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Characterization and alkaline pretreatment of rice husk varieties in Uganda for potential utilization as precursors in the production of activated carbon and other value-added products

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ABSTRACT

In this study, 13 rice husk (RH) varieties from 4 agro-ecological zones in Uganda were characterized, NaOH-pretreated, and evaluated for their potential utilization as precursors for production of bio-oil, ash, char, and activated carbon for selected applications. RH varieties were characterized through particle size analysis, bulk density, proximate and ultimate analyses, specific surface area, pore volume, as well as lignocellulosic and inorganic compositions. Selected RH varieties were subsequently pretreated at NaOH concentrations of 1–4%w/v, using pretreatment ratios of 5 g RH: 40 mL NaOH. Properties varied among RH varieties, suiting them as feedstocks for different applications. Upland rice husk varieties are more suited precursors for production of bio-oil, and activated carbon due to their relatively lower ash content, higher specific surface area, as well as higher volatile matter and fixed carbon contents. Upland rice husks could as well be employed in the preparation of electrodes for electrochemical devices, due to their relatively higher specific surface area. A high ash content (21–32% dry basis) of lowland rice husks presents good prospects for their calcination, since larger amounts of rice husk ash could be obtained, and employed in different applications. Lowland rice husk varieties could also be more suited precursors for production of char for soil amendment, due to their relatively higher ash content, which subsequently increases their char yields. However, alkaline pretreatment of rice husks using 2–4%w/v NaOH can reduce the ash content by as much as 74–93%, depending on the rice husk variety, which paves way for utilizing rice husks with a high ash content in different applications. Aside from ash reduction, the enhanced specific surface area (1.2–1.7 $m^2\,g^{-1}$), volatile matter (68–79%db) and fixed carbon (19–24%db) contents of NaOH-pretreated rice husks suggests they are more suited feedstocks than when employed in their raw form, for production of bio-oil, as well as activated carbon.

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1. Introduction

About 22 countries in Africa have developed ambitious National Rice Development Strategies (NRDS), aimed at doubling their total annual rice production from 14 million tons in 2008 to 28 million tons by the end of 2018 (Demont, 2013). Uganda is one of the 22 countries, and its NRDS seeks to more than triple its paddy production from about 177,800 Mt in 2008 to 680,000 Mt by the end of 2018 (MAAIF, 2009). Although the increase in paddy production could improve food security, the subsequent increase in rice husks generated from the milling process is of major environmental concern, if not properly managed. With about 20% of the total paddy weight constituting rice husks (Jung et al., 2013), the total annual generation of rice husks in Uganda is projected to be 136,000 Mt by the end of 2018. This more than triples the rice husk generation of 44,000 Mt in 2016 (Olupot et al., 2016), suggesting a potential increase in the burden associated with rice husk disposal. Presently, rice husk is one of the least utilized agricultural residues in Uganda and many other developing countries (Quispe et al., 2017), due to limitations in traditional methods to convert rice husks into useful products. For instance, disposal of rice husk via composting is constrained by the low nitrogen content of rice husk (Ji-lu, 2007), coupled with its high cellulose and lignin contents,

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which consequently lower its biodegradability (Genevini et al., 1997). Rice husk is also unfit for animal feed, and cannot be used in feed production because of its low nutritional properties and a high silica content (Moraes et al., 2014). Consequently, these limitations compel rice millers to opt for alternative disposal options, such as open dumping or merely burning in open air, causing numerous environmental problems (Olupot et al., 2016). However, concerted research efforts are being made to find ways of disposing of rice husks in a sustainable manner, including energy recovery via direct combustion (Quispe et al., 2017), pyrolysis (Zheng et al., 2006), gasification (Olupot et al., 2016), and liquefaction (Huang et al., 2013a,b). Rice husk could also be utilized as feedstock for production of rice husk ash, which has potential applications as a filler material in thermoplastics (Chaudhary et al., 2002), construction material to produce concrete (Padhi et al., 2018), and as an adsorbent for pollutants removal from water and wastewater (Shen et al., 2014). Moreover, once extracted from the rice husk ash, silica (SiO_2) could be converted to silicon for use as an anode material for high-capacity lithium-ion batteries (Jung et al., 2013). Silica could also be employed to manufacture zeolite, which has numerous applications as a catalyst, ion exchanger, or as an adsorbent (Mohamed et al., 2015; Shen et al., 2014; Sivakumar, 2015). Other possibilities to utilize rice husks include production of biocomposites as building materials (Choi et al., 2006), biochar as a soil amendment (Gamage et al., 2016), filler in composites (Santhiago et al., 2018), catalyst (Liu et al., 2015), and as an adsorbent (Lee et al., 2018). On the other hand, activated carbon resulting from the activation of rice husks could be employed as an adsorbent, as well as an active material in the preparation of electrodes for high-performance supercapacitors, and lithium-ion batteries (Ahiduzzaman and Sadrul Islam, 2016; Zhang et al., 2017). Research on these possibilities has been on the increase lately, not only due to the need to sustainably dispose of rice husks, but also to supplement efforts geared to finding low-cost, as well as sustainable alternative precursors for production of value-added, eco-friendly products. This could save developing countries costs that would otherwise be spent on the importation of fossil-derived products. For instance, by opting to produce low-cost activated carbons from rice husks, Uganda could reduce its annual budget of US $ 160,107, spent on the importation of commercial activated carbons (Mundi, 2018).

Depending on the intended application, different properties are considered important in the selection of rice husks as suitable precursors. For instance, in the production of activated carbon, a high carbon content, low level of ash, high thermal stability, small pore diameters, high porosity, as well as a high specific surface area are some of the properties of rice husks considered important (Kalderis et al., 2008; Yeganeh et al., 2006). These influence the activation efficiency, and consequently the adsorptive properties of the resultant activated carbon (Tan et al., 2017). These same properties could be considered important, in the selection of feedstocks for preparation of electrodes for electrochemical devices, since activated carbons usually employed as the active materials, also demand a high specific surface area and porosity (Mirzaeian et al., 2017). In the production of char for soil amendment, suitable feedstocks may exhibit a high fixed carbon content, as well as low volatile matter and moisture contents. On the other hand, if the intention is to employ rice husks as feedstocks for biofuel production, then the properties of important consideration may include; a higher heating value, high bulk density, as well as a low moisture, high volatile matter, high fixed carbon, low ash, high hydrogen, low nitrogen, and low sulphur contents (Olupot et al., 2016).

Although rice husks have been shown to exhibit some of the above mentioned properties expected of suitable feedstocks for different applications, the properties vary widely with rice variety, geographical location, climate, soil chemistry, and type of fertilizer employed in paddy growth (Benassi et al., 2015; Deiana et al., 2008). Consequently, different qualities of value-added products can be obtained from rice husks, even when prepared under similar conditions (Kumagai et al., 2009). Compared to feedstocks such as coconut shells, sugarcane bagasse, and hardwood, rice husks are unusually high in ash content, for which 76–99% of the total weight is silica (SiO_2) (Menya et al., 2018). Aside from paving way for utilization of rice husk ash as a source of silica for various silicon-based products, the high ash content of rice husks could also be a huge hindrance to the successful utilization of rice husks in some applications. For instance, activated carbons with relatively lower specific surface areas may be obtained when rice husks with a high ash content are activated (Menya et al., 2018; Yun et al., 2003). The ash obstructs pore development, which consequently leads to activated carbon with low adsorption capacity. Besides, during chemical activation, the activating agent is consumed when it reacts with silica (SiO_2) in the rice husk ash, reducing the activating agent/carbon ratio. Consequently, activation occurs only at the exterior of the rice husk, which decreases pore formation, and subsequently lowers the surface area of activated carbon (Liou and Wu, 2009). A high ash content also hinders the successful utilization of rice husks as feedstocks for biofuel production, by not only lowering the higher heating value of rice husks (Bazargan et al., 2014), but also by causing agglomeration, and fouling in components of thermochemical conversion systems (Van Hunget al., 2018). In such applications, the high ash content of rice husks should be lowered to suit them as potential feedstocks (Deiana et al., 2008). Previous studies have revealed that NaOH-pretreatment can potentially lower the ash content in rice husks by over 92 %wt, depending on the alkaline concentration, pretreatment ratio, soaking time, process temperature, and effectiveness of the water-washing stage (Hsieh et al., 2009; Usmani et al., 1994). The removal of SiO_2 from rice husks by NaOH-pretreatment is due to formation of water-soluble sodium silicate (Na_2SiO_3), when SiO_2 reacts with NaOH. Na_2SiO_3 is subsequently removed from rice husks via the water-washing stage (Liou and Wu, 2009).

Unlike elsewhere in the developing countries where rice is majorly grown, few studies have been conducted to tailor the different rice husk varieties in Uganda to specific applications. This study therefore aims at the characterization of non-treated and NaOH-pretreated rice husk varieties in Uganda, hitherto not evaluated for potential utilization as precursors in the production of bio-oil, ash, char as a soil amendment, and activated carbon as an adsorbent, as well as an active material in the preparation of electrodes for electrochemical devices. Characterization of the rice husk varieties involved determination of particle size, bulk density, proximate and ultimate properties, surface area, pore volume, as well as lignocellulosic and inorganic compositions. On the other hand, NaOH-pretreatment studies were conducted to establish the NaOH-concentration, which results in significant ash removal from the rice husk varieties. Pretreated rice husk varieties were subsequently characterized to determine the effect of NaOH pretreatment on their volatile matter and fixed carbon contents, specific surface area, total pore volume, as well as their char yields resulting from pyrolysis.

2. Materials and methods

2.1. Sample collection

About 60 kg of each of the thirteen paddy rice varieties dominantly grown in four selected agro-ecological zones of Uganda were obtained from Zonal Agricultural Research and Development Institutes (ZARDIs), and from selected rice irrigation schemes.

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