Utilization of Organic Wastes as a Bio-Resource: A Case Study of Corn Cobs in Nigeria

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1 Introduction and Background

Nigeria has a land area of over 923,000 km^2 and is one of the most populous country in the world. Waste management issues are of great importance in Nigeria, and these issues have been reported by several studies [2, 7, 11, 23]. Nigeria bordering Niger in the north, Cameroon in the east, and Benin in the west, as shown in Fig. 1.

Nigeria is a major corn producer in Africa and the 10th largest producer of corn in the world, harvesting 9.2 million tonnes in 2011 [3]. Corn is grown in six geopolitical zones of the country, and Northern Nigeria is the leading production base of corns. In 2006, the production of corn in the North-central geopolitical zone was about 31% of the national production and increased to 44% in 2009 [15]. The main objectives of this case study are to (i) identify various means of proper utilization of corn cobs as a bio-resource in Nigeria, and (ii) discuss its benefits as well as the challenges with respect to the Nigerian bio-resource industry.

Corn is a popular food in Nigeria which can be boiled, roasted, crushed, or processed into other food products by locals. It is also regarded as the most important cereal crop in Nigeria [3]. As a result of the popularity of corn crops in Nigeria, corn agricultural wastes such as crop residues is high. If the crop residues are not properly managed or utilized, it could pose serious threat to the environment and to the health of the residents [15]. Utilizing the corn crop residues as bio-resource would reduce the waste generated and generate revenue for the farmers [3].

Corn is a resourceful crop with a high socio-economic worth as all its derivatives (grain, stalk, leaves and cob) can be processed into other food and non-food

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S. Walbridge et al. (eds.), *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2021*, Lecture Notes in Civil Engineering 249,
https://doi.org/10.1007/978-981-19-1061-6_17

Fig. 1 Major cities in Nigeria [6]

related products [3]. The use of corn residues has been studied and reported by many others, as discussed below. Corn crop residues are versatile, and they are used as raw materials in many developed countries either as a source of energy generation or construction materials [15].

In this case study, we will specifically explore the use of corn cobs as bio-resource. Corn cobs are readily available in Nigeria compared to other biomass resources and reusing these agricultural wastes would reduce waste management issue and lessen the environmental impact in Nigeria.

2 Utilization of Nigerian Corn Cobs

A total of four potential reuse of corn cobs are identified from our literature review, including (i) energy generation, (ii) construction and engineering applications, (iii) animal feeds, and (iv) industrial effluent treatment. They are separately discussed below.

2.1 Energy Generation

As a result of the over dependence on crude oil, alternative energy source in Nigeria is much less explored. Corn cobs, or other crop residues, are good sources of energy. Table 1 summarised heating values from various crops. Corn cob has a heating value of 17.39–19.14 MJ/kg [15, 22], making it a potential thermo-chemical feedstock. Compared to sesame stalks, corn cobs are at least 21.2% higher in heating value (Table 1). As it is generated in large amounts in Nigeria, corncobs could serve as a good potential feedstock for biofuels. The use of coal can be substituted with corn cobs or blended with corncobs, reducing the reliance of conventional fossil fuels. This would reduce air pollutants as harmful emissions from coal combustion are significantly reduced. Compared with coal (0.8–1.9% N and 0.7–1.2% S), corncobs (0.41–0.57% N and 0.7–1.2% S) contain lower amounts of nitrogen and sulphur [15]. Hence, less sulphur oxides are emitted during corncob combustion than coal combustion. This is especially important in Nigeria, where its population is much higher than other African countries.

Instead of direct combustion, corn cobs can also be used to generate fuel gas with minimum processing such as drying and cutting. According to Ogunjobi and Lajide [18], biochar generated from the pyrolysis of corncob can contribute 83.6 billion MJ to the energy generation in Nigeria, and simultaneously preventing about 6.8 million tonnes of CO_2 emission into the environment. According to Yu et al. [27], biochar derived from the pyrolysis of corncob can also serve as direct carbon fuel cell yielding a maximum power of 185 mW/cm^2 at a current density of 340 ^{mA}/cm^2 and at 750 °C.

Hydrogen fuel can also be derived from corn cobs. A recent study by Tang et al. [25] investigated hydrogen production from corncob using mesophilic bacterium clostridium hydrogeniproducens. They found that corncobs pretreated with alkali soaking, steam explosion, and acid explosion produce 90%, 86%, and 65%, hydrogen, respectively, using enzymatic hydrolysates as the biocatalyst. Given the abundance of corn cobs, they can be regarded as a potential hydrogen fermentation substrate. Hydrogen can be used as alternative energy resource to drive zero-emission vehicles with the use of hydrogen fuel cell [13].

Biagini et al. [4] studied gasification of corncob in a demonstration plant using a downdraft reactor. It was reported that a satisfactory plant operability was obtained with potential net power efficiency from 21.1–21.6%, gas specific production at 2 m^3/kg, and gas heating value at 5.6–5.8 MJ/m^3. The reported results are comparable

Table 1 Heating values from various crops

Crop residue	Heating values, MJ/kg	Reference
Corn cob	17.39–19.14	[15, 22]
Cotton stalk	17.40	[9]
Wheat stalk	17.15	[22]
Rice straw	15.54	[8]
Sesame stalk	14.35	[28]

to those of wood materials (chips, briquettes, and pellets) used as a feedstock in most studies in downdraft gasifiers.

A recent study by Sulaiman et al. [24] examined the production of biomass as energy source using plant residue pellets. The residues investigated were granulated corn cob residues, granulated corn stalks, and an equal mix of granulated corn stalk and corncob residues. The residues were compacted at a pressure of 200 MPa and pelletized using cassava starch as a binder. The pellets were analyzed using emission, proximate, ultimate, and calorimetry analyses. They reported that the equal mix of corn cob and stalk residues exhibited the best properties with a low nitrogen content of 0.64% and a hydrogen content of 6.22%. It also had a high heating value of 32.9 kJ/kg. Hence, it can be concluded that corn residues, regardless of residue types, are good biofuels for energy generation. The results are significant given the growth of population and its associated energy demand in Nigeria.

2.2 Construction and Engineering Applications

Corncobs can be used in manufacturing of low-cost particle boards, which can be used in building construction. The use of corn cobs in construction applications has the potential of using large amount of these agricultural waste. The use of waste materials in engineering projects saves valuable virgin construction materials and supports sustainable infrastructure. Faustino et al. [5] investigated the use of particle boards made from corncobs as a sound-proofing material. They reported that particle boards made from corncobs have comparable acoustic insulation properties when compared to other conventional materials such as expanded polystyrene and glass wool. Particle boards made from corn cobs could also serve as partition walls in buildings [19]. Ecological characteristics of construction materials are increasingly valued by architects and engineers. Concrete containing corncob-based aggregates can be used in various building and construction applications.

As discussed in Sect. 2.1, energy generation appears to be an attractive use of the corn cobs. Combustion and gasification of corn cobs produce ashes, and these ashes could then be utilized as additives to improve engineering performance of Portland cement. According to Adesanya and Raheem [1], ashes derived from burnt corn cobs can served as pozzolanic material to produce blended cement. The ash derived could also serve as a supplementary material for developing high performing and low-cost aluminum hybrid composites [15].

The literature review results suggest that corn cobs are versatile and has great potential in construction and engineering applications.

2.3 Animal Feeds

The third identified use is the use of corn cobs as animal feeds [14, 16, 17]. Crop residues are commonly used as feed for the livestock across the globe. Corn cobs can be used as an ingredient pig feeds in Nigeria. A Nigerian study reported the effect of corn cob meal on the growth and nutrient digestibility of 36 pigs [17]. They found that up to 10% of corn cobs in pig ration has no negative impacts on the livestock weight gain and other performance indicators. The major challenge associated with the use of corn cobs as pig feeds is the lignocellulosic nature (20–30% lignin, 45–55% cellulose, 25–35% hemicellulose) of the crop residue [10].

High fiber content in corn cobs, and a lack of specialized digestive in pig's digestive track may reduce the digestion rate [10]. On the other hand, Kanengoni et al. [10] also claimed that high dietary fiber associated with corn cobs hinders the production of pathogenic bacteria in the intestines, promotes the growth of lactic acid bacteria, and improves intestinal health of the pigs. Kanengoni et al. [10] further suggested that alternation of the structure of the fibrous components in maize cobs can be achieved by fermentation, heating, and grinding of corn cobs. The processed corn cobs can then be used as feed for pigs.

Millet et al. [14] reported that a balanced diet using corn cobs can be used to produce comparable meat and carcass traits with common feeding practice for organic pork. The literature review results generally support the use of corn cobs as ingredient for pig feeds. However, processing of corn cobs is typically required, and may increase the material overall cost.

2.4 Industrial Effluent Treatment

The last identified use of corn cobs is for water and wastewater treatment. Due to rapid population growth, clean water is a precious resource in Nigeria. Corn cobs, as well as corn stalks, have been investigated for their suitability in the removal of copper ion (Cu^{2+}) from wastewater effluents. According to Mohlala et al. [15], corn cob is more effective in the removal of copper than the corn stalk.

It appears that processed corn cobs offer wider range of applications in wastewater remediation. Uranium is toxic, and weakly radioactive. According to Mahmoud [12], powdered corncob can remove Uranium (VI) from an aqueous solution when applied in a batch and a fixed bed system. However, uptake rate of uranium ion in a fixed bed system is dependent on the bed height, the feed flow rate, and the initial concentration of the solution [12].

A study by Shim et al. [20] investigated the use of silica extracted from corn cob for treatment of contaminated water. They found that 84–88% Cu and 83–87% Cd were removed from the contaminated water within 24 h. The corn cob silica beads displayed are more effective in removing Cu and Cd from wastewater compared to zeolite beads. In their study, the removal efficiency of Cd, Cu, and phenol were

99%, 98% and 93%, respectively. However, it was also suggested that regeneration of the silica beads for reuse could be a challenge [20]. Ultrafine amorphous silica in nanoscale (50 nm) obtained from corncob could serve as potential future materials for controlled release applications, wastewater treatment technology catalyst, as well as dielectric materials [26].

2.5 Project Feasibility and Processing Cost

Figure 2 summaries the identified use of corn cobs with respect to the degree of processing. Literature on waste reuse and recycling generally indicate that project success depends on the required material processing cost, time, and expertise. As such, we recommend reusing Nigerian corn cobs with no, or minimum processing such as drying, cutting, and/or grinding. Specifically, we recommend the following five corn cobs applications: (i) ingredient for animal feeds, (ii) fuel gas production, (iii) insulation materials for construction projects, (iv) filtration materials for wastewater treatment, and (v) bio-char production.

3 Benefits and Challenges of Utilizing Bio-Resources in Nigeria

As a highly populous country, proper utilization of bio-resources in Nigeria is important socio-economically as it serves as a means of employment and income generation. Bio-energy industries would require skilled labor, contribute to a knowledge-based economy, and establish new markets. These new bio-resource businesses are likely to be in the rural area to take advantage of the cheaper land price and higher availability of crop residue. Rural agriculture and meat and livestock industrials might also benefit from these newly established bio-resource businesses. This would increase the number of jobs in the rural sectors, improve the income of the locals, and create wealth.

It is believed proper utilization of bio-resources would lead to development of rural areas in Nigeria. The bio-resource industry would attract investments, resulting development in rural infrastructure [21]. Roads, railways, schools, power stations, clinics, and research institutions are all important elements for a thriving rural community. As shown in Fig. 3, commercialization of the corn cobs would attract other investors and entrepreneurs for development of the Nigerian rural areas.

Some challenges are identified with the development of bio resource industries in Nigeria. Lack of basic amenities in the rural areas may hinder the development of the industries, especially at the beginning stage. Development of the bio resource industry in Nigeria would likely require subsidiary funding from the government either as long-term loans or through incentives [21]. However, getting these loans

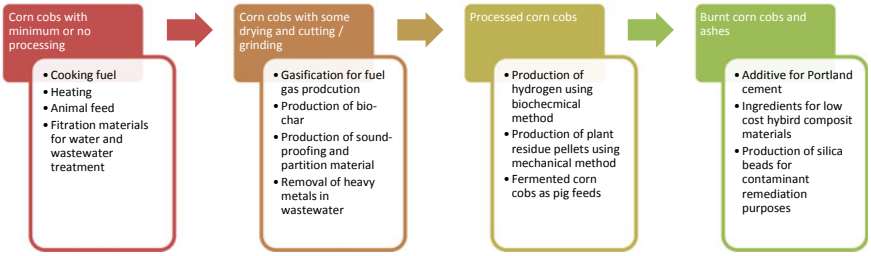

Fig. 2 The use of corn cobs as resource in Nigeria

Fig. 3 Potential benefits of the establishment of the bio-resource sector in Nigeria

may be difficult because of the lower level of income within the rural communities. Another issue would be the availability of skilled workers with adequate technical knowledge in the bio resource industry in rural Nigeria [21].

Competing use of corn cobs could also be a potential challenge. In this case study, several corn cob reuse approaches are identified. In the short term, approaches with minimum processing are recommended. In the long term, a comprehensive study on the economic and environmental performance of the alternatives should be conducted to select the most appropriate approach to corn cobs. At a minimum, the following three studies are recommended for implementation of a given project: cost effectiveness study, product life-cycle analysis, and full environmental impact assessment.

4 Conclusions

In Nigeria, corn cobs are used mainly for domestic cooking in rural areas, with a large amount improperly disposed or left to decay in soil. Research efforts have been made to use corn cobs in various applications. In this case study, potential reuse of corn cobs is identified, including energy generation, construction and engineering applications, animal feeds, and industrial effluent treatment. Literature review results suggest that corn cobs are versatile and can be used in several applications with or without further processing. We recommend reusing Nigerian corn cobs with no, or minimum processing. Specifically, we recommend the following five corn cobs applications: (i) ingredient for animal feeds, (ii) fuel gas production, (iii) insulation materials for construction projects, (iv) filtration materials for wastewater treatment, and (v) bio-char production.

Generated in large quantities, corn cobs may be an important resource in Nigeria. Utilizing corn cobs as bio resource in Nigeria would be very rewarding as it is largely available across the country. Unfortunately, a comprehensive study on the use of corn cob is not yet available. This case study represents the first step in this area. Reusing corn cobs contributes to local economy, reduces solid waste generated, and lessens greenhouse gas emission.

Acknowledgements The research reported in this paper was supported by a grant from the Natural Sciences and Engineering Research Council of Canada (RGPIN-2019-06154) to the third author (K. T. W. Ng), using computing equipment funded by FEROF at the University of Regina. The authors are grateful for their support. The views expressed herein are those of the writers and not necessarily those of our research and funding partners.

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