

## **PREPARATION OF BIOCHAR AS A SOIL AMENDMENT FROM RICE HUSK AND CORN COB BY SLOW PYROLYSIS PROCESS**

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### **ABSTRACT**

**Biochar is a light weight, highly porous material with high carbon content, a portion which has a stable chemical structure resistant to decay. However, there are no established farmer scale pyrolyzers and pyrolysis methods to produce good quality rice husk biochar (RH-BC) and corn cob biochar (CC-BC). In this experiment, an attempt was made to modify the existing pyrolyzer (Kunthaniya) for RH-BC and to develop a new pyrolyzer (CCP) for CC-BC. Temperature changes in the pyrolysis process were monitored. Slow pyrolysis was practiced as it is the process to produce biochar as soil amendment. Total elemental analysis, Nutrient content analysis and proximate analyses were carried out for feedstocks as well as for RH-BC and CC-BC. Modified pyrolyzer (RHP) produced slow pyrolysis condition while Kunthaniya did not give slow pyrolysis condition. BC yield (%) was quantitatively similar in Kunthaniya and RHP nonetheless BC produced by Kunthaniya contained incompletely carbonized particles and ash to the amount of 21%. Firewood consumption was 20 times higher in Kunthaniya than in RHP and production efficiency was almost half (0.59) in Kunthaniya compared to RHP. Corn cob pyrolyzer (CCP) was well under slow pyrolysis condition. Rice husk biochar (RH-BC) and CC-BC showed quantitative differences, and more similarities than differences qualitatively. Biochar were alkaline in pH, while Vm /FC**

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**ratio of both RH-BC and CC-BC was greater than 1.0 showing susceptibility for biological decay. RH-BC and CC-BC contained high quantities of Ca, Mg, K and P.**

**Key words: Biochar, Corn cob, Rice husk, Slow pyrolysis**

### INTRODUCTION

Thermal conversion of agricultural byproducts into biochar (BC) through pyrolysis and their application into agricultural lands offers a range of benefits (Manya, 2012 and Verheijen *et al.*, 2014). Some of the benefits of biochar application to soils are increased nutrient retention through enhanced cation exchange capacity (Liang *et al.*, 2006), direct contribution of essential plant nutrients (Chan *et al.*, 2007 and Deenik *et al.*, 2011) and mitigation of nutrient deficiencies by adjusting soil pH (Deenik *et al.*, 2010).

High carbon (C) contents of Corn Cob (CC) and Rice Husk (RH) shows a high potential of producing biochar (Lachke, 2002). Approximately 800,000 mt of RH and 39,000 mt of CC are being produced annually in Sri Lanka (AgStat 2016). Rice husk though showed a certain demand for industrial uses, is not fully utilized whereas CC is yet remaining as an agricultural waste. Therefore, a potential exit to use these materials as feedstocks to produce biochar under local conditions.

According to Song and Guo (2012), slow pyrolysis is often considered as the most feasible production process capable of yielding biochar having consistent and reliable product qualities suited to be used in agriculture. “Kunthaniya” is presently used by Sri Lankan farmers to produce RH-BC and the product is often referred as the partially burnt paddy husk (PBPH). However, this technique doesn’t produce uniform product. Therefore, modifications to the process of pyrolysis are needed to assure the consistent output quality of the product and on the other hand, Kunthaniya is not suitable to produce CC-BC because of the larger particle of the corn cobs. Hence, objectives of this study were to improve the pyrolysis conditions of the existing “Kunthaniya” to produce biochar having consistent product quality with rice husk and to develop a method to produce CC-BC from CC and to characterize the biochar output produced from the two processes for their important physio-chemical properties.

### MATERIALS AND METHODS

Rick husk (RH) and Corn Cob (CC) were used as feedstocks to prepare biochar in this study. Two types of pyrolysis were selected considering the particle size differences of RH and CC. For RH, traditional ‘Kunthaniya’ (Figure 1) was used and it was modified and named as Rice Husk Pyrolyzer (RHP) (Figure 2). In the Kunthaniya, a metal barrel was used as a chamber (Figure 1) and it was modified by fixing an adjustable part to the chimney and an inhale tube with a shutter to the opening of the chamber (Figure 2). Barrel method was used for the Corn Cob Pyrolyser (CCP) (Figure 3) to produce CC-BC in which two barrels in two different sizes were used as furnace and retort (Figure 3).

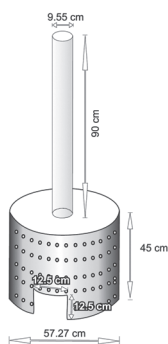


Figure 1: Kunthaniya

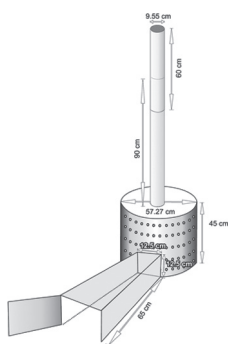


Figure 2: Rice husk pyrolyzer (RHP)

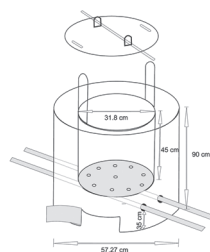


Figure 3: Corn cob pyrolyzer (CCP)

When using Kunthaniya and RHP, approximately 75 kg of sun dried RH feedstock ( $\leq 12\%$  moisture) was placed surrounding the main chamber after the outer surface of the chamber was sufficiently heated (Figure 4). In CCP approximately 5 kg of feedstock ( $\leq 12\%$  moisture) was filled into the retort and tighten the lid (Figure 5).

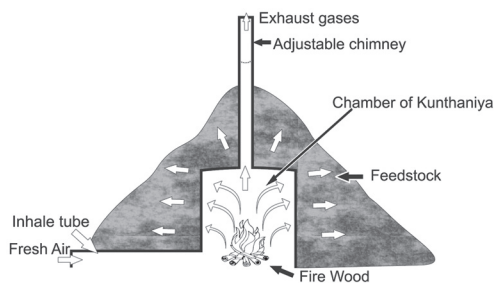


Figure 4. Pyrolysis process of RHP

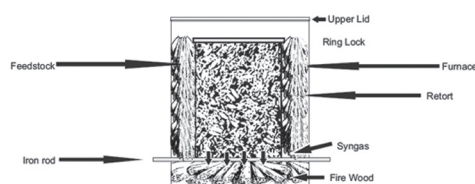


Figure 5. Pyrolysis process of CCP

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During the pyrolysis process temperature was measured on the surface of the chamber of Kunthaniya and RHP and surface of the retort of CCP in every 20 minutes using Rex-C700 (model C700FK06 M\*AN, range 0-1200 °C) thermo-couple. Simultaneously, temperature of the feedstocks was also measured in the Kunthaniya and in RHP.

Batch processing was practiced for all pyrolyzers. A known amount of firewood (kg per cycle) was added and dry weight of the final product was measured at the end of each batch separately. Biochar yield (BC yield %) was calculated as a portion of the feedstock quantity used in dry weight basis.

### **Total elemental analysis**

Dry-ashing method described by Campbell and Plank (1998) was used for total elemental analysis of feedstock for the determination of total K, Ca, Mg, Fe, Mn, and Cu (TK, TCa, TMg, TFe, TMn, TCu.). Nitric acid wet-digestion described by Campbell and Plank (1998) was used for the determination of phosphorous (P) and sulfur (S) in feedstocks and processed for 2 additional hours to reach a clear colorless endpoint.

A modified dry-ashing method suggested by Enders *et al.*, (2012) was used for the digestion of biochar samples (because of the high chemical recalcitrance nature of them). Samples were ashed in ceramic crucible for 8 h at 500 °C in a muffle furnace (Hobersal HD 230) and 5.0 ml of 70 % concentrated HNO<sub>3</sub> acid was added to each crucible and the contents were transferred to digestion tubes and heated on the digestion block (VELP scientific DK20 heating digester) at 120 °C until dryness was reached. Tubes were allowed to cool and another 1.0 ml HNO<sub>3</sub> (70 %) and 4.0 ml H<sub>2</sub>O<sub>2</sub> (30 %) was added to each tube and samples were dried in the digestion block at 120 °C. The residue was solubilized in hot distilled water, filtered (Whatman No 42) and used for analysis. Biochar and feedstock were processed in triplicate and blanks were included in digestion.

Kjeldahl method was followed for total Nitrogen (TN) and Vanadomolybdate method (Stewart, 1989) was followed for phosphorus (TP) determination using Jenway 6305 UV/vis spectrophotometer. Total potassium (TK), Total Calcium (TCa), Total Magnesium (TMg), Total Iron (TFe), Total Manganese (TMn), Total Copper (TCu) were determined using Fast Sequential Atomic Absorption Spectrophotometer (Varian-

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AA240FS) (Jackson, M.L. 1960).  $\text{SO}_4\text{—S}$  was measured turbidimetrically (Sam Portch and A. Hunter 2002).

### **Available Nutrients analysis**

Olson method was followed for available Phosphorus (Ava-P) and ASI analytical methods (Sam Portch and A. Hunter 2002) was followed for exchangeable potassium (Ex K) and exchangeable micro nutrients.

### **Other chemical analysis**

Cation Exchange Capacity (CEC) was measured using an ammonium acetate extraction (pH=7) as described by Rowell (1994). The pH and EC of the samples were measured in a 1:10 (soil: moisture) suspension using a pH meter (ORION 4 star) and Electrical Conductivity meter (ORION 4 star).

### **Proximate analysis**

Moisture, volatile matter (Vm), ash and fixed carbon (FC) content were also measured as described by Ender *et al.*, (2012).

### **Statistical analysis**

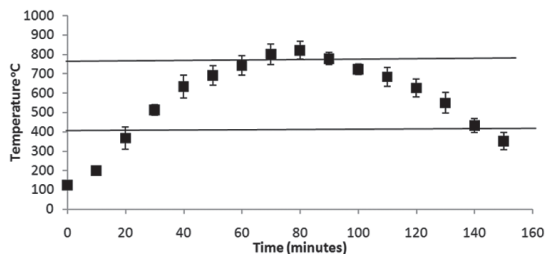
Data were statistically analyzed following the GLM procedure using Statistical Analysis Software (SAS 1988) and mean comparisons were done using Duncan Multiple Range Test at  $p < 0.05$  probability level.

## **RESULTS AND DISCUSSION**

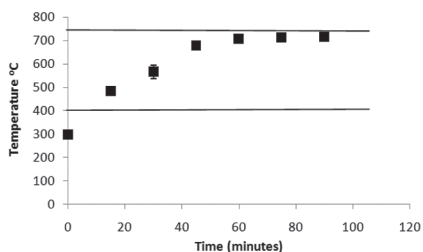
Important parameters that determine the quality of the product are temperature and heating rate in the pyrolysis process (Bruun, 2012). The general method of slow pyrolysis is running between 400 °C to 750 °C with typical heating rates between 1 and 30 °C  $\text{min}^{-1}$  (Lua *et al.*, 2004).

Kunthaniya reached its maximum temperature of about 800 °C ( $\pm 90$  °C) in the chamber surface and went down rapidly exceeding the expected slow pyrolysis temperature range (Figure 6a) whereas RHP rise the surface temperature of the chamber to 700 °C ( $\pm 10$  °C) (Figure 6b) and holding at the maximum temperature for 15 minutes for same amount of feedstock.

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**Figure 6a. Relationship between time and the surface temperature in traditional Kunthaniya**  
Bars at each measurement point is the standard deviation



**Figure 6b. Relationship between time and temperature in rice husk pyrolyzer (RHP)**  
(Bars show standard deviation)

As the primary air supplied to the chamber of the Kunthaniya was blocked by the feedstock, fire inside the chamber was extinguished and temperature went down. When more firewood was added to Kunthaniya, it generated more heat but extinguished again exceeding the slow pyrolyzing limit (Figure 6a and Figure 7a). Introduction of an inhale tube to the opening of RHP didn't block the air supply into the chamber. Adjusting the length of the chimney with the introduced adjustable part to RHP, it was created sufficient draft of fresh air for continues and controlled combustion. Because of that, pyrolyzing process was carried out within the slow pyrolysis temperature range (Figure 6b and Figure 7b). Temperature changes across the heap of feedstock in the meantime of operating the pyrolysis process in both Kunthaniya (Figure 7a) and RHP (Figure 7b) shows that heat distribution was more consistent in RHP than Kunthaniya.

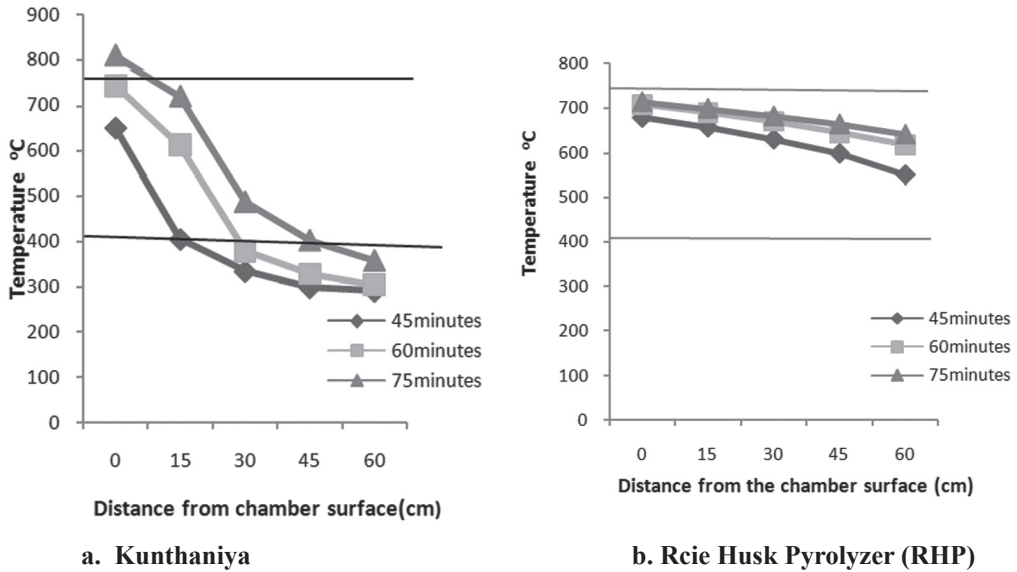


Figure 7. Temperature change in Kunthaniya and RHP.

Therefore, RHP can produce more consistent quality product than Kunthaniya. It was estimated that uncarbonized and incompletely carbonized portion and the ash portion in the output of Kunthaniya was nearly 11 % and 10 % even though both pyrolyzers were able to produce similar quantities of BC (Table 1). Other than that, RHP had higher production efficiency and less fire wood consumption compared to that of Kunthaniya (Table 1).

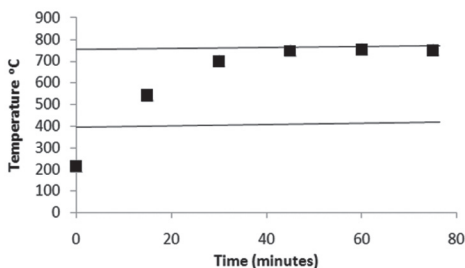
Table1. Biochar yield%, Firewood consumption and Production efficiency in the different pyrolysis processes

| Process    | BC yield % | Fire wood consumption (kg/ kg of BC) | Production efficiency (kg of BC/hr) |
|------------|------------|--------------------------------------|-------------------------------------|
| RHP        | 48 ± 1.1   | 0.08±0.04                            | 32.0±0.85                           |
| Kunthaniya | 47± 2.2    | 1.60±0.04                            | 18.8±1.78                           |
| CCP        | 33 ±1.7    | 6.82±0.64                            | 26.4±0.36                           |

Values with ± are standard deviation

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Figure 8 shows that, CCP was under slow pyrolysis temperature range and where the material was charred at the maximum of 755 oC ( $\pm 53$  oC) in the surface of the retort and holding at the final temperature for 15 minutes.



**Figure 8. Relationship between time and temperature in corn cob pyrolyzer (CCP)**

Bars show standard deviation

### Biochar yield (%) and quality of biochar

RHP and CCP were operated approximately at similar temperatures with different feedstocks. BC yield (%) of CCP was 32 % while RHP and CCP yielded a higher quantity (Table 1). It is accepted fact that the type of feedstock is one factor that affects the biochar yield (Shariff, 2016). Shariff (2016) further revealed that CC yielded 32 % at 400 °C in 60 min pyrolysis time and beyond 400 °C, mass loss rate was very low as the most important reaction of aromatization process is taking place at 400 °C (Fisher *et al.*, 2002). Therefore, BC yield (%) of CCP was in acceptable range in the study. Kyle *et al.*, (2013) reported that RH-BC yield at 600 °C-700 °C between 5 °C min<sup>-1</sup> and 100 °C min<sup>-1</sup> heating rate was 40 % -50 % and the higher yield (%) of RH is because of the inorganics (especially silica) present in the feedstock (Kalapathy *et al.*, 2000).

Since the pyrolysis of RHP and CCP was approximately at similar temperatures but feedstocks used were different, quality of the RH-BC and CC-BC was different as reported by (Vassilev *et al.*, 2010).

**Table 2. Results of the proximate and other chemical analysis of biochar in dry weight basis**

| Biochar | Moisture%                   | Vm<br>%                     | Ash<br>%                   | FC<br>%                    | Vm/<br>FC | pH<br>(1:10)                | CEC cmol<br>kg-1            |
|---------|-----------------------------|-----------------------------|----------------------------|----------------------------|-----------|-----------------------------|-----------------------------|
| RH-BC   | *3.64 <sup>a</sup><br>±0.82 | 40.23 <sup>a</sup><br>±2.00 | 35.73 <sup>a</sup><br>±0.5 | 25.06 <sup>b</sup><br>±2.2 | 1.6       | 10.34 <sup>a</sup><br>±0.05 | 9.11 <sup>b</sup><br>±0.36  |
| CC-BC   | 3.56 <sup>a</sup><br>±0.078 | 41.54 <sup>a</sup><br>±0.34 | 19.46 <sup>b</sup><br>±0.2 | 39.08 <sup>a</sup><br>±0.6 | 1.06      | 7.84 <sup>b</sup><br>±0.049 | 11.76 <sup>a</sup><br>±0.56 |

\*Values with ± are standard deviation

The ash content of biochar derived from agriculture wastes under slow pyrolysis was influenced mainly by feedstock and to a lesser extent by pyrolysis temperature (Mukome *et al.*, (2013). Mukome *et al.*, (2013) further revealed that high silica (Si) content in rice plant is strongly related to the high ash content of RH-BC. That may be the cause to have significantly higher ash contents in RH-BC than CC-BC in this study. Volatile-matter content depends greatly on temperature with no influence from feedstock (Kyle *et al.*, 2013). That may be the reason for observed similar volatile matter content in RH-BC and CC-BC. A strong negative correlation between ash and fixed C (Kyle *et al.*, 2013) explained why CC-BC contained low ash and high levels of FC, whereas high ash RH-BC exhibited low FC concentrations.

Within the temperature range from 350 °C to 750 °C in pyrolysis, pyrolysis of higher temperature minimize the biochar fraction susceptible to decay (Kyle *et al.*, 2013). Biochar produced at Vm/FC ratio at < 0.26, become highly resistant to further decomposition, biologically as well as thermally (Antal *et al.*, 2003). Both RH-BC and CC-BC produced at high temperature (Figure 6b and Figure 8) showed higher Vm/FC ratio of greater than 1.00 (Table 2) in both RH-BC and CC-BC. Therefore both RH-BC and CC-BC are expected to be moderately resistant to decay in soil.

### pH of biochar

Lydia *et al.*, (2015) showed that biochar derived under slow pyrolysis using agriculture wastes, pH values ranged from slightly to strongly alkaline as the acid functional groups, such as carboxyl (–COOH) and phenolic (–OH), in plant materials become depleted with increasing pyrolysis temperature. It was further shown that

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production temperatures above 400 °C are sufficient to raise the pH up to 7.5 (Lydia *et al.*, 2015). Another contributing factor to the rise in pH at more severe pyrolysis conditions is the relative increase of ash content in the biochar (Frederik *et al.*, 2013). Therefore, alkaline pH of RH-BC and CC-BC and its marked differences are acceptable.

**Nutrient content of the biochar**

The potential of biochar as a source of plant nutrients may also depend on the feedstock and pyrolysis temperatures (Zhang *et al.*, 2013). In general, Ca, Mg, K and P are the major constituents of biochar that was produced under slow pyrolysis condition using agriculture wastes and rest of the elements are found at minor to trace concentrations (Nattaporn *et al.*, 2013). Nutrient contents of RH-BC and CC-BC also show similar results (Table 3). Higher pyrolysis temperature may proportionately increase the availability of K while decreasing the availability of P (Zhang *et al.*, 2013). This was also evident in the composing RH-BC and CC-BC (Tables 4 and 5). Further to that of the nutrient availability, the P found in biochar produced under conditions described early is less than 15 % while that of K can reach 50 % (Camps *et al.*, 2015). This study also yielded similar results (Tables 4 and 5).

**Table 3.Total elemental composition of biochar**

| Biochar | TK<br>(mg/kg)              | TP<br>(mg/kg)              | TCa<br>(mg/kg)               | TMg<br>(mg/kg)              | TFe<br>(mg/kg)               | TMn<br>(mg/kg)             | TCu<br>(mg/kg)               | TN<br>(%)                     |
|---------|----------------------------|----------------------------|------------------------------|-----------------------------|------------------------------|----------------------------|------------------------------|-------------------------------|
| RH-BC   | *5903 <sup>b</sup><br>±218 | 1675 <sup>a</sup><br>± 178 | 1390 <sup>b</sup><br>±9.25   | 880 <sup>b</sup><br>± 21.62 | 16.12 <sup>b</sup><br>±0.49  | 150 <sup>a</sup><br>±5.14  | 9.09 <sup>a</sup><br>± 1.96  | 0.027 <sup>a</sup><br>± 0.006 |
| CC-BC   | 8789 <sup>a</sup><br>±174  | 1881 <sup>a</sup><br>±140  | 1873 <sup>a</sup><br>± 53.94 | 895 <sup>a</sup><br>± 24.09 | 46.56 <sup>a</sup><br>± 3.24 | 142 <sup>a</sup><br>± 6.39 | 10.64 <sup>a</sup><br>± 1.02 | 0.015 <sup>a</sup><br>± 0.009 |

\*Values with ± are standard deviation

**Table 4.Concentration of exchangeable/available nutrients (mg/kg) in biochar**

| Biochar | Ex K                      | Ava P                      | Ex Ca                       | Ex Mg                        | Ex Fe                        | Ex Mn                       | Ex Cu                       | Ex Zn                       |
|---------|---------------------------|----------------------------|-----------------------------|------------------------------|------------------------------|-----------------------------|-----------------------------|-----------------------------|
| RH-BC   | *1089 <sup>b</sup><br>±28 | 141 <sup>a</sup><br>±16.26 | 27.83 <sup>a</sup><br>±1.34 | 103.12 <sup>a</sup><br>±5.23 | 10.20 <sup>a</sup><br>± 4.00 | 55.92 <sup>a</sup><br>±0.96 | 3.30 <sup>a</sup><br>±0.11  | 13.16 <sup>a</sup><br>±0.35 |
| CC-BC   | 5190 <sup>a</sup><br>±50  | 185 <sup>a</sup><br>±26.99 | 30.82 <sup>a</sup><br>±7.23 | 65.39 <sup>b</sup><br>±3.84  | 3.83 <sup>a</sup><br>± 0.19  | 23.08 <sup>b</sup><br>±0.84 | 1.05 <sup>b</sup><br>± 0.07 | 6.44 <sup>a</sup><br>±0.26  |

\*Values with ± are standard deviation

**Table 5. Proportion of exchangeable/ available nutrient content over the total element content (%) in biochar**

| Biochar | K     | P    | Ca   | Mg    | Fe    | Mn    | Cu    |
|---------|-------|------|------|-------|-------|-------|-------|
| RH-BC   | 18.45 | 8.36 | 1.94 | 11.71 | 62.50 | 37.58 | 36.30 |
| CC-BC   | 59.05 | 6.86 | 1.60 | 7.26  | 8.17  | 16.19 | 9.9   |

### Suitability of feedstock

Other important parameter that determines the quality of biochar is the quality of the feedstock (Bruun, 2012). Moisture content (%) of RH and CC is a very important factor to complete the pyrolysis process as described in the study because of both RHP and CCP are derived at farmer scale. Due to the high volatile matter content in both feedstocks (Table 2), they are suitable for the thermo-chemical conversion process of pyrolysis and the fixed carbon makes it a potential feedstock for the production of high quality biochar via slow pyrolysis process (Noor, *et al.*, 2012).

**Table 6. Proximate and elemental analysis of feedstocks on dry matter basis in %**

| Feedstock | Fixed C          | VM              | Ash             | Moisture       | Total N        | Total P x 10 <sup>-4</sup> | Total K x 10 <sup>-4</sup> | SO <sub>4</sub> -2-S |
|-----------|------------------|-----------------|-----------------|----------------|----------------|----------------------------|----------------------------|----------------------|
| RH        | *15.02<br>± 0.98 | 64.41<br>± 0.56 | 21.33<br>± 0.27 | 11.3<br>± 0.21 | 0.13<br>± 0.09 | 1786<br>± 5.68             | 7168<br>± 6.34             | 0.02<br>± 0.002      |
| CC        | 11.19<br>± 0.45  | 80.62<br>± 0.65 | 09.05<br>± 0.39 | 11.1<br>± 0.11 | 0.15<br>± 0.02 | 1830<br>± 4.32             | 7741<br>± 7.31             | 0.018<br>± 0.003     |

\*Values with ± are standard deviation

Figures for CC and RH in Table 6 show quite similar results to Noor *et al.*, (2012) and Kyle *et al.*, (2013). Elemental composition of two feed stocks reveals that they have low percentage of nitrogen and sulfur (Table 6). Therefore they are environmentally friendly when used as feed stocks for pyrolysis process since they will give off low rates of NO<sub>2</sub> and SO<sub>2</sub> during biochar production (Kyle *et al.*, 2013).

According to temperature data reported at pyrolysis, Kunthaniya had deviation from slow pyrolysis condition. Modifications introduced to Kunthaniya were well fitted

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and thereof RHP was well under slow pyrolysis condition and produced consistent quality product. Rice husk pyrolyzer was more efficient than Kunthaniya. Corn cob pyrolyzer was also well under slow pyrolysis condition. Biochar yield (%) and its qualities of RHP and CCP were within an acceptable range. Biochar produced in RHP and CCP were in alkaline pH, moderately susceptible for biological decay.

## CONCLUSIONS

Modification made to Kunthaniya favored consistent and control combustion during pyrolysis process within the temperature range of slow pyrolysis in RHP. Rice Husk Pyrolyzer (RHP) had more production efficiency and less fire wood consumption compared to Kunthaniya. Corn cob pyrolyzer (CCP) also was under slow pyrolysis temperature range. Biochar yield % of CCP was 32 % while RHP yielded 40 %-50 % of the produce. pH of RH-BC and CC-BC was alkaline. Vm/FC ratio of both RH-BC and CC-BC was >1.00 that indicating moderately susceptibility for decay in soil. Major constituents of RH-BC and CC-BC were Ca, Mg, K and P and other elements are present at minor to trace concentrations. Due to high content of volatile matter in RH and CC, they are suitable feed stocks for the thermo-chemical conversion process of pyrolysis. Therefore, there is a potential to produce RH-BC and CC-BC using RHP and CCP with appropriate quantities to be used as a soil amendment.

## REFERENCES

- AgStat. 2016. The pocket book of agriculture statistics, Socio Economic and Planning Centre, Department of Agriculture, Peradeniya, Sri Lanka.
- Antal, M.J., Gronli, M. 2003. The art, science, and technology of charcoal production. *Industrial and Engineering Chemistry Research* 42: 1619–1640.
- Bruun, E.W. 2012. Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics. *Soil Biology and Biochemistry* 46: 73–79.
- Campbell, C. R., and C. O. Plank. 1998. Preparation of plant tissue for laboratory analysis. In *Handbook of reference methods for plant analysis*. Eds. Y. P. Kalra. pp. 37–49. Boca Raton, FL.: CRC Press.

- Camps, A. M., Amonette, J.E., Singh, B., Wang, T., Schmidt, H.P. 2015. A biochar classification system and associated test methods. Eds. J. Lehmann, S. Joseph, *Biochar for Environmental Management*. pp. 165–194. Routledge, London.
- Chan, K.Y., L. Van Zwieten, I. Meszaros, A. Downie and S. Joseph. 2007. Agronomic values of green waste biochar as a soil amendment. *Australian Journal of Soil Research* 45: 629–634.
- Deenik, J. L., A. Diarra, G. Uehara, S. Campbell, Y. Sumiyoshi and M. J. Antal. 2011. Charcoal ash and volatile matter effects on soil properties and plant growth in an acid ultisol. *Soil Science* 176: 336–345.
- Deenik, J. L., T. McClellan, G. Uehara, M. J. Antal and S. Campbell. 2010. Charcoal volatile matter content influences plant growth and soil nitrogen transformations. *Soil Science Society America Journal* 74: 1259–1270.
- Enders, A., K. Hanley, T. Whitman, S. Joseph and J. Lehmann. 2012. Characterization of biochars to evaluate recalcitrance and agronomic performance, *Bioresource Technology* 114:644–653.
- Fredrik, R., V. Sven, D. Dane and P. Wolter. 2013. Production and characterization of slow pyrolysis biochar: influence of feedstock type and pyrolysis conditions *GCB Bioenergy* 5: 104–115
- Fisher, T., M. Hajaligol, B. Waymack, D. Kellog. 2002. Pyrolysis behavior and kinetics of biomass derived materials. *Journal of Analytical Applied Pyrolysis* 62: 331-349.
- Jackson, M.L. 1960. *Soil chemical analysis*. International Potash Institute, Berne (Switzerland) Monthly communication; *Soil testing and plant analysis*, September 1971. p5.
- Kalpathy, U., A. Proctor and J. Shultz. 2000. A simple method for production of pure silica from rice hull ash. *Bio resources Technology* 73: 257-262.

## PREPARATION OF BIOCHAR AS A SOIL AMENDMENT

- Kyle, C., E. K. Ondr Ejmas, Saranp Sohi, B. Peter and Andrew Cross. 2013. The effect of pyrolysis conditions on biochar stability as determined by three methods. *GCB Bioenergy* 5:122–131.
- Lachke, A. 2002. Biofuel from D-xylose the Second Most Abundant Sugar <http://www.iisc.ernet.in/academy/resonance/May2002/pdf/May2002p50-58.pdf> (Accessed on 10.07.2017)
- Liang, B., J. Lehmann, D. Solomon, J. Kinyangi, J. Grossman, B. O'Neill, J.O. Skjemstad, J. Thies, F.J. Luizao and J. Petersen. 2006. Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal* 70: 1719–1730.
- Lua, A.C., T. Yang and J. Guo. 2004. Effects of pyrolysis conditions on the properties of activated carbons prepared from pistachio-nut shells. *Journal of Analytical and Applied Pyrolysis* 72: 279–287.
- Lydia Fryda and Rianne Visser. 2015. Biochar for Soil Improvement: Evaluation of Biochar from Gasification and Slow Pyrolysis. *Agriculture* 5: 1076-1115.
- Manya, J. J. 2012. Pyrolysis for biochar purposes: A review to establish current knowledge gaps and research needs. *Environmental Science and Technology* 46: 7939–7954.
- Mukome, F. N. D., X. Zhang, L. C. R. Silva, J. Six and S. J. Parikh. 2013. Use of chemical and physical characteristics to investigate trends in biochar feedstocks. *Journal Agricultural and Food Chemistry* 61: 2196–2204.
- Nattaporn, P., J. G. Robert, W. Wanpen, D. Apinya and D. Timtong. 2013. The Effects of Pyrolysis Conditions on the Chemical and Physical Properties of Rice Husk Biochar. *International Journal of Material Science (IJMSCI)* 3 (3).
- Noor, N. M., A. Shariff and N. Abdullah. 2012. Slow pyrolysis of cassava wastes for biochar production and characterization. *Iranica Journal of Energy and Environment* 3: 60–65.

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Rowell, D. L. 1994. *Soil Science Methods and Applications*. Langman Group, UK.

Sam Portch and Arvel Hunter 2002. *A systematic Approach to Soil Fertility Evaluation and Improvement*. Special publication 5. laboratory analytical methods. Canpotex, Hong-Kong. 30-44.

Shariff, A. 2016. Corn cob as a potential feedstock for slow pyrolysis of biomass. *Journal of Physical Science*. 27(2): 123–137.

Song, W., and M. Guo. 2012. Quality variations of poultry litter biochar generated at different pyrolysis temperatures. *Journal of Analytical Applied Pyrolysis* 94: 138-145.

Stewart, E. A. 1989. *Chemical Analysis of Ecological Materials*. 2nd Edition. Blackwell Scientific Publications, Oxford London, Edinburg, Boston Melbourne.

Vassilev, S. V., D. Baxter, L. K. Andersen, C. G. Vassileva and T. J. Morgan. 2010. An overview of the chemical composition of biomass Fuel. 89: 913–933.

Verheijen, F. G. A., E. R. Graber, N. Ameloot, A. C. Bastos, S. Sohi and H. Knicker. 2014. Biochars in soils: New insights and emerging research needs. *European Journal Soil Science*. 65: 22–27.

Zhang, P., H. Sun, L. Yu, T. Sun. 2013. Adsorption and catalytic hydrolysis of carbaryl and atrazine on pig manure-derived biochars: impact of structural properties of biochars. *Journal of Hazardous Materials*. 244:217–224.