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Full Length Article

Optimization of Pyrolysis Yields of Paper Mulberry (*Broussonetia papyrifera*) and Application of Biochar Product for the Improvement of Maize Growth

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Abstract

Pyrolysis is the most commonly employed technology to convert widely available biomass materials into useful products like biofuels. In the present study, pyrolysis of paper mulberry (*Broussonetia papyrifera*) was performed in order to observe the effect of temperature and particle size on product distribution and yield, and application of biochar product to improve growth and yield of maize. The experiments were performed in a fixed-bed reactor using three pyrolysis temperatures (350°C, 450°C, 550°C) and three particle sizes (1 mm, 2 mm and 3 mm) of *B. papyrifera*. The pyrolysis products were collected within three different groups as gaseous products, liquids and solid biochar. The results showed that the maximum biochar product was obtained at 350ºC and 3 mm particle size while the highest bio-oil yield was attained at 450ºC and 2 mm particle size. However, the optimum gas yield was achieved at 550ºC and 1 mm particle size. A pot experiment was conducted to determine the effect of produced biochar on maize plant emergence, growth and yield. The results showed a substantial increase in plant height, shoot dry weight and maize yield compared to untreated control. These findings revealed that the production of biofuels can be improved by optimizing operating conditions and biochar produced during pyrolysis could be used as soil amendment for improving growth and yield of maize.

Keywords: Temperature; Particle Size; Biomass; Paper mulberry; Biochar; Maize

Introduction

The rising energy demands round the globe, deminishing fossil fuel reserves and emerging environmental issues due to burning of fossil fuels, have forced the scientific community to identify and formulate fuels, which are energy efficient, renewable and environment friendly. In this context, biofuels have turned out to be the best alternative fuels on account of their characteristics like renewability, biodegradability, fuel diversity, sustainability, local availability and reduced emmisions. The biofuels are solid, liquid or gaseous fuels derived from biomass (Dmitri *et al.,* 2011). Since, biomass refers to a very diverse group of natural and waste materials including wastes therefore, a careful selection of the most appropriate species is one of the decisive factors for the success or failure of a bio-fuel as it dictates the cost and performance of the biofuel produced.

It is not surprising that the major share of energy from biomass, supplied to almost half of the world's population, mainly comes from wood (Demirbas, 2005). The burning of wood, compared to fossil fuels, is much advantagious, particularly in carbon economy (Gnansounou *et al.,* 2009). However, in a country like Pakistan, where the woody vegetation is already prone to risks, the selection of appropriate species is a real challenge. Yet, several problematic species invite the attention of researchers for their controlled and useful eradication. *Broussonetia papyrifera* (paper mulberry), has known to interfere with the population of the local flora of Islambad, the Federal Capital, through its superficial invasion characteristics. The species is also considered to pose allergy-related health problems to humans. However, the species, on account of its fast growth rate & high biomass yields (Khatoon and Ali, 1999) is thought to be a good candidate for biofuel production. Keeping in view the aforementioned facts, the species was selected in this experiment for biofuel production.

Two most common conversion methods viz. the thermal and the biochemical technologies are primarily used for the production of biofuels (Ertas, 2010). However, keeping in view its advantages over the other method, pyrolysis (thermal) was used for bio-fuel production in the conducted study. Typically, pyrolysis consists of thermal decomposition in the absence of oxygen or with such a limited supply that combustion or gasification does not occur to any appreciable extent. Pyrolysis occurs at

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relatively low temperatures around 450–550°C to produce liquid (bio-oil), gaseous and solid (char) fractions (Ma *et al.,* 2012). Apart from being easy and efficient, the experimental conditions of the process can be optimized to maximize the production of either chars, oils or gases depending on the product required (Sharypov *et al.,* 2002). The proportion of products formed is strongly dependent on the reaction temperature, time and heating rate.

The conducted study aimed at characterization of biochar produced from pyrolysis of paper mulberry. The biochar produced at three different temperatures and particle sizes was analyzed for proximate and ultimate analysis. The chief objectives of the study were to explore the possibility of using *B. papyrifera* as a candidate for sustained biofuel production under different temperature and particle size range. The effect of produced biochar on maize plant growth parameters was also determined.

Materials and Methods

Sample Collection and Preparation

Uniform samples of Wood (02 kg/sample, < 2 cm) of *Brossonetia papyrifera* (paper mulberry) were collected from different equi-distant sample plots throughout the Islamabad city and were air-dried for 15 d to remove moisture contents, and to obtain constant weight (Okello *et al.,* 2001). The air dried samples were crushed, ground and sieved to obtain 27 samples of three different particle sizes (1, 2 and 3 mm). The samples were kept in an air-tight glass jar and were finally exposed to a temperature of 105°C overnight, just before performing the pyrolysis tests.

Pyrolysis Apparatus

A quartz tube reactor was used for pyrolysis having a quartz tube of 30 cm length and 5 cm diameter. The tube was placed in an electrically heated horizontal oven. Helium was fed into the front of the reactor before heating, at a flow rate of 200 mL/min for 60 min to remove the air from the system (Sanchez *et al.,* 2009).

Procedure: Air dried sample of 50 g having different particle size ranges was placed and pyrolyzed in the quartz tube reactor. The reactor temperature was increased with a heating rate of 20ºC/min up to 350ºC at a Helium gas flow rate of 100 mL/min and was held for 30 min at the desired temperature (Demirbas, 2005). The simple thermocouple (NiCr–Ni) was placed directly in the pyrolysis medium to measure the temperature of the sample placed in the reactor. The heating rate and final temperature of the reactor was controlled by using a PID controller (Ucar *et al.,* 2008).

Product Separation

The pyrolysis products were collected as solid residue (char), liquid (bio-oil) and gaseous products. The bio char samples were weighed and collected in jars for further analyses. The vapors produced in the process were carried by the Helium gas to the lower part of the pyrolysis reactor containing a two neck flask, filled with ice to collect the oils (condensable gas fraction). The pyrolytic oil obtained was weighed and kept in small vials under an inert atmosphere. The quantity of gas product was determined with using the mass balance. Finally, the gases were fed into gas sampler and a sample was taken for gas composition analysis. The product yield (biochar and bio-oil) was calculated by the method described by Abnisa *et al*. (2011) as follow:

$$Yield\ weight\ (\%) = \frac{Desired\ product\ (g)}{Paper\ Mulberry\ (g)} \times 100$$

b. Pot Experiment

A glasshouse pot experiment using maize plants was performed to determine the effect of the paper mulberry biochar on growth and yield of maize plants. The pot trials were carried out in a temperature controlled (20–25°C) glasshouse environment. The experimental design was randomised block design with four treatments and three replications. The four treatments were: (i) control (ii) 350°C (iii) 450°C (iv) 550°C. However the particle size was kept constant at 1mm. In each pot 5 kg of air-dried soil was filled and biochar was applied at the rate of 10 t ha^{-1} (Van Zwieten *et al.,* 2007). Five seeds of maize were germinated in each pot for 15 d. After 15 d the germinated maize seedlings were thinned and the healthy plant from each pot was selected. During the pot trial, the maize plants were daily watered up to their field capacity. The experiment was conducted for 16 weeks.

Statistical Analysis

The data obtained was subjected to statistical analysis by using Analysis of variance (ANOVA) under completely randomized design to study the effect of temperature, particle size and the possible effects of biochar on the products obtained. The statistical analysis was carried out using the Sigma plot version 11 Software. A confidence level of 95% for the F-distribution was selected and treatment mean obtained was compared by LSD at 5% level of significance.

Results

Product Yields of Pyrolysis

Effects of temperature on product yield: Temperature significantly influenced the product yields from pyrolysis of *B. papyrifera* at 350, 450 and 550°C for size of 1mm (Fig. 1). At the lowest pyrolysis temperature i.e. 350°C, biochar was the major product. The biochar yield significantly decreased as the final reactor temperature was increased from 350 to 550°C. When the pyrolysis temperature was increased from 350 to 450°C, the quantity of bio-oil increased to a maximum value i.e. 38%. At higher temperature of 550°C, the bio-oil yield decreased to 36% as compared to 450°C while gas products reached to a maximum value. The results of the experiment showed that the gas yields were 31.55, 38.97, and 46.00% at temperature of 350, 450 and 550°C, respectively.

The second series of experiment was carried out at the same temperature range 350, 450 and 550ºC while keeping the particle size of biomass at 2 mm. As shown in Fig. 2, the maximum biochar yield was obtained at 350°C (39.28%). After that the biochar yields started decreasing at higher temperatures. As the reaction temperature increased from 350 to 450°C, the amount of condensable pyrolysis vapors also attained a maximum value of 41.15% from 37.12%. At still higher pyrolysis temperature of 550°C, the bio-oil showed a slight decrease of 5.5% from the highest value of bio-oil yield. However, the gas yields showed a gradual increase in concentration as the temperature progressed. The lowest and highest gas release observed was 23.65% and 32.45% at the temperature of 350°C and 550°C respectively (Fig. 2).

Fig. 3 shows data regarding percentage of products achieved at 350, 450 and 550°C using the biggest particle size of 3 mm. The biochar yields found were 41.88, 38 and 32.51% for the temperature ranges of 350, 450 and 550°C respectively The maximum biochar yield was about 41.88% obtained at the lowest temperature of 350°C and the lowest biochar yield was 32.51% obtained at the highest temperature used. At 350°C, the quantity of bio-oil obtained was 35.42%. At 450°C, the value of bio-oil reached up to 37.7% but was reduced to 36.49% at the final temperature of 550ºC. The results clearly illustrate that the maximum yield of bio-oil (37.7%) was obtained at the pyrolysis temperature of 450°C. The gas distribution depicted a linear increase with increasing pyrolysis temperature. The gas release was about 22.7, 24 and 31% at 350, 450 and 550°C, respectively (Fig. 3).

Effects of particle size on product yields: The effects of three particle sizes, viz. 1, 2 and 3 mm on product yields from pyrolysis of *B. papyrifera* at 350°C are shown in Fig. 4. The results indicate that the particle size, significantly affected the biochar yields. As the particle size changed from 1 mm to 2 mm, the biochar yields increased to 1.78%. However, the increase in yield at 3 mm was about 4.38% as compared to 1 mm. The results of experiment showed that highest biochar yield was obtained at 1 mm that is about 41.88%. However, the bio-oil production first increased and then showed a declining trend. The quantity of bio-oil obtained at 2 mm and 3 mm was 2.82% and 1.12% higher as compared to 1 mm. The gas yields showed a slight increase in concentration of 4.6 and 5.5% at 2 and 3 mm relative to 1 mm, where the least gas yield was observed.

Fig. 5 shows the difference among the product yields obtained at 450°C with particle sizes 1 mm, 2 mm and 3

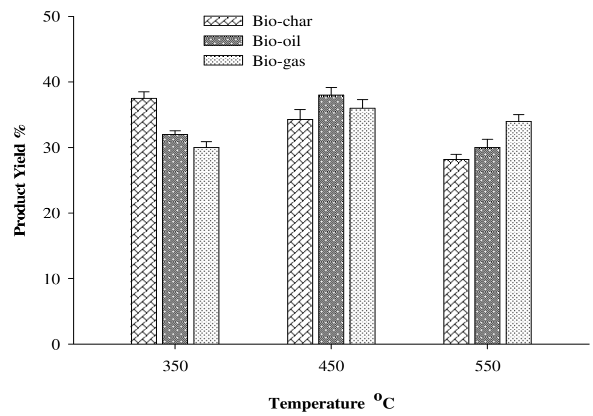

Fig. 1: Effect of temperature on pyrolysis product yield at 1 mm of *B. papyrifera*

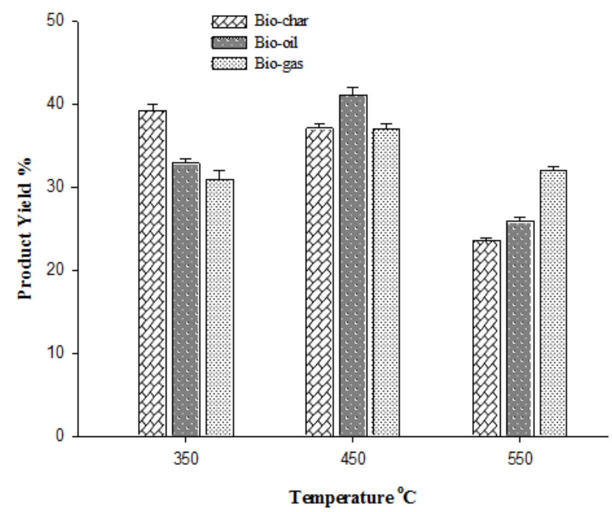

Fig. 2: Effect of temperature on pyrolysis product yield at 2 mm of *B. papyrifera*

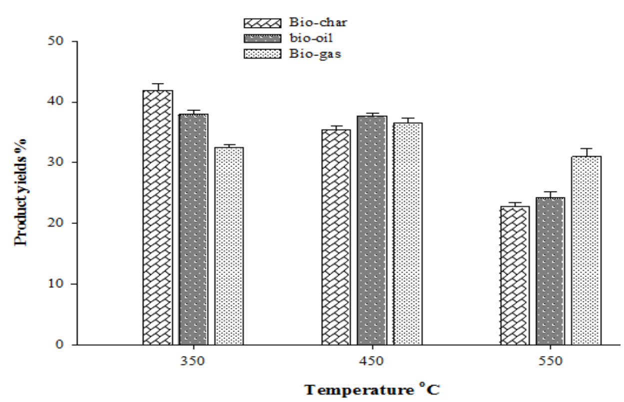

Fig. 3: Effect of temperature on pyrolysis product yield at 3 mm of *B. papyrifera*

mm. The biochar yield depicted an increase in production with increasing particle size. The yields of biochar at 2 mm were only 0.91% higher as compared to 1 mm while it showed a significant increase of about 6% at 3 mm. The bio-oil obtained at 2 mm was slightly higher as compared to bio-oil concentration at both, 1 mm and 3 mm. The increase was about 3.5 and 3.8%. The maximum gas yields of about 30% were observed at the lowest particle size. The gas yields found at 2 mm and 3 mm were 4.6 and 5.7% lower relative to 1 mm.

The third experiment was conducted with the same particle sizes range while varying the temperature to 550°C. It was observed that the effect of particle size was least profound on biochar and bio-oil yields at higher temperature. The smallest particle size formed biochar yield of 30%, which was 1 and 2.51% lower than particle sizes 2 and 3 mm. The yield of bio-oil obtained with particle size 2 mm was only 1% higher while it was 0.49% higher at 3 mm relative to 1 mm bio-oil. However, there was significant difference in the yield of gas at the three particle sizes used. The increase in gas yields was about 1.5% and 3% at 2 mm and 3 mm (Fig. 6).

Effect of Biochar on Maize Growth

Effect of biochar of plant height: The results showed that different types of biochar significantly affected the plant height of maize (Fig. 7). However, biochar produced at 550°C showed the highest plant height (118 cm), followed by biochar produced at 450°C (109 cm) and 350°C (104.5 cm) at the end of 16th week. The maximum plant height at the end of 4th week was 17, 20 and 24.4 cm in case of biochar prepared at 350, 450 and 550°C respectively.

Effect of biochar on shoot dry weight of maize plant: The shoot dry weight of maize also varied significantly among all treatments (Fig. 8). The average shoot dry weight ranged from 61.9 g plant^{-1} for control to 92 g plant^{-1} recorded for biochar prepared at 550°C. However no significant difference in shoot dry weight of maize plants was observed in biochar prepared at 350°C (73.8 g plant^{-1}) and 450°C (79.7 g plant^{-1}).

Effect of biochar on yield: Application of biochar prepared at 550°C also showed significant effect on the yield of maize plant which was followed by biochar prepared at 350 and 450°C (Fig. 9). The maximum average yield per plant was observed in case of biochar of 550°C which was 20% greater than the application of biochar of 450°C treatment. Biochar made at 350°C showed the lowest yields (Fig. 9).

Discussion

The pyrolysis temperature played a significant role in the distribution of pyrolysis products. At the lowest pyrolysis temperature, 350°C, the decomposition of paper mulberry was comparatively slow. So, biochar was the major product along with vapors of primary decomposition of biomass.

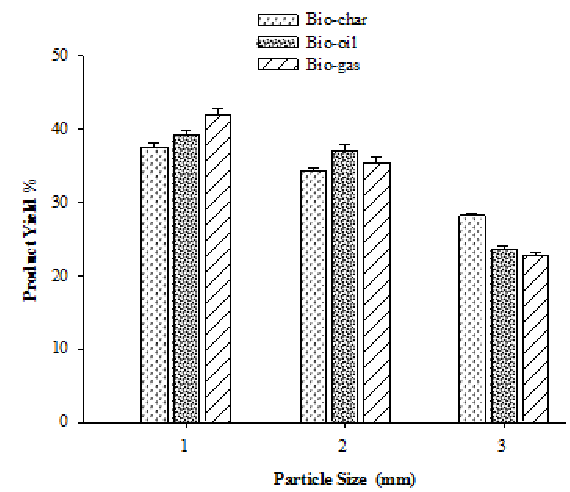

Fig. 4: Effect of particle sizes on pyrolysis product yields at 350°C

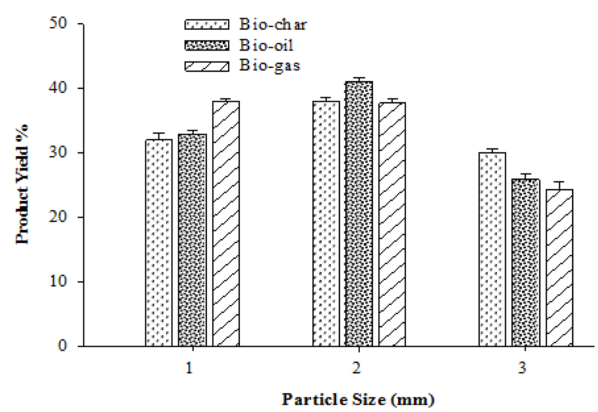

Fig. 5: Effect of particle sizes on pyrolysis product yields at 450°C

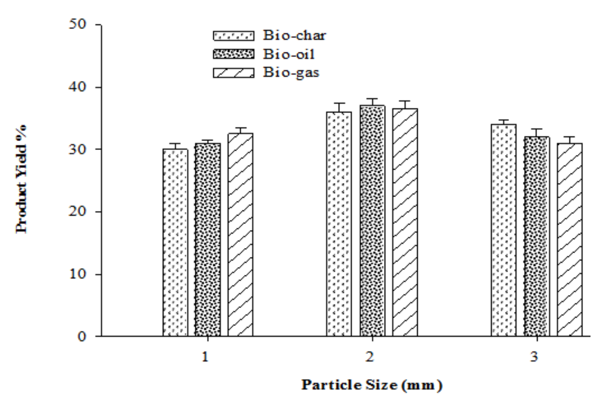

Fig. 6: Effect of particle sizes on pyrolysis product yields at 550°C

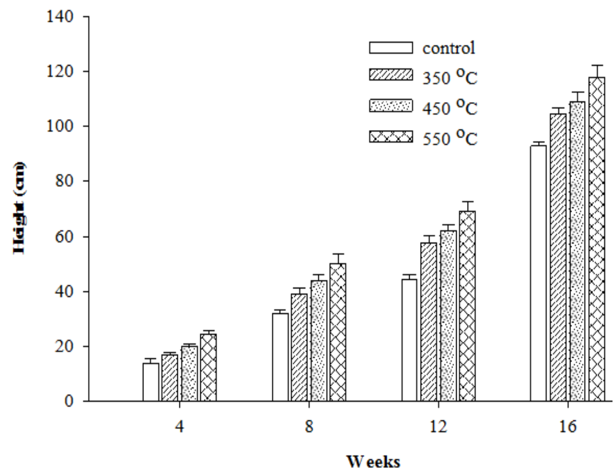

Fig. 7: Weekly plant height of maize plants after applying different biochars

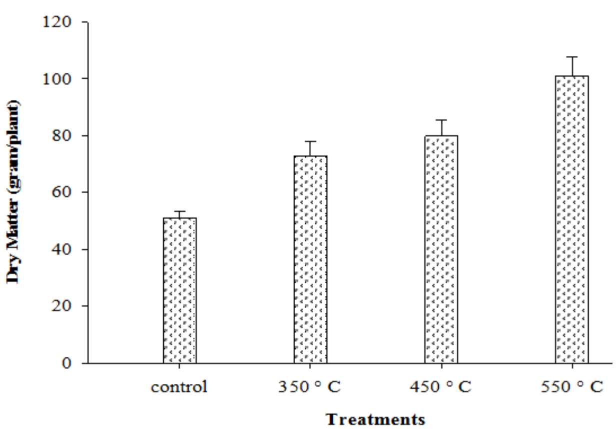

Fig. 8: Dry matter production of maize per plant after applying different biochars

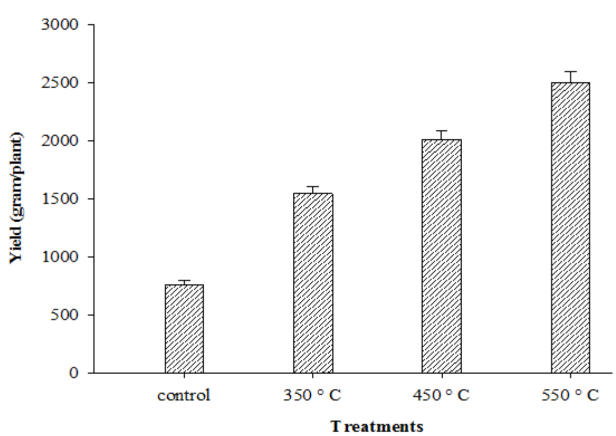

Fig. 9: Maize plant grain yields obtained after applying different biochars

The low biochar yield at higher temperature could either be due to the greater primary decomposition of the paper mulberry (Parihar, 2007). Large sized particles were heated slowly. Hence, the average temperature of the pyrolysing particle was low, resulting in incomplete pyrolysis. Only restricted reactions like dehydration are possible in the inner part of the particle, when heated slowly. Thus, the core of the large particles becomes well carbonized and does not decompose completely, increasing biochar yield (Pattiya and Suttibak, 2012) and reducing volatile yield. With particle size 3 mm, the yield of bio-oil decreased owing to inadequate rate of heat transfer inside the particles, whereas the biochar production increased. However, the gas yield increased when the particle size was reduced from 3mm to 1 mm, due to overheating of the small particles favoring higher conversion of vapors into gas (Park *et al.,* 2009; Heo *et al.,* 2010). So in this study, 2 mm particle size was found optimum for producing bio-oil.

The results of the pot trial indicated the potential of biochar prepared from paper mulberry to improve grain yield of maize and it was 65% higher than untreated control. Previously it has been reported that biochar applied to soils improved the availability of nitrogen, phosphorus and major cations (Lehmann *et al.,* 2003). Our study showed considerable improvement in plant yields when biochar was applied at 50g/kg to the soil (Fig. 2b), suggesting release of important plant nutrients from the biochar. The highest yield of maize plant (2500 g plant^{-1}) in the present work was obtained from the biochar prepared at 550°C (which was 20% higher than the yield produced with 450°C biochar. The reason might be that at higher temperatures, biochars especially from wood residues enhanced mineralisation of carbon compounds retained in biochar (Hamer *et al.,* 2004). Moreover, this fertilizer effect of biochar was also supported by increased water holding capacity of the soil due to the large surface area of the applied biochar (Steinbeiss *et al.,* 2009).

Thus it can be concluded that paper mulberry biochar has a great potential to produce biofuel. The solid fuel i.e. biochar can also be applied as fertilizer for agricultural crops.

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