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Jute and Mesta Stick Charcoal Production using Smokeless Fire in Kon-Tiki-Kiln, an Open Earth Pyrolysis Process

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ABSTRACT

In India, annually about 27 lakh tonnes of jute stick is produced which is mostly underutilized. The jute stick charcoal production potential is around 7.56 lakh tonnes annually which has wide range of uses, e.g., environmental protection, water purification, various industrial uses, building heat preservation, medicine, agricultural uses and so on. The production and export of jute stick charcoal and the return from its fibre counterpart together will strengthen the ever sick jute farmers' economy. Biochar was made from jute and mesta stick in Kon-Tiki-Kiln, in open earth pyrolysis process at ICAR-CRIJAF, Barrackpore, Kolkata, WB. The earth kiln is a circular cone hole in the ground about 1 m deep with 45° angles and an upper diameter of about 2m.Charcoal production efficiency from mesta stick was 34% and for jute it was 28%.The pH for jute and mesta were 9.87 and 9.34, respectively. Bulk density was 0.0908 g/cc and 0.132 g/cc for jute and mesta, respectively. Maximum water holding capacity of mesta biochar was 637 % and 673 % for jute**.** Biochar prepared from jute sticks contained higher phosphorus (5.5 g kg^{-1}) and potassium (11 g kg^{-1}) as compared to mesta but total nitrogen content was more in mesta (5.8 g kg^{-1}). In In eastern India, in winter months (December to February) as the air temperature remains very cool, the atmospheric temperature will not be affected due to heat arising out of the burning flames of the open earth pyrolysis process. In these months it can be done in the dried up retting tanks only giving it a desired shape as described. Trenches of similar depth and side walls can also be for open earth pyrolysis process.

Introduction

Biochar (BC) is the carbon-rich recalcitrant material produced by the pyrolysis of biomass i.e. heating in the partial or complete absence of oxygen. Biochar amendment to soils acts as a carbon sequestration technique which can also enhance soil fertility (Lehmann *et al.*, 2007). Agronomic benefits of biochar-amended soils can be the result of improved soil physical properties (bulk density, porosity, water holding capacity, permeability, aggregation), biological properties (improved environment for microbial populations such as mycorrhizae) and chemical properties (pH, CEC and nutrient retention capacity).The most commonly used feedstock to produce biochar is agricultural waste, such as corn, rice, fruit peels, and wood from forests. In addition, biochar derived from original materials, such as daily manure, wastewater sludges and micro algae, has also been studied in the last decade (Son *et al.*, 2018; Kizito *et al.*, 2015).

In India, annually about 27 lakh tonnes of jute stick is produced which is mostly underutilized. The jute stick charcoal production potential is around 7.56 lakh tonnes annually which has wide range of uses, e.g., environmental protection, water purification, various industrial uses, building heat preservation, medicine and so on. The production and export of jute stick charcoal and the return from its fibre counterpart together will strengthen the ever sick jute farmers' economy. Of late Bangladesh is exporting its jute stick charcoal to Australia, Vietnam, China and Hong Kong etc**.** This charcoal being porous in nature effectively adsorb all kinds of floating material, sulfide, hydride, methanol, benzene, phenol and other harmful chemical substances, petroleum and its products, pesticides, detergents, synthetic dyes, amine and many synthetic organic compounds.

Various pyrolysis technologies can be used to produce biochar which may result in a large variation in biochar properties. Low temperature pyrolysis (300–500°C) has shown increased biochar yield and carbon content whereas high temperature pyrolysis (>500°C) has revealed lower biochar yield and higher surface area with increased adsorption capacities for various compounds [Manya *et al.*, 2012]. Under rural (sub)-tropical conditions, biochar has mostly been produced with medium-sized traditional kilns made of bricks or simple earth mound heaps, improved retort kilns [Adam, 2009] or top-lit up-draft (TLUD) pyrolysis units. Traditional kilns can be operated using all kinds of mixed biomass feed stocks. However, pyrolysis gases such as methane (CH4), carbon monoxide (CO) and aerosols (PM 2.5 and PM 10) are released untreated, and this leads to greenhouse gas emissions, pollutant emissions and loss of energy [Cornelissen *et al.*, 2016]. Improved retort kilns have features to recirculate the produced syngases into the combustion chamber, resulting in up to 75% less toxic and greenhouse gas emissions as well as higher conversion efficiency (40–50%) compared to traditional brick kiln, due to less losses of energy-rich molecules [Bailis *et al.*, 2013]. On the other hand, improved retort kilns are more costly, difficult to operate and often consume a lot of start-up biomass materials. TLUD kilns burn feedstock cleanly, thereby reducing gas emissions, as the syngases are combusted largely in the flame front. There are some limitations with using relatively small TLUDs as they produce so little biochar (around 300 g per run) that they are mainly useful for small-scale kitchen gardening [Cornelissen *et al.*, 2016]. Larger TLUDs, while generating more biochar, require significant investments and expertise in order to be operated successfully.

To circumvent such challenges, the flame curtain, open pit "Kon-Tiki" kiln was developed [Schmidt and Taylor, 2014] which follows the principle of pyrolyzing biomass layer after layer in an open, conically built metal kiln that is easy to operate, fast, and results in low greenhouse gas emissions. It thus allows biochar production in relatively large quantities (700 to 850 L volume biochar in 4–5 hours) [Cornelissen *et al.*, 2016]. The flame curtain kiln can even be operated as a simple conically shaped hole in the ground, leading to the same low emissions and similar biochar quality as the metal version, but essentially without any cost apart from the few hours of labour required to dig and prepare the soil pit. Through open earth pyrolysis process, jute farmers will be able to produce charcoal from jute and mesta sticks or other agricultural crop residues using smokeless fire in Kon-Tiki-Kiln. With benefits such as high quality biochar, low emission, no need for start-up fuel, fast pyrolysis time and easy and cheap construction and operation the 'Kon TIki' flame curtain technology represent a promising possibility for sustainable rural biochar production with mean emission factors of CO_2 = 4300 ± 1700, CO = 54 ± 35, non-methane volatile organic compounds (NMVOC) = 6 ± 3, CH_4 = 30 ± 60, aerosols (PM10) = 11 ± 15, total products of incomplete combustion (PIC) = 100 ± 83 and NOx = 0.4 ± 0.3. It has been reported that the flame curtain kilns emit significantly ($p<0.05$) lower amounts of CO, PIC and NOx than retort and traditional kilns, and higher amounts of CO_2 (Cornellisen *et al.,* 2016.).

Studies reported that compared with the non-fertilized control, a 26% (CI: 15%–40%) increase in yield was observed with the use of inorganic fertilizer only, whereas integrated use of biochar along with inorganic fertilizer caused a 48% (CI: 30%–70%) increase. Compared with the use of inorganic fertilizer only, the addition of biochar along with inorganic fertilizer caused a 15% (CI: 11%–19%) increase in yield, indicating that biochar was as effective as fertilizers in increasing crop yields when added in combination (Lili Ye *et al.,* 2019).

Materials and Methods

Mesta and jute stick charcoal production in Kon-Tiki-Kiln at ICAR-CRIJAF

Biochar was made from jute and mesta stick in Kon-Tiki-Kiln, in open earth pyrolysis process at ICAR-CRIJAF, Barrackpore, Kolkata, WB. The earth kiln is a circular cone hole in the ground about 1 m deep with 45° angles and an upper diameter of about 2m. A scaffold was made at the bottom of the pit [Fig. 1a] where properly dried sticks were arranged in crisscross manner loosely, up to the top. Few bundles of straw were spread over the jute stick stacks and were ignited with a lighter at the top [Fig. 1b]. The top layer started burning with an overlying flame [Fig. 1c] which was allowed to continue only for two minute still the onset of ash formation at the top. Then the flame was put out with green grass bed (2-3 inches depth, [Fig. 1d]. Three minutes after it, the stack was quenched with 50 lit of water and left for cooling of charcoal. For open earth pyrolysis, similar steps haves been reported by Ecker, 2105. We collected charcoal from the pit [Fig. 1e] 30 minutes after initiation of charcoal making process. Biochar samples were collected and their important characteristics were analysed.

The production efficiency of biochar was calculated using the equation described below-Production efficiency % = (Mass of biochar/ Mass of raw materials) × 100%. After preparation of biochar they were dried in a hot air oven at 110 °C for 24 h, pulverized to fine powder, sieved and used for further characterization. The pH and bulk density of the biochar samples were determined by procedures outlined by Ahmedna *et al.,* 1997. For pH determination, 1% (w/w) suspension of biochar in de-ionized water was prepared and the suspension was heated to 90°C with stirring for 20 min. The suspension was then allowed to cool to room temperature and the pH was measured using a pH meter. For bulk density, a glass cylinder (25 ml) was filled to a specified volume with 40 mesh powder biochar, dried in an oven at 80^0C overnight. The cylinder was tapped for 1–2 min to compact the char and the bulk density was calculated and presented as g/ml following the formula (Ahmedna *et al.,* 1997).

Bulk density (g/ml) = Weight of dry material (g) / Volume of packed dry materials (ml)

Maximum water holding capacity of biochar was determined gravimetrically from saturated biochar (75 hours), after removing free water rom it gravitationally. Phosphorus was determined by molybdophosphoric acid method. K was determined by flame photometer.

The basic principle of smokeless fire

If layers of wood are piled loosely, with enough small branches in the upper layer, and burnt at the top, nearly all the resulting wood gas will pass through the overlying flame front and burn. So there is only a clean, smoke free combustion gas. Radiant heat from the flame chars the wood beneath layer by layer. Air is drafted in from the sides of the pile, but is updrafted into the flame and consumed in combustion.

Under the nearly oxygen-free fire front the char is mostly preserved. As the pyrolysis reduces the wood chunks to smaller pieces that pass down through the loose pile, fresh layers of wood are continually exposed to off-gassing heat below the fire front. By observing the flame and the onset of ash build up on the outer layers of the charred wood we can determine the right moment to quench with water or smother with dirt, and instead of producing ash alone, we may retain close to a fifth of the wood as charcoal (Schmidt HP and Taylor P, 2014).

In In eastern India, in winter months (December to February) as the air temperature remains very cool, the atmospheric temperature will not be affected due to heat arising out of the burning flames of the open earth pyrolysis process.

In these months it can be done in the dried up retting tanks only giving it a desired shape as described. Trenches of similar depth and side walls can also be for open earth pyrolysis process.

Results and Discussion

Biochar production efficiency was different for jute and mesta biomass. Mesta stick charcoal production efficiency was 34% of the total mesta stick used in the open earth pyrolysis process. Jute stick charcoal production was efficiency28%of the total jute stick used in the open earth pyrolysis process, Ghorai *et al.,* 2020. The variable biochar production efficiency may be due to variable density in each biomass. Various operational process also affect the production efficiency. It was observed that from jute sticks 35-40% charcoal was obtained when carbonized at 300°C and it contained 75 % fixed carbon and 4-6% ash (Banerjee, 1980). Biochar produced are black colour, light weight and brittle in nature. To avoid over heating of micro climate, charcoal production should be undertaken in cooler months (December to February) in dried up jute retting ponds itself as described in this process. To produce charcoal at large scale the pit area should be increased to convenient size for proper recovery of charcoal from jute/mesta sticks. Framers will be able to generate cash from it or it can be utilised in agri-horticultural crops as soil amendment including carbon sequestration in soil.

The pH for jute and mesta were 9.87 and 9.34, respectively (Table 1). Biochar produced is alkaline in nature which indicated that biochar can be used as soil ameliorating agent for management of acid soils. Jeffery *et al.,* (2011) found that biochar could increase soil pH by 0.1-2.0 units in a wide range of soils varying in native pH values. Increase in soil pH with biochar addition would result in a greater availability of primary and secondary nutrients like K, P, Ca, Mg (Asai *et al.,* 2009; Glaser *et al.,* 2002; Major *et al.,* 2010). The other advantage of increased pH due to biochar addition is the reduction of Al toxicity in acidic soils. Farmers apply large amount of lime which results in increase in cost of cultivation and lime application emits large amount of GHG emissions. Therefore to maximize the benefits of biochar it should be applied to acidic soils to neutralize acidic soils and reduce GHG emissions.

Table.1 Characteristics of biochar from jute and mesta biomass

S.No.	Physico-chemical properties	Jute	Mesta
1	pH	9.87	9.34
2	Bulk Density	0.0908	0.132
3	Moisture	673	637
4	Nitrogen (g kg^{-1})	4.99	5.8
5	Phosphorus (g kg^{-1})	5.5	3.6
6	Potassium (g kg^{-1})	11.0	8.28

Fig.1 Open earth pyrolysis process for charcoal production from jute and mesta stick

Bulk density was 0.0908 g/cc and 0.132 g/cc for jute and mesta, respectively. Lower bulk density values will be beneficial for soil because it will improve soil bulk density, porosity, water retention, and hydraulic conductivity. Hydrological properties such as maximum water holding capacity were 637 % for mesta and 673 % for jute**.**

The composition of biochar depends upon the nature of feedstock and pyrolysis conditions and published literature suggests a wide variation in biochar compositions. Biochar prepared from jute residues contained higher phosphorus (5.5 g kg^{-1}) and potassium (11 g kg^{-1}) as compared to mesta but total nitrogen content was more in mesta (5.8 g kg^{-1}).

At this stage, it is not possible to draw any quantitative conclusion on the impact of jute and mesta biochar on crop yield. Nonetheless, composition of jute and mesta biochar suggests that their production and their application in soil has a very promising potential for development of sustainable agricultural system in India and also for global climate change mitigation. Use of jute and mesta biochar will offer both environmental and economical benefits. This can be assessed by critically evaluating the production and application of jute and mesta biochar in the form of pilot or demonstration project.

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