pressure and a mechanical process, the pseudo-stem banana tree also performed soda chemical pulping to the combination of the fibrous material of the pseudo-stem and rachis. The application process was performed initially on a laboratory scale and pilot plant later after obtaining the values of operating conditions. The variety used is coming from *Musa sp* National Agronomic Institute Caacupé City-Paraguay.

Fibrous materials were prepared from pseudo stem using three different methods followed by grouping into each test performed with the relevant reduction process, later cooking process was performed on a laboratory scale and pilot plant. The process of disintegration was done by a high-speed grinder and the drainability was measured by correcting this experimentation temperature and consistency. Finally, the lab sheets were prepared with measured physical properties. According to Lilian *et al.* (2015), the process performance and mechanical strength properties which were satisfactory for a type of paper Containerboard paper called wave could be. These promising results indicate that obtaining pulp from the pseudo stem of the banana tree is technically feasible. It is necessary to do further experimental work to confirm these preliminary findings like extending the range of operation digestion conditions and detailed refining.

Production of bioethanol

Renewable energy is now capturing a good share of the worldwide headlines because of concerns about declining supplies of fossil fuels, escalating population, and industrialization triggering ever-increasing demand for fuels. Currently, bioethanol is produced from alcoholic fermentation of molasses or simple sugars, which are produced from crops generating starch or sugar. While technologies to produce ethanol from simple carbohydrates are well established, the technologies to produce bioethanol from complex lignocellulosic biomass are still under development. Agricultural waste products (like banana pseudo stem) may be economically converted to bioethanol.

Different pretreatments, enzymatic hydrolysis, fermentation using different microbes, product separation and post-treatment of the liquid are the main steps of the currently employed ethanol production process from lignocellulosic biomass. Pretreatment processes of lignocellulose are necessary to break down lignin and increase the accessibility of enzymes and microbes to carbohydrates (Hendriks and Zeeman, 2009). Pretreatments like concentrated acids, wet oxidation, solvents and metal complexes are effective, but too expensive as compared to the glucose costs. Steam and alkali-based pretreatments are the ones that, according to the factors determining the economic effectiveness have a high potential of which, alkali pretreatment in particular has been shown to effectively remove lignin, but leave the carbohydrate portions relatively intact Various alkali and acid treatments were carried out of which alkali treatments (5% plant biomass with 1 N NaOH, for 18 h at room temperature) were found to be optimum for delignification.

Enzyme production by co-cultivation of *A. ellipticus* and *A. fumigatus* was performed and these microorganisms exhibit cellulolytic activities like hydrolytic and -glucosidase activities under co-culture experiments. Saccharification and ethanol production were produced by using lab-scale bioreactors. There is still a need to develop: a more efficient and economic pretreatment process; a hyper-cellulase producing strain for improved saccharification and, an improved yeast strain capable of utilizing both pentose and hexose sugars, which in turn would increase ethanol production (Snehal *et al.*, 2014).

Other applications

Paper board, tissue paper, etc., can be prepared out of banana pseudo stem. Banana fibers can be used as a natural sorbent, and bio-remediation agent for bacteria innatural water purifiers, for mushroom production, in handicrafts and textiles when mixed with paddy straw. It is also used in the production of marine cordages, high quality paper cardboards, tea bags, string thread, high quality fabric material, paper for currency notes, and good rope for tying purposes. Fibers from the pseudo stem, leaf sheath and rachis are used in making fibre based products. Pseudo stem fiber bundles have higher specific strength modulus and lower strain at break than leaf sheath and rachis fiber bundles, having values comparable to other lignocellulosic fibers. Banana fiber is a natural sorbent has a high potential in absorbing spilled oils in refineries.

With the fairly low amount of ash and lignin and a high amount of holocellulose, pseudo stem and petioles are suitable for pulping in the paper industry. Banana and banana pseudo stems contain pathogenesis-proteins possessing antimicrobial properties. Lectins, found in banana plant tissues, can be effectively used for human consumption. Pseudo stem can be recycled to be used as bio-fertilizer. It contains a good amount of cellulose and starch and can be used as cattle feed. The outer covering of pseudostem is mostly cellulosic material while the core or pith is rich inpolysaccharides and other trace elements but lower in lignin content.

The waste banana pith can be used as a colour absorbent in wastewater containing textile dyes. Pithis used as food after boiling and addition of spices in many parts of India.

The seawater resistance of the pseudo-stem fiber and its natural buoyancy characteristic have made a market for this fiber in shipping cable manufacture. This fiber is also used to produce fishing nets, other types of cordage, mats, packaging, sheets, etc. Banana pseudo-stem fiber was used to make traditional dresses such as kimono and kamishimo. This fiber is usually used due to its lightweight and comfort. Furthermore, banana pseudo-stem fiber is also utilized to produce cushion covers, bag, table cloth, curtains, and others (Mohapatra *et al.*, 2010). Additionally, there are some potential uses of banana fibers, such as: to be used as natural absorbent, for the production of mushrooms, arts/handicrafts, string thread, paper cardboard, tea bags and high-quality textiles/fabric materials, currency note paper, and many other products. The use of banana fiber as a natural absorbent also has promising potential to absorb oil spilling in oil refineries. It also can be used as an absorbent in coloured wastewater from the dyes of the textile industry (Bello *et al.*, 2018; Phirke *et al.*, 2001). Banana and banana pseudo-stem contain pathogenesis proteins, which possess antimicrobial properties (Bello *et al.*, 2018). The pseudo-stem can also be converted into a bio-fertilizer (Jordan and Chester, 2017). It also contains a high amount of cellulose and starch, and thus it can be utilized as feed for cattle (Ray *et al.*, 20213). Moreover, there have been numerous research studies that reported the use of banana pseudo-stem fiber in the fabrication of polymer/fiber composites [Pappu *et al.*, 2015 Basak *et al.*, 2016].

Conclusion

Banana plants are considered one of the world's most useful plants. Almost all of the parts of this plant, for example, fruit, peel, leaf, pseudo-stem, stalk, and inflorescence, can be utilized. The banana fruit itself is one of the most popular fruits that is a valuable commodity all around the world. Nevertheless, banana pseudo-stem usually becomes biomass waste once the harvest time of banana fruit is finished. Therefore, researchers have started to extract the fibers and other components from the stem and used them to produce various value-added products. The fibers from the banana pseudo-stem can be extracted by a decorticator machine. The next processes are retting and degumming of the fibers. The fibers derived from the banana pseudo-stem can be made into several value-added products, such as rope, cordage, fishing nets, mats, packaging material, paper sheets, textile fabrics, bags, table cloth, handicrafts, absorbents, polymer/fiber composites, etc. Additionally, other components derived from the banana pseudo-stem can also be used. The central core can be used for making pickles, candy, and soft drinks, whereas banana pseudo-stem sap (BPS) can be used for mordant for fixing colour and organic liquid fertilizer, while the scutcher can be used for making compost and vermicompost. The exploitation of banana pseudo stems as a source for bioethanol production from the sugars released due to different chemical and biological pretreatments, fiber extraction with the help of pectinases, production of activated carbon as electrode materials for supercapacitors and biosynthesis of metallic nanoparticles came into light.

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