RESPONSE OF VARIOUS SOURCES OF BIOCHAR IN IMPROVING SOIL HEALTH AND THE PROCESSING QUALITY OF POTATO

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CERTIFICATE

*This is to certify that thesis entitled, "**RESPONSE OF VARIOUS SOURCES OF BIOCHAR IN IMPROVING SOIL HEALTH AND THE PROCESSING QUALITY OF POTATO**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRONOMY**, embodies the result of a piece of bona-fide research work carried out by **KONGCON KUMAR SARDER**, Registration no. **14-06128** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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Dedicated To

My Beloved Parents

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ABSTRACT

A field experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2019 to March, 2020 in Rabi season to find out the response of various sources of biochars in improving soil health and the processing quality of potato crop. The experiment had two factors. Factor A: Four different types of biochar, i. B_1: Maize cob (5.00 t ha^{-1}), ii. B_2: Mahogany wood (5.00 t ha^{-1}), iii. B_3: (Cow dung + Sawdust) (5.00 t ha^{-1}) and iv. B_4: Cow dung (5.00 t ha^{-1}) and Factor B: Three different types of potato, i. V_1: BARI Alu-29 (Courage), ii. V_2: BARI Alu-28 (Lady Rosetta) and iii. V_3: BARI Alu-25 (Asterix). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three (3) replications. Total 36 unit-plots were made for the experiment with 12 treatments. Different potato varieties and/or different sources of biochar showed significant impact on different morphological, yield and qualitative characters of potato. The maximum number of tubers $hill^{-1}$ (7.56), the maximum weight of tubers $hill^{-1}$ (307.39 g), the highest tuber yield (30.74 t ha^{-1}), the maximum marketable yield (22.59 t ha^{-1}), the highest specific gravity of tuber (1.067 g cm^{-3}) , the maximum tuber dry matter (22.27%) and the maximum starch content on potato (16.73 mg g^{-1} FW) were recorded from B_1 (Maize cob) treatment. In case of combination treatment, the maximum weight of tuber $hill^{-1}$ (369.69 g), the highest tuber yield (36.97 t ha^{-1}) and the maximum marketable yield (27.17 t ha^{-1}) was observed in Asterix variety of potato with maize cob biochar (V_3B_1) treatment combination. This combination (V_3B_1) also exhibited highest specific gravity (1.070), dry matter (22.67) and starch content (16.90 mg g^{-1} FW). So the application of maize cob biochar as the source of biochar with potato variety BARI Alu-25 (Asterix) seemed to be more suitable for getting higher yield and good quality potato.

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LIST OF ABBREVIATIONS

ABBREVIATION	ELLABORATION
AEZ	Agro-Ecological Zone
Agric.	Agriculture
Agra.	Agricultural
Agron.	Agronomy
Annu.	Annual
Appl.	Applied
Vm	Vermicompost
Biol.	Biology
Chem.	Chemistry
cm	Centi-meter
CV	Coefficient of Variance
DAS	Days After Storage
DAP	Days After Planting
Dev.	Development
Ecol.	Ecology
Environ.	Environmental
etci	and others
Exptl.	Experimental
g	Gram (s)
Hortc.	Horticulture
i.e.	that is
J.	Journal
kg	Kilogram (s)
LSD	Least Significant Difference
M.S.	Master of Science
m^2	Meter squares
mg	Milligram
Nutr.	Nutrition
Physiol.	Physiological
Progress.	Progressive
Res.	Research
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
T	Tuber size
Soc.	Society
SRDI	Soil Resource Development Institute
t ha^{-1}	Ton per hectare
UNDP	United Nations Development Programme
Viz	*videlicet* (L.), Namely
%	Percentage
@	At the rate of
μMol	Micromole

LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
BBS	Bangladesh Bureau of Statistics
CV %	Percent Coefficient of Variance
cv.	Cultivar (s)
DAS	Days After Sowing
eds.	Editors
et al.	et alia (and others)
etc.	et cetera (and other similar things)
FAO	Food and Agricultural Organization
L.	Linnaeus
LSD	Least Significant Difference
i.e.	id est (that is)
MoP	Muriate of Potash
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TDM	Total Dry Matter
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
var.	Variety
viz.	Namely

CHAPTER I

INTRODUCTION

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INTRODUCTION

Potato (*Solanum tuberosum* L.) belonging to the family Solanaceae is cultivated in nearly 150 countries and is the world's single most vital tuberous crop with an important role in the global food network and food security (Sing, 2010). It originated in the central Andean area of South America (Keeps, 1979). It is the fourth world crop after wheat, rice and maize. Bangladesh is the 8th potato producing country in the world. In Bangladesh, potato ranks 2nd after rice in production (FAOSTAT, 2018). The total area under potato crop, national average yield and total production in Bangladesh are 475488 hectares, 19.925 t ha^{-1} and 9474098 metric tons, respectively (BBS, 2018). The area and production of potato in Bangladesh has been increasing during the last decades but the yield per unit area did not change. The yield of potato in Bangladesh is very low (19.36 t ha^{-1}) in comparison to that of the other leading potato growing countries of the world, 74.45 t ha^{-1} in Kuwait, 59.53 t ha^{-1} in Belgium, 52.89 t ha^{-1} in France, 51.97 t ha^{-1} in USA, 47.53 t ha^{-1} in Denmark and 46.21 t ha^{-1} in UK (FAOSTAT, 2018).

Bangladesh has a great agro-ecological potential of growing potato. Potato has a great importance in rural economy in Bangladesh. It is not only a cash crop but also an alternative food crop compares to rice and wheat. The organic matter of most of the soils of Bangladesh is below 2% as compared to an ideal minimum value 4% (Bhuiyan, 2015). Severe degraded land has become the main causes of low crop productivity. Agricultural land that has been intensively cultivated for continuous cultivation of food crops causes severe degradation and further decreases yields (Sitorus *et al*., 2011). Soils obtaining inorganic fertilizers continuously show a decrease in productivity and tend to suffer secondary nutrient deficiencies as well as micronutrients (Sheth *et al*., 2017). So, it is high time concern about soil health for ensuring sustainable crop production. The addition of soil amendment is necessary to restore the fertility of the soil.

The price of inorganic fertilizers is ever increasing day by day. So the integrated application of inorganic and organic fertilizers, usually termed integrated nutrient management, is widely recognized as a way of enhancing yield and or improving productivity of the soil sustainability. Integrated use of chemical fertilizers and some of organic source such as cow dung, vermicompost, farm yard manure (FYM), biochar that can increase the effectiveness of fertilizers, yield of potato and may improve soil physical properties. Biochar is the solid product of pyrolysis, which is to be used for environmental management and increase crop production. It is a solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment. Biochar application to soils can potentially aid mitigation of climate change by sequestering carbon (C). Biochar additions to agricultural soil have been reported to climate gas emission, as well as improve soil fertility and crop productivity (Lehmann *et al.*, 2003). In addition, biochar also reduces emissions of other greenhouse gases from soil such as nitrous oxide (N_2O) and methane (CH_4) (Rondon *et al.*, 2005). Biochar addition can develop plant productivity directly because of its nutrient content and release characteristics, or indirectly, through improved nutrient conservation.

Biochar is one of the soil amendments that can improve soil fertility (Ding *et al.*, 2016 and Hunt *et al*., 2010). Biochar application changes different soil physical properties, aggregate structure, increase soil C:N ratio. It reduces soil bulk density, increase soil porosity, cation exchange capacity, soil pH, nutrient availability, increase C content and trap CO_2 gas within soil. Biochar compensate climate change through slower return of terrestrial organic C as CO_2 gas to the atmosphere. It decreases leaching loss which is main problem for N fertilizer by retain water into soil. Biochar has been described as a possible means to upgrade soil fertility as well as other ecosystem services and sequester carbon (C) to mitigate climate change (Sohi *et al.*, 2010). The observed effects on soil fertility have been described mainly by a pH increase in acid soils (Van Zwieten *et al.*, 2010) or improved nutrient conservation through cation adsorption (Liang *et al.*, 2006).

Biochar is an organic amendment used for soil improvement and it is produced by pyrolysis of biomass under low or anaerobic conditions (Nair *et al*., 2014). It is a mixture of char and ash, but it is mainly (70 - 95%) carbon (C). It can be produced using different biomass types, for example, switch grass, corn residue, or hardwoods. It has the potential to mitigate climate change, via carbon sequestration, decrease soil acidity and increase agricultural productivity (Sun and Lu, 2014; Hale, 2013; Jeffery *et al*., 2011; Jha *et al*., 2010; Woolf *et al*., 2010 and Lehmann *et al*., 2009). The term 'biochar' was coined by Read to describe charcoal used for soil improvement (Read *et al*., 2004). Lean and Rind (2008) stated that it is a stable solid, rich in carbon, and can endure in soil for thousands of years. Biochar represents as a stable form of carbon thus provides a good carbon storage strategy as a soil amendment (Galinato *et al*., 2011). Previous studies showed that, it has good effect on some soil physical properties such as reducing soil bulk density (Mukherjee and Lal, 2013; Busscher *et al*., 2011 and Mankasingh *et al*., 2011), increases the water retention capacity (Karhu *et al*., 2011 and Vaccari *et al*., 2011) and increases soil pH, EC, CEC of acidity soil (Abewa *et al*., 2014) and reduced fertilizers need. Other it's impacts such as soil's aggregation or porosity greatly depend on soil type, biochar'srates and types (Busscher *et al*., 2011 and Busscher *et al*., 2010). Biochar application to soil can serve as a source of nutrients, C, and habitat for microorganisms, thereby increasing microbial activities in soils (Thies and Rillig, 2009). Changes in soil chemistry regulated by biochar are implicated, with alterations in microbial diversity and activity, with porosity in biochar particles acting as refuges for soil organisms, *e.g.* mycorrhizal fungi (Reverchon *et al*., 2014 and Spokas *et al*., 2012). Biochar also can be a direct nutrient source for plants. It has been found to contain many plant nutrients, including N, P, K, Ca, Mg, S and micronutrients. Total soil nutrient concentrations can be 3 to 5-fold greater relative to the surrounding infertile soil with increased nutrient availability (Glaser *et al*., 2001). It provides protection against some foliar and soil-borne diseases and reduces pressure on forests (Ndameu, 2011).

Biochar can play important role for improving yield and quality of potato. Nair (2015), on potato cv. Atlantic, found that there was a general trend of increasing yields with increasing biochar application rates. Graber *et al*. (2010) mentioned that treating tomato plants by biochar positively enhanced plant height and leaf size. Different studies take places on biochar upon vegetables. The yield of tomato fruit was significantly higher in beds with charcoal than without charcoal (Yilangai *et al.*, 2014). Dou *et al*. (2012) revealed that biochar treatment could increase yield, sugar content and appearance quality of sweet potato, which was conducive to bringing more economic profits for farmers, and improving food safety through using organic fertilizers, and finally promoting sustainable crop production.

The aim of this work was to evaluate the response of different biochar sources on growth, yield and quality of three potato varieties which have an effect on potato production in Bangladesh with the following objectives:

i. To find out the suitable sources of biochar for maximizing potato yield with superior quality and

ii. To study the performance of biochar on improving soil characters.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Potato is an important cash crop of global economic importance. Extensive research work on this crop has been done in several countries, especially in the South East Asia for the improvement of its yield and quality. In Bangladesh recently, it has been drawn attention to improve yield and quality due to increasing its industrial demand. Very few information was available regarding the effect of biochar on soil amendment through carbon sequestration, yield and processing quality of potato varieties. Although this idea was not a recent one but research findings in this regard was scanty. Some of the pertinent works on these technologies reviewed in this chapter.

2.1 Effect of variety on growth and yield of potato

Das (2018) conducted an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.*, factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. Dehydrated potato yield was significantly differed by the varietal difference. The highest dehydrated potato yield (6.39 t ha^{-1}) was recorded from the V_2 followed by V_1 (6.35 t ha^{-1}) whereas the lowest one (4.67 t ha^{-1}) was recorded from V_3. The highest dehydrated potato yield (10.09 t ha^{-1}) was recorded from the treatment combination V2B4 whereas the lowest one (4.04 t ha^{-1}) was recorded from V_3B_2 which was statistically similar with V_3B_4, V_3B_3, V_3B_1 and V_2B_2. The highest french-fry potato yield (4.32 t ha^{-1}) was recorded from the V_3 and Both the variety V_1 and V_2 did not produce any french-fry potato. The highest french-fry potato yield (5.70 t ha^{-1}) was recorded from the treatment combination V_3B_4 whereas V_1 and V_2 in combination with all the biochar levels did not produce any french-fry potato. The highest chips potato (7.19 t ha^{-1}) was produced by the V_3 and the lowest chips potato (3.61 t ha^{-1}) was produced by the V_2. The highest chips potato (9.03 t ha^{-}

^{1}) was produced by the treatment combination V_3B_4 and the lowest chips potato (2.08 t ha^{-1}) was produced by the treatment combination V_2B_0. The highest canned potato (6.74 t ha^{-1}) was produced by the V_2 and the lowest canned potato (3.09 t ha^{-1}) was produced by the V_3. The highest canned potato (8.10 t ha^{-1}) was produced by the treatment combination V_2B_4 and the lowest canned potato (2.46 t ha^{-1}) was produced by the treatment combination V_3B_0 which was statistically similar with V_3B_1.

Kassim *et al.* (2014) found that reducing physiological functions of above ground part of potato plant (leaf area and total chlorophyll content), the number and the weight of tuber decreased, so the productivity of the plant decreased.

Abebe (2013) carried out an experiment at three distinct locations in the Amhara region of Ethiopia for evaluation of the specific gravity of 25 potato varieties. The pooled specific gravity values ranged from 1.058 to 1.102. The specific gravity of tubers of the improved variety Belete was the highest while that of Menagesha was the lowest. Furthermore, the specific gravity values for varieties grown at Debretabor were higher than those for the corresponding varieties grown at Adet and Merawi. He mentioned that specific gravity is the measure of choice for estimating dry matter and ultimately for determining the processing quality of potato varieties.

Behjati *et al.* (2013) conducted a field experiment to evaluate the yield and yield components on promising potato clones. Clone No. 397031-1, had the highest yield and Lady Rosetta variety had the lowest yield compared with other varieties. The lowest and highest average number of main stems per plant, related to Lady Rosetta and clone No. 397067-2. Lady Rosetta variety had the highest number of tubers per plant and clone No. 397067-2 had the lowest number of tubers per plant. The lowest and highest average tuber weight per plant related to clone No. 397067-2 and Lady Rosetta variety respectively.

Hossain (2011) conducted three experiments with BARI released twelve potato varieties to determine the yield potentiality, natural storage behavior and degeneration rate for three consecutive years. He found that the highest emergence was observed in

Granola at 34 DAP. At 50 DAP plant height (cm) of Diamant was (43.50), BARI TPS-1 (47.70), Felsina (52.00), Asterix (52.97), Granola (38.30), Cardinal (46.33). Foliage coverage (%) of Diamant was (83.33), BARI TPS 1 (85.56), Felsina (82.22), Asterix (89.44), Granola (85.56), Cardinal (81.67). No. of stems hill^{-1} of Diamant was (4.06), BARI TPS 1 (3.21), Felsina (3.14), Asterix (4.03), Granola (3.30), Cardinal (3.89). Tuber yield hill^{-1} (g) of Diamant was (244.2), BARI TPS-1 (227.9), Felsina (300.1), Asterix (276.9), Granola (277.0), Cardinal (316.9). Under the grade 28-40mm, the highest number (48.63%) of seed tubers was produced by Granola which was statistically identical with Asterix (46.43%). Under the same grade (28-40 mm), the highest weight (43.46%) of seed tubers was produced by Patrones followed by Asterix (37.16%), Granola (36.64%) and Multa (35.39%) among which there was no significant variation.

Karim *et al.* (2011) conducted an experiment with ten exotic potato varieties (var. All Blue, All Red, Cardinal, Diamant, Daisy, Granola, Green Mountain, Japanese Red, Pontiac and Summerset) to determine their yield potentiality. The highest total tuber weight per plant (344.60g) recorded in var. Diamant and total tuber weight plant^{-1} was the lowest (65.05 g) recorded in var. All red, all blue varieties showed the most potential yield in this experiment.

BARI (2009a) conducted an experiment with three potato varieties to observe their performance on yield under different soil moisture levels. The highest plant height (50.75 cm) was found in Cardinal which was similar to Diamant (48.88 cm). The lowest plant height was observed in Granola (38.50 cm). The highest foliage coverage (93.25%) was observed in Diamant followed by Cardinal (92.75%) and the lowest in Granola (90.33%). The highest no. of stems hill^{-1} (6.25) was observed in Cardinal which was similar to Diamant (5.42) and the lowest in Granola (4.75). The highest no. of tubers hill^{-1} (13.83) was observed in Granola which was similar to Cardinal (13.33) and the lowest in Diamant (11.92).

BARI (2009b) conducted an experiment with twenty-five varieties which were evaluated at six locations. They found that, plant height (cm) in case of Diamant

(47.87), Sagitta (56.20), Quincy (95.40); No. of stem $hill^{-1}$ in Diamant (3.66), Sagitta (2.53), Quincy (2.26); Foliage coverage at 60 DAP (%) in Diamant (73.33), Sagitta (93.67), Quincy (92.00); No of tuber $hill^{-1}$ in Diamant (6.72), Sagitta (3.94), Quincy (9.95); Weight of tuber $hill^{-1}$ (kg) in Diamant (0.30), Sagitta (0.34), Quincy (0.35); Dry matter (%) in case of Diamant (19.54), Sagitta (20.10), Quincy (18.70).

BARI (2009c) conducted an experiment with twelve varieties were evaluated at six locations in their third generation. They found that, plant height (cm) in case of Diamant (50.93), Granola (69.10), Sagitta (41.33), Quincy (65.87); No. of stem $hill^{-1}$ in Diamant (5.66), Granola (3.20), Sagitta (3.46), Quincy (4.86); Foliage coverage at 60 DAP (%) in Diamant (92.00), Granola (91.00), Sagitta (89.33), Quincy (96.00); No. of tuber $hill^{-1}$ in Diamant (7.24), Granola (6.82), Sagitta (5.23), Quincy (5.76); Weight of tuber $hill^{-1}$ (kg) in Diamant (0.38), Granola (0.26), Sagitta (0.33), Quincy (0.35); Dry matter (%) in case of Diamant (20.80), Granola (20.45), Sagitta (19.80), Quincy (18.40).

BARI (2009d) conducted an experiment with twenty-eight varieties were evaluated at five locations. They found that, plant height at 60 DAP (cm) in case of Diamant (54.13), Sagitta (47.27), Quincy (80.93); No. of stem $hill^{-1}$ in Diamant (4.66), Sagitta (5.40), Quincy (5.80); Foliage coverage at 60 DAP (%) in Diamant (93.67), Sagitta (90.67), Quincy (97.00); No. of tubers $hill^{-1}$ in Diamant (8.11), Sagitta (5.41), Quincy (6.95); Weight of tubers $hill^{-1}$ (kg) in Diamant (0.28), Sagitta (0.37), Quincy (0.45); Dry matter (%) in case of Diamant (19.91), Sagitta (20.60), Quincy (18.34).

BARI (2009e) conducted an experiment with four exotic potato varieties along with check Diamant, Cardinal and Granola were evaluated at six locations in Regional Yield Trial. They found that plant height (cm) in case of Diamant (51.20), Cardinal (48.27), Meridian (48.33) and Laura (41.00); No. of stem $hill^{-1}$ in Diamant (5.93), Cardinal (6.20), Meridian (5.67) and Laura (4.73); Foliage coverage (%) in Diamant (88.33), Cardinal (90.33), Meridian (95.67) and Laura (86.67); No. of tuber $hill^{-1}$ in Diamant (9.48), Cardinal (9.81), Meridian (9.63) and Laura (7.50); Weight of tuber $hill^{-1}$ (kg) in case of Diamant (0.313), Cardinal (0.377), Meridian (0.490) and Laura

(0.430); Dry matter (%) in case of Diamant (22.69), Cardinal (21.03), Meridian (19.49) and Laura (20.22).

BARI (2009f) conducted an experiment with seven potato varieties were evaluated at MLT site. They found that plant height (cm) in case of Diamant (43.00), Lady Rosetta (37.00), and Courage (44.47); No of stem plant^{-1} in Diamant (3.57), Lady Rosetta (2.80), and Courage (3.67); No of tuber plant^{-1} in Diamant (8.07), Lady Rosetta (5.67), and Courage (6.70).

BARI (2009g) conducted adaptive trails with new potato varieties at eleven districts. The mean yield of varieties over locations arranged in order of descending as BARI TPS-1 (23.87 t ha^{-1}), Granola (23.68 t ha^{-1}), Diamant (23.63 t ha^{-1}), Asterix (20.83 t ha^{-1}) and Raja (18.28 t ha^{-1}).

Guler (2009) observed that first, second, third class tuber yields and total tuber yield, tuber number per plant, mean tuber weight and leaf chl were significantly influenced by potato cultivar. There were significant correlations between chl and yield and yield related characters. Total yield significantly correlated with leaf chl. Correlations between first class yield and total yield as well as total yield and tuber number per plant were highly significant.

Mahmud *et al.* (2009) assessed the yield of seed size tubers in five standard potato cultivars (Cardinal, Multa, Ailsa, Heera, and Dheera) in relation to dates of dehaulming (65, 70, and 80 days after planting) in a Seed Potato Production Farm, Debijong, Panchagarh. The maximum seed tuber yield was recorded from Cardinal at 80 DAP followed by Heera and Cardinal at 70 DAP, Dheera and Ailsa at 75 DAP.

Haque (2007) conducted a field experiment with 12 exotic potato germplasm to determine their suitability as a variety in Bangladesh. He found that all the varieties gave more than 90% emergence at 20-35 DAP. He also observed that Plant height (cm) of Quincy was (87.8), Sagitta (65.8), Diamant (62.6); No. of stems hill^{-1} was counted in Diamant (7.2), Quincy (4.5), Sagitta (4.4); Plant diameter (cm) of Sagitta was (4.0), Quincy (3.7), Diamant (2.6) at 60 DAP; Foliage coverage (%) of Sagitta was (100.0), Diamant (98.3), Quincy (96.6); No. of tubers plant^{-1} of Diamant was (13.06), Sagitta (8.34), Quincy (6.71); Wt. of tubers plant^{-1} (kg) of Quincy was (0.64), Sagitta (0.63), Diamant (0.49); Dry matter (%) of Sagitta was (20.8), Diamant (20.1), Quincy (18.5).

Das (2006) carried out an experiment to study the physio-morphological characteristics and yield potentialities of potato varieties. He found that Foliage coverage (%) of Diamant was (93.3), Asterix (71.7), Granola (66.7), Quincy (90.0), Courage (63.3), Felsina (83.3), Lady Rosetta (83.3), Laura (78.3); No. of tubers hill^{-1} of Diamant (11.7), Asterix (8.00), Granola (11.3), Quincy (9.33), Courage (7.33), Felsina (8.00), Lady Rosetta (10.3), Laura (8.33); Tuber weight hill^{-1} (g) of Diamant (380), Asterix (285), Granola (275), Quincy (300), Courage (320), Felsina (333), Lady Rosetta (348), Laura (258); Dry matter (%) of Diamant (25), Asterix (17.5), Granola (23), Quincy (31), Courage (34.5), Felsina (22.5), Lady Rosetta (22.0), Laura (27.0); Regarding size grade distribution of tubers the varieties Courage, Espirit, Granola, Lady rosetta, Laura were found superior.

BARI (2005) evaluated twenty-one varieties along with two standard checks Diamant and Granola at seven locations. The yields of the varieties varied from location to location as well as within location. Of all the stations, except Pahartoli, none crossed the check variety Diamant but comparatively higher yields were produced by the varieties Espirit, Courage, Innovator, Quincy, Matador, Markies, Laura and Lady Rosetta.

Kumar *et al.* (2005) determined under water weight, specific gravity, dry matter and starch content of potatoes grown at Modipuram, Uttar Pradesh. He found that there was a positive correlation between under water weight and specific gravity (r=0.99), under water weight and dry matter (r=0.92).

Mondol (2004) conducted an experiment to evaluate the performance of seven exotic (Dutch) varieties of potato. He found that plant height (cm) of Diamant was (18.07), Granola (13.47); No. of main stem hill^{-1} of Diamant (4.36), Granola (4.90); No. of tubers hill^{-1} of Diamant (12.00), Granola (10.93); Weight of tubers plant^{-1} (kg) of Diamant (0.57), Granola (0.39); Dry matter (%) of Diamant (17), Granola (16.30).

Alam *et al.* (2003) conducted a field experiment with fourteen exotic varieties of potato under Bangladesh condition. The highest emergence (91%) was observed from Cardinal which was statistically identical with most of the varieties except the variety Granola (63%). The highest number of stems per hill was recorded in Ailsa (4.59) followed by Cardinal (4.50). Significantly maximum number of leaves hill^{-1} was produced from the plants of the variety Ailsa (53.80), which was followed by Cardinal (49.75). The yields ranged of exotic varieties were 19.44 to 46.67 t ha^{-1}. Variety Ailsa produced the maximum yield (46.67 t ha^{-1}) which was followed by Cardinal (42.21 t ha^{-1}).

Hossain (2000) conducted an experiment to study the effects of different levels of nitrogen on the yield of seed tubers in four potato varieties. He found that the tallest plants were produced by the seedling tubers of BARI TPS-1 (74.51 cm) and the shortest plants came from the variety Diamant (58.63 cm); Foliage coverage (%) of Diamant at 75 DAP was (79.00), BARI TPS-1 (89.00); No. of stems hill^{-1} of Diamant was (3.50), BARI TPS-1 (2.71); No. of tubers hill^{-1} of Diamant was (7.85), BARI TPS-1 (9.55); Weight of tubers hill^{-1} of Diamant was (416.67), BARI TPS-1 (491.33); Dry matter of tuber (%) of Diamant was (19.71), BARI TPS-1 (18.18).

Rabbani and Rahman (1995) studied the performance of 16 Dutch potato varieties in their third generation. They reported that the height of the plants significantly varied among the varieties. The highest foliage coverage at maximum vegetative growth stage was found in the variety Cardinal (93.3%) followed by Diamant. The highest yield of tubers per hectare was obtained from Cardinal (35.19 t ha^{-1}) followed by Romano (30.09 t ha^{-1}) and the lowest from Stroma (11.11 t ha^{-1}).

2.2 Effect of biochar on plant growth parameter

2.2.1 Plant height

Ali (2017) carried out an experiment in Rabi season to observe the effect of biochar on the yield and quality of potato and to find out the optimum dose of biochar along with inorganic fertilizer. The experiment was comprised of 8 treatments; those were, T_1 = Control, T_2 = RFD (Recommended Fertilizer Dose), T_3 = RFD + Biochar @ 5 t ha^{-1}, T_4 = RFD + Biochar @ 10 t ha^{-1}, T_5 = ⅔ of RFD + Biochar @ 5 t ha^{-1}, T_6 = ⅔ of RFD + Biochar @ 10 t ha^{-1}, T_7 = ½ of RFD + Biochar @ 5 t ha^{-1} and T_8 = ½ of RFD + Biochar @ 10 t ha^{-1}. The tested variety was BARI ALU-7 (Daimant). Results showed a significant variation among the treatments in respect of majority of the observed parameters. The tallest plant was recorded from RFD + Biochar @ 10 t ha^{-1} treatment.

Nair *et al.* (2014) conducted an experiment to assess the effect of biochar application in potato production. Four application rates of biochar (0, 2.50, 5.0, or 10.0 t ha^{-1}, 0 t ha^{-1} was referred to as control) were applied by hand on April 12, 2012. Each plot was measured 15 ft. by 30 ft. Experimental design was randomized complete block design with four replications. The researchers observed that the tallest plant (47.60 cm) was recorded from 10 t ha^{-1} biochar treated plot. On the other hand, the shortest plant (45.70 cm) was recorded from control plot (no biochar application).

2.3 Effect of biochar on plant yield contributing parameter

2.3.1 Number of tubers $hill^{-1}$

Ali (2017) carried out an experiment in Rabi season to observe the effect of biochar on the yield and quality of potato and to find out the optimum dose of biochar along with inorganic fertilizer. The experiment was comprised of 8 treatments; those were, T_1 = Control, T_2 = RFD (Recommended Fertilizer Dose), T_3 = RFD + Biochar @ 5 t ha^{-1}, T_4 = RFD + Biochar @ 10 t ha^{-1}, T_5 = ⅔ of RFD + Biochar @ 5 t ha^{-1}, T_6 = ⅔ of RFD + Biochar @ 10 t ha^{-1}, T_7 = ½ of RFD + Biochar @ 5 t ha^{-1} and T_8 = ½ of RFD + Biochar @ 10 t ha^{-1}. The tested variety was BARI ALU-7 (Daimant). Results showed a significant variation among the treatments in respect majority of the observed parameters. The highest number of tubers hill^{-1} was found from RFD + 5 ton biochar ha^{-1} treatment.

Nair *et al.* (2014) conducted an experiment to assess the effect of biochar application in potato production. Four application rates of biochar (0, 2.50, 5.0, or 10.0 t ha^{-1}, 0 t ha^{-1} was referred to as control) were applied by hand. The researchers observed that the highest number of marketable tuber (242 tubers m^{-2}) was recorded from 10 t ha^{-1} biochar treated plot. On the other hand, the lowest number of marketable tuber (227 tubers m^{-2}) was reported from control plot (no biochar application).

2.3.2 Weight of tuber hill^{-1}

Ali (2017) carried out an experiment in Rabi season to observe the effect of biochar on the yield and quality of potato and to find out the optimum dose of biochar along with inorganic fertilizer. The experiment was comprised of 8 treatments; those were, T_1 = Control, T_2 = RFD (Recommended Fertilizer Dose), T_3 = RFD + Biochar @ 5 t ha^{-1}, T_4 = RFD + Biochar @ 10 t ha^{-1}, T_5 = ⅔ of RFD + Biochar @ 5 t ha^{-1}, T_6 = ⅔ of RFD + Biochar @ 10 t ha^{-1}, T_7 = ½ of RFD + Biochar @ 5 t ha^{-1} and T_8 = ½ of RFD + Biochar @ 10 t ha^{-1}. The tested variety was BARI ALU-7 (Daimant). Results showed a significant variation among the treatments in respect of majority of the observed parameters. The highest weight of tubers g hill^{-1} was found from RFD + 5 ton biochar ha^{-1} treatment.

2.4 Effect of biochar on plant yield parameter

2.4.1 Potato yield

Das (2018) conducted an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.*, factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. The investigation revealed that biochar had significant effect on most of the growth, yield and quality contributing parameters of potato studied in this experiment. Results showed that growth, yield and quality contributing parameters of potato increased with increasing biochar level. Among the fifteen treatment combinations, Asterix with biochar level 10.00 t ha^{-1} performed superior than other combination in most of the parameters and it produced the maximum potato yield (27.33 t ha^{-1}). However, in case of yield, V_3B_4, V_3B_3 and V_3B_2 treatment combinations were statistically similar. Whereas no biochar (B_0) treatment showed the lowest values irrespective of varieties. It was concluded that biochar level @ 5.00 t ha^{-1} would be beneficial for maximizing yield.

Ali (2017) carried out an experiment in Rabi season to observe the effect of biochar on the yield and quality of potato and to find out the optimum dose of biochar along with inorganic fertilizer. The experiment was comprised of 8 treatments; those were, T_1 = Control, T_2 = RFD (Recommended Fertilizer Dose), T_3 = RFD + Biochar @ 5 t ha^{-1}, T_4 = RFD + Biochar @ 10 t ha^{-1}, T_5 = ⅔ of RFD + Biochar @ 5 t ha^{-1}, T_6 = ⅔ of RFD + Biochar @ 10 t ha^{-1}, T_7 = ½ of RFD + Biochar @ 5 t ha^{-1} and T_8 = ½ of RFD + Biochar @ 10 t ha^{-1}. The tested variety was BARI ALU-7 (Daimant). Results showed a significant variation among the treatments in respect majority of the observed parameters. The maximum yield of tubers (34.10 t ha^{-1}) was produced from RFD + Biochar @ 5 t ha^{-1} treatment. The minimum yield of tubers (16.60 t ha^{-1}) was produced from control treatment.

Youseef *et al.* (2017) carried out an investigation during the summer season of 2017 to study the effect of biochar addition on the production of some potato cultivars (Accent, Cara and Spunta) grown in sandy soil conditions. The experiment included 12 treatments, which were the combinations between three cultivars of potato *viz*., Accent, Cara, and Spunta and four amounts of biochar (0.00, 1.25, 2.50, and 5.00 m^3 ha^{-1}). The result of the experiment revealed that, the highest potato yield (15.515 t ha^{-1}) was recorded from 'Spunta' potato variety and the lowest potato yield (14.910 t ha^{-1}) was recorded from 'Accent' potato variety. The highest potato yield (17.023 t

ha^{-1}) was recorded from 5.00 m^3 ha^{-1} biochar treated field and the lowest potato yield (13.249 t ha^{-1}) was recorded from control plot (no biochar).

Gautam *et al*. (2017) conducted experiments to investigate the biochar amendment of soil and its effect on crop production of smallholder farms in Rasuwa district of Nepal. They reported that the biochar-amended treatment gave around 17.50% to 40% higher yields in case of potato compared to control treatment.

2.4.2 Marketable potato yield

Das (2018) conducted an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.*, factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. The investigation revealed that biochar had significant effect on most of the growth, yield and quality contributing parameters of potato studied in this experiment. Results showed that growth, yield and quality contributing parameters of potato increased with increasing biochar level. Among the fifteen treatment combinations, Asterix with biochar level 10.00 t ha^{-1} performed superior than other combination in most of the parameters and it produced the maximum marketable potato yield (21.30 t ha^{-1}). Whereas no biochar (B_0) treatment showed the lowest values irrespective of varieties.

Youseef *et al.* (2017) carried out an investigation during the summer season of 2017 to study the effect of biochar addition on the production of some potato cultivars (Accent, Cara and Spunta) grown in sandy soil conditions. The experiment included 12 treatments, which were the combinations between three cultivars of potato *viz*., Accent, Cara, and Spunta and four amounts of biochar (0.00, 1.25, 2.50, and 5.00 m^3 ha^{-1}). The result of the experiment revealed that, the highest marketable potato yield (12.411 t ha^{-1}) was recorded from 'Cara' potato variety and the lowest marketable potato yield (11.949 t ha^{-1}) was recorded from 'Accent' potato variety. The highest marketable potato yield (13.325 t ha^{-1}) was recorded from 5.00 m^3 ha^{-1} biochar treated field and the lowest marketable potato yield (10.835 t ha^{-1}) was recorded from control plot (no biochar).

Nair *et al.* (2014) conducted an experiment to assess the effect of biochar application in potato production. Four application rates of biochar (0, 2.50, 5.0, or 10.0 t ha^{-1}, 0 t ha^{-1} was referred to as control) were applied by hand on April 12, 2012. Each plot was measured 15 ft. by 30 ft. Experimental design was randomized complete block design with four replications. They found that, the highest marketable tuber weight (36.40 kg m^{-2}) was recorded from 10 t ha^{-1} biochar treated plot. On the other hand, the lowest marketable tuber weight (31.70 kg m^{-2}) was recorded from control plot (no biochar application).

2.4.3 Non-marketable potato yield

Nair *et al.* (2014) conducted an experiment to assess the effect of biochar application in potato production. Four application rates of biochar (0, 2.50, 5.0, or 10.0 t ha^{-1}, 0 t ha^{-1} was referred to as control) were applied by hand on April 12, 2012. Each plot was measured 15 ft. by 30 ft. Experimental design was randomized complete block design with four replications. They found that, the highest non-marketable tuber weight (3.10 kg m^{-2}) was recorded from control plot (no biochar application). On the other hand, the lowest non-marketable tuber weight (1.80 kg m^{-2}) was recorded from 10 t ha^{-1} biochar treated plot. Therefore, it was concluded that, biochar might improve the potato quality, which reduced the non-marketable potato yield.

2.5 Effect of biochar on qualitative parameter

2.5.1 Dry matter content in potato

Das (2018) conducted an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.*, factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix);

factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. The investigation revealed that biochar had significant effect on most of the growth, yield and quality contributing parameters of potato studied in this experiment. Results showed that growth, yield and quality contributing parameters of potato increased with increasing biochar level. Among the fifteen treatment combinations, Asterix with biochar level 10 t ha^{-1} performed superior than other combination in most of the parameters and it produced the maximum potato dry matter (22.01 %). However, in case of dry matter content V_3B_3, V_3B_2 and V_2B_4 combinations were statistically similar. Whereas no biochar (B_0) treatment showed the lowest values irrespective of varieties. It was concluded that biochar level @ 5.00 t ha^{-1} would be beneficial for maximizing dry matter content. However, in case of quality parameters, 10.00 t ha^{-1} showed the best performances.

Ali (2017) carried out an experiment in Rabi season to observe the effect of biochar on the yield and quality of potato and to find out the optimum dose of biochar along with inorganic fertilizer. The experiment was comprised of 8 treatments; those were, T_1 = Control, T_2 = RFD (Recommended Fertilizer Dose), T_3 = RFD + Biochar @ 5 t ha^{-1}, T_4 = RFD + Biochar @ 10 t ha^{-1}, T_5 = ⅔ of RFD + Biochar @ 5 t ha^{-1}, T_6 = ⅔ of RFD + Biochar @ 10 t ha^{-1}, T_7 = ½ of RFD + Biochar @ 5 t ha^{-1} and T_8 = ½ of RFD + Biochar @ 10 t ha^{-1}. The tested variety was BARI ALU-7 (Daimant). Results showed a significant variation among the treatments in respect majority of the observed parameters. The maximum value of quality parameter like percentage of dry matter content (23.41) was recorded from RFD + Biochar @ 5 t ha^{-1} treatment.

Youseef *et al.* (2017) carried out an investigation during the summer season of 2017 to study the effect of biochar addition on the production of some potato cultivars (Accent, Cara and Spunta) grown in sandy soil conditions. The experiment included 12 treatments, which were the combinations between three cultivars of potato *viz.*, Accent, Cara, and Spunta and 4 amounts of biochar (0.00, 1.25, 2.50, and 5.00 m^3 ha^{-1}). The result of the experiment revealed that, the highest dry matter content of potato (19.87 %) was recorded from 'Spunta' potato variety and the lowest dry matter content of potato (15.58 %) was recorded from 'Accent' potato variety. The highest dry matter content of potato (18.67 %) was recorded from 5.00 m^3 ha^{-1} biochar treated field and the lowest dry matter content of potato (17.38 %) was recorded from control plot (no biochar).

2.5.2 Total Soluble Solid (TSS)

Das (2018) conducted an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.,* factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. The investigation revealed that biochar had significant effect on most of the growth, yield and quality contributing parameters of potato studied in this experiment. Results showed that growth, yield and quality contributing parameters of potato increased with increasing biochar level. Among the fifteen treatment combinations, Asterix with biochar level 10.00 t ha^{-1} performed superior than other combination in most of the parameters and it produced the maximum total soluble sugar content (5.07° Brix).

2.5.3 Specific gravity

Das (2018) conducted an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.,* factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. The investigation revealed that biochar had significant effect on most of the growth, yield and quality contributing parameters of potato studied in this experiment. Results showed that growth, yield and quality contributing parameters of potato increased with increasing biochar level. Among the fifteen treatment combinations, Asterix with biochar level 10.00 t ha^{-1} performed superior than other combination in most of the parameters and it produced the maximum specific gravity (1.09 g cm^{-3}). Whereas no biochar (B_0) treatment showed the lowest values irrespective of varieties.

Ali (2017) carried out an experiment in Rabi season to observe the effect of biochar on the yield and quality of potato and to find out the optimum dose of biochar along with inorganic fertilizer. The experiment was comprised of 8 treatments; those were, T_1 = Control, T_2 = RFD (Recommended Fertilizer Dose), T_3 = RFD + Biochar @ 5 t ha^{-1}, T_4 = RFD + Biochar @ 10 t ha^{-1}, T_5 = ⅔ of RFD + Biochar @ 5 t ha^{-1}, T_6 = ⅔ of RFD + Biochar @ 10 t ha^{-1}, T_7 = ½ of RFD + Biochar @ 5 t ha^{-1} and T_8 = ½ of RFD + Biochar @ 10 t ha^{-1}. The tested variety was BARI ALU-7 (Daimant). Results showed a significant variation among the treatments in respect majority of the observed parameters. The maximum value of quality parameter specific gravity (1.065 g cm^{-3}) was recorded from RFD + Biochar @ 5 t ha^{-1} treatment.

Youseef *et al.* (2017) carried out an investigation during the summer season of 2017 to study the effect of biochar addition on the production of some potato cultivars (Accent, Cara and Spunta) grown in sandy soil conditions. The experiment included 12 treatments, which were the combinations between three cultivars of potato *viz.*, Accent, Cara, and Spunta and 4 amounts of biochar (0.00, 1.25, 2.50, and 5.00 m^3 ha^{-1}). These treatments were arranged in a split plot design with 3 replicates. The result of the experiment revealed that, the highest specific gravity (1.079 g cm^{-3}) was recorded from 'Spunta' potato variety and the lowest specific gravity (1.053 g cm^{-3}) was recorded from 'Accent' potato variety. The highest specific gravity (1.074 g cm^{-3}) was recorded from 5.00 m^3 ha^{-1} biochar treated field and the lowest specific gravity (1.069 g cm^{-3}) was recorded from control plot (no biochar).

2.5.4 Starch content on potato

Youseef *et al.* (2017) carried out an investigation to study the effect of biochar addition on the production of some potato cultivars (Accent, Cara and Spunta) grown in sandy soil conditions. This experiment included 12 treatments, which were the combinations between three potato *viz.*, Accent, Cara, and Spunta and 4 amounts of biochar (0.00, 1.25, 2.50, and 5.00 m^3 ha^{-1}). The result of the experiment revealed that, the highest starch content (65.24%) was recorded from 'Spunta' potato variety and the lowest starch content (48.49%) was recorded from 'Accent' potato variety. The highest starch content (59.31%) was recorded from 5.00 m^3 ha^{-1} biochar treated field and the lowest starch content (56.04%) was recorded from control plot (no biochar).

2.6 Effect of soil health

2.6.1 Soil pH

Gautam *et al*. (2017) conducted experiments to investigate the biochar amendment of soil and its effect on crop production of small holder farms in Rasuwa district of Nepal and they reported that the soil pH was 5.30 with or without biochar application.

Timilsina *et al.* (2017) conducted a field experiment to assess the effects of biochar application on soil properties and production of Radish on loamy sand soil. The experiment was conducted with five levels of biochar (0, 5, 10, 15 and 20 kg ha^{-1}), each replicated for four times. The results revealed that, the effect of biochar application on soil pH was not significant among the treatments (7.27–7.67) but it was increased with higher rates of biochar application.

Yang *et al.* (2015) reported that in the corn land soil the maximum soil pH (6.97) was observed when 4 t ha^{-1} rice stalk-derived biochar (RB) was applied while the minimum soil pH (6.81) was observed when 2 t ha^{-1} rice stalk-derived biochar (RB) was applied. In the peanut land soil, the maximum soil pH (7.03) was observed when 2 t ha^{-1} rice stalk-derived biochar (RB) was applied while the minimum soil pH (6.19) was observed when 4 t ha^{-1} corn stalk-derived biochar (CB) was applied. In the sweet potato land soil, the maximum soil pH (7.15) was observed when 4 t ha^{-1} rice stalk-derived biochar (RB) was applied while the minimum soil pH (7.10) was observed when 2 t ha^{-1} rice stalk-derived biochar (RB) was applied.

Nair *et al.* (2014) conducted an experiment to study the biochar application in potato production. Four application rates of biochar (0, 2.5, 5.0, or 10.0 t ha^{-1}, 0 t ha^{-1} was referred to as control) were applied by hand. They found that, maximum soil pH (5.90) was recorded from 10 t ha^{-1} biochar treated plot. On the other hand, the minimum soil pH (5.30) was recorded from control plot (no biochar application).

Dou *et al*. (2012) conducted two field experiments to observe the effects of Biochar, Mokusakueki and Bokashi application on soil nutrients concentrations, yields and qualities of sweet potato. Results showed that soil pH observed in biochar treatment was significant and remarkably higher than Mokusakueki and Bokashi treatments.

2.6.2 Organic carbon content in soil

Gautam *et al*. (2017) conducted experiments to investigate the biochar amendment of soil and its effect on crop production of small holder farms in Rasuwa district of Nepal and they reported that the maximum soil organic matter (1.70%) was recorded from biochar treated plot and the minimum soil organic matter (1.50%) was observed from no biochar treated plot.

Timilsina *et al.* (2017) conducted a field experiment to assess the effects of biochar application on soil properties and production of Radish (*Raphanus sativus* L.) on loamy sand soil. The experiment was conducted with five levels of biochar (0, 5, 10, 15 and 20 kg ha^{-1}). The results revealed that, the effect of biochar application on soil organic matter was highly significant. The highest soil organic matter (2.915%) was obtained from 20 kg ha^{-1} biochar application which was significantly higher ($p < 0.001$) than other treatments, and it was the lowest (1.165%) from no biochar application, but was at par with 5 kg ha^{-1} biochar amended soil. Soil treated with 10 and 15 kg ha^{-1} biochar applications had similar organic matter content ($p > 0.01$) but significantly higher ($p < 0.001$) than 5 kg ha^{-1} and soil without biochar applications.

2.6.3 Nitrogen content in soil

Gautam *et al*. (2017) conducted experiments to investigate the biochar amendment of soil and its effect on crop production of small holder farms in Rasuwa district of Nepal. They reported that the highest total nitrogen (1422 ppm) was scored by biochar treated plot and the lowest total nitrogen (1089 ppm) was observed from no biochar treated plot.

Timilsina *et al.* (2017) conducted a field experiment to assess the effects of biochar application on soil properties and production of Radish on loamy sand soil. The experiment was conducted with five levels of biochar (0, 5, 10, 15 and 20 kg ha^{-1}). The results revealed that, the effects of biochar application on nitrogen content in soil were highly significant. Addition of different doses of biochar had higher nitrogen contents of soil compared with no addition of biochar. The highest nitrogen content (1.2 g kg^{-1}) was found from 20 kg ha^{-1} biochar application which was significantly higher ($p < 0.001$) from other treatments. The lowest (0.70 g kg^{-1}) nitrogen content was obtained from no biochar amended soil.

Yang *et al.* (2015) reported that in the corn land soil the maximum nitrogen content (0.078%) in soil was observed when 4 t ha^{-1} rice stalk-derived biochar (RB) was applied while the minimum nitrogen content (0.041%) in soil was observed when 2 t ha^{-1} corn stalk-derived biochar (CB) was applied. In the peanut land soil, the maximum nitrogen content (0.082%) in soil was observed when 4 t ha^{-1} corn stalk-derived biochar (CB) was applied while the minimum nitrogen content (0.043%) in soil was observed when 2 t ha^{-1} rice stalk-derived biochar (RB) was applied. In the sweet potato land soil, the maximum nitrogen content (0.072%) in soil was observed when 2 t ha^{-1} rice stalk-derived biochar (RB) was applied while the minimum nitrogen content (0.065%) in soil was observed when 4 t ha^{-1} corn stalk-derived biochar (RB) was applied.

2.6.4 Potassium content in soil

Gautam *et al*. (2017) conducted experiments to investigate the biochar amendment of soil and its effect on crop production. They reported that the highest exchangeable potassium (72.60 ppm) was recorded from biochar treated plot and the lowest exchangeable potassium (67.00 ppm) was observed from no biochar treated plot.

Timilsina *et al.* (2017) conducted a field experiment to assess the effects of biochar application on soil properties and production of Radish on loamy sand soil. The experiment was conducted with five levels of biochar (0, 5, 10, 15 and 20 kg ha^{-1}). The results revealed that, the effects of biochar application on available potassium contents in soil was highly significant ($p < 0.001$). The increased rates of biochar application increased the available potassium content in soil. The highest available potassium content (12.3 mg kg^{-1}) in soil was found from 20 kg ha^{-1} biochar application which was consistent with 15 kg ha^{-1} but significantly higher ($p < 0.001$) than other treatments. The lowest available potassium content (7.70 g kg^{-1}) was found from no biochar amended soil and it was significantly ($p < 0.001$) lower than other treatments.

Yang *et al.* (2015) reported that in the corn land soil the maximum potassium content (2.50%) in soil was observed when 4 t ha^{-1} corn stalk-derived biochar (CB) was applied while the minimum potassium content (2.26%) in soil was observed when 2 t ha^{-1} rice stalk-derived biochar (RB) was applied. In the peanut land soil, the maximum potassium content (2.57%) in soil was observed when 2 t ha^{-1} corn stalk-derived biochar (CB) was applied while the minimum potassium content (2.09%) in soil was observed when 4 t ha^{-1} corn stalk-derived biochar (CB) was applied. In the sweet potato land soil, the maximum potassium content (2.31%) in soil was observed when 2 t ha^{-1} rice stalk-derived biochar (RB) was applied while the minimum potassium content (2.31%) in soil was observed when 4 t ha^{-1} corn stalk-derived biochar (RB) was applied.

Dou *et al.* (2012) conducted two field experiments to observe the effects of Biochar, Mokusakueki and Bokashi application on soil nutrients concentrations, yields and qualities of sweet potato. Results showed that the maximum exchangeable potassium (51 mg 100 g^{-1} soil) was recorded from biochar treatment and the minimum one (43 mg 100 g^{-1} soil) was recorded from Mokusakueki treatment.

2.7 Effect of biochar on yield of potato on processing purpose

2.7.1 Dehydrated potato yield

Das (2018) conducted an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.*, factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. The highest dehydrated potato yield (6.94 t ha^{-1}) was recorded from the B_4 whereas the lowest one (4.74 t ha^{-1}) was recorded from B_2.

2.7.2 French-fry potato yield

Das (2018) carried out an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.*, factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. French-fry potato yield was significantly influenced by the different biochar levels. The highest french-fry potato yield (1.90 t ha^{-1}) was recorded from the B_4 treatment whereas the lowest one (0.99 t ha^{-1}) was recorded from B_0 treatment.

2.7.3 Chips potato yield

Das (2018) set up an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.*, factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. Biochar levels exerted significant influence on chips potato yield. The highest chips potato (6.82 t ha^{-1}) was produced by the B_4 and the lowest chips potato (3.94 t ha^{-1}) was produced by the treatment B_0.

2.7.4 Canned potato yield

Das (2018) conducted an experiment to evaluate the effect of variety and biochar on yield and some quality parameters of potato along with soil properties. The experiment was consisted of two factors, *i.e.*, factor A: Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V_3: BARI Alu-25 (Asterix); factor B: Biochar level (5): B_0: 0.00 t ha^{-1}, B_1: 2.50 t ha^{-1}, B_2: 5.00 t ha^{-1} and B_3: 7.50 t ha^{-1} and B_4: 10.00 t ha^{-1}. Biochar levels exerted significant difference on canned potato yield. The highest canned potato (6.04 t ha^{-1}) was produced by the B_4 and the lowest canned potato (3.96 t ha^{-1}) was produced by the treatment B_0.

CHAPTER III

MATERIALS & METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, intercultural operations, data collection and statistical analysis. The details of experimental materials and methods are described below:

3.1 Experimental period

The experiment was conducted at the Agronomy Research Field, Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from 2nd November, 2019 to 15th March, 2020.

3.2 Geographical location

The experimental area was situated at $23^0 77'$N latitude and $90^0 33'$E longitude at an altitude of 8.6 meter above the sea level (Anon., 2004).

3.3 Agro-Ecological Region

The experimental site belongs to the agro-ecological zone of "Madhapur Tract", AEZ-28 (Anon, 1988a). This was a region of complex relief and soils developed over the Madhapur clay, where floodplain sediments buried the dissected edges of the Madhapur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (Anon, 1988b). The experimental site is shown in the map of AEZ of Bangladesh in Appendix I.

3.4 Climate of the experimental site

Experimental site was located in the sub-tropical monsoon climatic zone, set a parted by winter during the months from November, 2019 to February, 2020. Plenty of sunshine and moderately low temperature prevails during experimental period, which is suitable for potato growing in Bangladesh. The weather data during the study period at the experimental site are shown in Appendix II.

3.5 Soil

Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish-brown mottles. Soil pH was 5.6 and has organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system and above flood levels. The soil data during the study period at the experimental site are shown in Appendix III.

3.6 Experimental treatments

The experiment consisted of two factors such as source of biochar and potato variety. The treatments were as follows:

Factor A: Four different types of biochar

i. B_1: Maize cob (5.00 t ha^{-1}),

ii. B_2: Mahogany wood (5.00 t ha^{-1}),

iii. B_3: (Cow dung + Sawdust) (5.00 t ha-1) and

iv. B_4: Cow dung (5.00 t ha^{-1}).

Factor B: Three different types of potato

i. V_1: BARI Alu-29 (Courage),

ii. V_2: BARI Alu-28 (Lady Rosetta) and

iii. V_3: BARI Alu-25 (Asterix).

Treatment combinations are as: B_1V_1, B_1V_2, B_1V_3, B_2V_1, B_2V_2, B_2V_3, B_3V_1, B_3V_2, B_3V_3, B_4V_1, B_4V_2 and B_4V_3.

3.7 Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three (3) replications. Total 36 unit plots will be made for the experiment with 12 treatments. The size of each unit plot was 2.6 m x 1.2 m. Row to row and plant to plant distances were 60 cm and 25 cm respectively. Distances maintained between replication and plots were 1.0 m and 0.8 m. The final layout of the experimental plots has shown in (Appendix X).

3.8 Planting material

The planting materials comprised the certified seed tubers of three potato varieties. The variety was BARI Alu-25 (Asterix), BARI Alu-28 (Lady Rosetta) and BARI Alu-29 (Courage).

3.9 Collection of tubers

The variety of seed potato (certified seed) was collected from, Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur and from BARI sub-station. Individual weight of seed potato was 60–70 g.

3.10 Crop management

3.10.1 Preparation of tuber

Collected seed tubers were kept in room temperature to facilitate sprouting. Finally sprouted potato tubers were used as planting material.

3.10.2 Land preparation

The land of the experimental site was first opened in 02 November 2019 with power tiller. Later on, the land was ploughed and cross-ploughed four times followed by laddering to obtain the desirable tilth. The corners of the land were spaded and weeds and stubbles were removed from the field. The land was finally prepared on 10th November, 2019 three days before planting the seed. In order to avoid water logging due to rainfall during the study period, drainage channels were made around the land. The soil was treated with insecticides (Bifar 5G @ 4 kg ha^{-1}) at the time of final land preparation to protect young plants from the attack of soil inhibiting insects such as cutworm and mole cricket.

3.10.3 Manure and fertilizer application

The crop was fertilized as per recommendation of TCRC (2004). The experimental soil was fertilized with following dose of urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, zinc sulphate and boric acid.

Fertilizers	**Dose (kg ha^{-1})**
Cow dung	10,000
Urea	325
TSP	220
MoP	250
Gypsum	120
Zinc Sulphate	14
Boric Acid	6

Source: Mondal *et al.*, 2011.

Cow dung was applied 10 days before final land preparation. Total amount of triple super phosphate, muriate of potash, gypsum, zinc sulphate, boric acid and half of urea was applied at basal doses during final land preparation. The remaining 50% urea was side dressed in two equal splits at 35 and 50 days after planting (DAP) during first and second earthing up.

3.10.4 Biochar application

The different types of biochar was applied at 7 days before planting as per treatment.

3.10.5 Planting of seed tuber

The well sprouted healthy and uniform sized potato tubers were planted according to treatment. Seed potatoes were planted in such a way that potato does not go much under soil or does not remain in shallow. On an average, potatoes were planted at 4–5 cm depth in soil on 15th November, 2019.

3.11 Intercultural operations

3.11.1 Weeding

Weeding was necessary to keep the plant free from weeds. The newly emerged weeds were uprooted in 20, 35 and 50 DAP respectively at carefully from the field after complete emergence of sprouts and afterwards when necessary.

3.11.2 Irrigation

Just after full emergence the crop was irrigated by flooding at 15 days after planting (DAP) so that uniform growth and development of the crop was occurred and also moisture status of soil retain as per requirement of plants. The second, third and fourth irrigation were done at 25, 45 and 65 DAP, respectively.

3.11.3 Mulching

Mulching were necessary to keep the pots to conserve soil moisture. Natural mulching was done for breaking the surface crust as and when needed.

3.11.4 Earthing up

Earthing up process was done in the plot at two times, during crop growing period. First was done at 35 DAP and second was at 50 DAP.

3.11.5 Plant protection measures

Dithane M-45 was applied at 30 and 60 DAP as a preventive measure for controlling fungal infection. Ridomil Gold (0.25%) was sprayed at 45, 55, 65 and 75 DAP to protect the crop from the attack of late blight.

3.11.6 Haulm cutting

Haulm cutting was done at 13th February, 2020 at 90 DAP, when 40-50% plants showed senescence and the tops started drying. After haulm cutting the tubers were kept under the soil for 10 days for skin hardening. The cut haulm was collected, bagged and tagged separately for further data collection.

3.11.7 Harvesting of potatoes

Harvesting of potato was done on 23th February, 2020 at 10 days after haulm cutting. The potatoes of each plot were separately harvested, bagged and tagged and brought to the laboratory. The yield of potato $hill^{-1}$ was determined in gram. Harvesting was done manually by hand.

3.12 Recording of data

3.12.1 Plant characters

The following data were recorded during experimentation period:

i. Plant height (cm)
ii. Number of tubers $hill^{-1}$
iii. Average weight of tuber (g)
iv. Weight of tuber $hill^{-1}$ (g)
v. Tuber yield ($t\ ha^{-1}$)
vi. Marketable yield ($t\ ha^{-1}$)
vii. Non-marketable yield ($t\ ha^{-1}$)
viii. Specific Gravity ($g\ cm^{-3}$)
ix. Dry matter content (%)
x. Total soluble solid (˚brix)
xi. Starch content ($mg\ g^{-1}$ FW)
xii. Reducing sugar ($mg\ g^{-1}$ FW)
xiii. Yield of potato for chips production ($t\ ha^{-1}$)
xiv. Yield of potato for French fry production ($t\ ha^{-1}$)
xv. Yield of potato for flakes production ($t\ ha^{-1}$)
xvi. Yield of potato for canned production ($t\ ha^{-1}$)

3.12.2 Soil Analysis

i. Soil pH,
ii. Soil organic carbon,
iii. Nitrogen content (%) in soil and
iv. Potassium content (%) in soil.

3.13 Experimental measurements

A brief outline of the data recording procedure followed during the study is given below:

3.13.1 Plant height (cm)

Plant height refers to the length of the plant from ground level to the tip of the tallest stem. It was measured at an interval of 15 days starting from 30 DAP till 60 DAP.

3.13.2 Number of tubers hill^{-1}

Number of tubers hill^{-1} was counted at harvest. Tuber numbers hill^{-1} was recorded by counting all tubers from each plant.

3.13.3 Average weight of tuber (g)

Average tuber weight was measured by using the following formula-

$$\text{Average tuber weight (g)} = \frac{\text{Yield of tuber hill}^{-1}\ \text{(g)}}{\text{Number of tubers hill}^{-1}}$$

3.13.4 Weight of tuber hill^{-1} (g)

Tubers of each plot were collected separately from which weight of tuber hill^{-1} was recorded in gram.

3.13.5 Tuber yield (t ha^{-1})

Tubers of each plot were collected separately from which yield of tuber hill^{-1} was recorded in gram and converted to ton hectare^{-1}.

3.13.6 Marketable yield and non-marketable yield (t ha^{-1})

On the basis of weight, the tubers have been graded into marketable tuber (> 20g) and non-marketable tuber (< 20g) and converted to t ha^{-1} (Hussain, 1995).

3.13.7 Specific Gravity (g cm^{-3})

It was measured by using the following formula (Gould, 1995)-

$$\text{Specific gravity } (g\ cm^{-3}) = \frac{\text{Weight in air}}{\text{Weight in water at } 4^0\ C}$$

3.13.8 Dry matter content (%)

The samples of tuber were collected from each treatment. After peel off the tubers the samples were dried in an oven at 72°C for 72 hours. Dry matter content was calculated as the ratio between dry and fresh weight and expressed as a percentage (Barton and Longman, 1989).

3.13.9 Total soluble solids (˚brix)

TSS of harvested tubers was determined in a drop of potato juice by using Hand Sugar Refractometer "ERMA" Japan, Range: 0–32% according to (AOAC, 1990) and expressed as brix value.

3.13.10 Starch content (mg g^{-1} FW)

The residue remained after extraction for sugar, was washed for several times with water to ensure that there was no more soluble sugar in the residues. After that using tap water and mark up to 250 ml beaker. Stir well on a magnetic stirrer. Then 0.5 mL solution was taken from the beaker into 3 test tubes. 0.5 mL was taken during the stirring. Then boiling the test tubes for 10 min at 100˚C. 1 mL Amyloglucosidase solution was added and mix well and heat at 50-60˚C for 2 hrs in hot water. After cooling, a 0.5 mL Copper solution was added and mix well, heat at 100C for 10 min., cool in tap water again added 0.5 mL Nelson solution, mix well and added 7 mL distilled water, mix well (Final volume = 9.5 mL), and measure the absorbance at 660 nm (Abs4). Calculate starch content using the glucose standard curve.

3.13.11 Reducing sugar (mg g^{-1} FW)

3.13.11.1 Extraction of sugar

For the analysis of sugar content like glucose and sucrose potato flesh was extracted. For each extraction, 1.0 g fresh sample of chopped potato was taken from uniform tuber samples. Sugar was extracted using 5ml of 80% ethanol heat at 80°C for 30 min using a dry block heat bath and the extracts was centrifuged at 5000 rpm for 10 min and decanted the supernatant. 8mL 80% EtOH, was added and it was repeated 4 and 5 for 3 times in total. All the supernatants were mixed well and the final volume was made up to 25 mL using 80% EtOH. The residue is used for starch analysis.

3.13.11.2 Reducing sugar determination (glucose)

Reducing sugar was estimated by the photometric adaptation of the Somogyi method with some modification. Copper solution and Nelson reagent and standard glucose solution (0.5 mL) were used. 3 mL sample solution was put into a small glass container. Then it was completely dried up on an electric heater, 3 mL distilled water was added, and then mixed well. Then .5ml solution was taken from this, two times and was put in different test tubes. In one test tube, 0.5 mL Copper solution was added and was boiled (100°C) for 10 min. After boiling, immediately the test tube was cooled in tap water. 0.5 mL Nelson reagent in the test tube was added, and mixed them well. After 20 min, 8 mL distilled water was added and mixed well (Total volume = 9.5 mL). 33 After that the absorbance at 660 nm (Abs1) was measured and the reducing sugar content was calculated.

3.13.12 Grading of tuber (t ha^{-1})

Tubers harvested from each treatment were graded by weight on the basis of diameter into the < 30 mm, 30–45 mm, 45–75 mm and > 75 mm for canned, flakes, chips and French fry potato production, respectively and converted to t ha^{-1} (Hussain, 1995). A special type of frame (potato riddle) was used to grading of tuber.

3.13.13 Soil pH

Soil pH was measured with the help of a glass electrode pH meter using soil water suspension ratio being maintained at 1:2.5 (Jackson, 1962).

3.13.14 Soil organic carbon

Organic carbon in soil sample was determined by wet oxidation method of Walkley and Black (1935).

3.13.15 Total nitrogen

Total nitrogen content of soil was determined followed by the Micro Kjeldahl distillation method.

3.13.16 Exchangeable potassium

Exchangeable K was determined by 1N NH_4OAc (pH 7) extraction method and by using flame photometer and calibrated with a standard curve (Page *et al*., 1982).

3.14 Statistical Analysis

The data obtained for different characters were statistically analyzed following the analysis of variance techniques by using MSTAT-C computer package programme. The significant differences among the treatment means were compared by Least Significant Different (LSD) at 5% levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

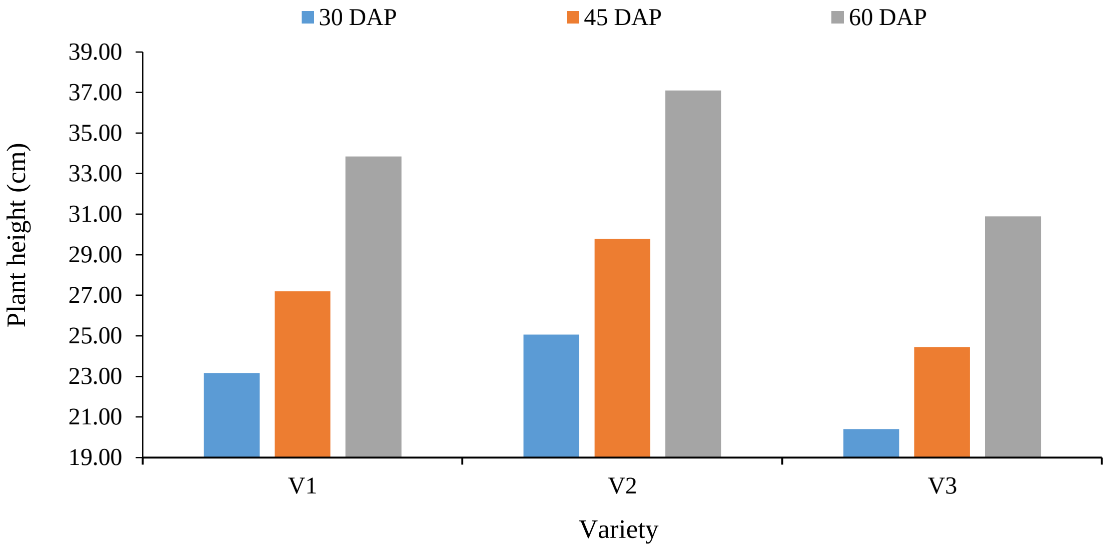
RESULTS AND DISCUSSION

The experiment was conducted to find out the response of various sources of biochar in improving soil health and the processing quality of potato varieties. The results obtained from the study have been presented, discussed and compared in this chapter through table(s) and figures. The analysis of variance of data in respect of all the parameters has been shown in Appendix IV to IX. The results have been presented and discussed with the help of table and graphs and possible interpretations given under the following headings. The analytical results have been presented in Table 1 through Table 9 and Figure 1 through Figure 12.

4.1 Plant height (cm)

4.1.1 Effect of variety

The plant height of potato varieties was measured at 30, 45 and 60 DAP. It was evident from Figure 1 and Appendix IV that the height of plant was significantly influenced by variety at all the sampling dates. Figure 1 showed that plant height increased with advancing growing period irrespective of varieties, the potato height increased rapidly at the early stages of growth. At 30, 45 and 60 DAP, 'Lady Rosetta' showed the longest plant (25.06, 29.78 and 37.09 cm, respectively) whereas, the shortest plant (20.40, 24.45 and 30.89 cm, respectively) was found from the variety 'Asterix'. Present investigation referred, 'Lady Rosetta' as the best in terms of plant height. The variations in the plant height among the varieties also recorded by Rabbani (1996) and Bashar (1978) in their experimental results. Plant height of a crop depends on the plant vigour, cultural practices, growing environment and the varietal characters. In the present experiment since all the varieties were grown in the same environment and were given same cultural practices, the variation in the plant height among the varieties might be due to the varietal character.

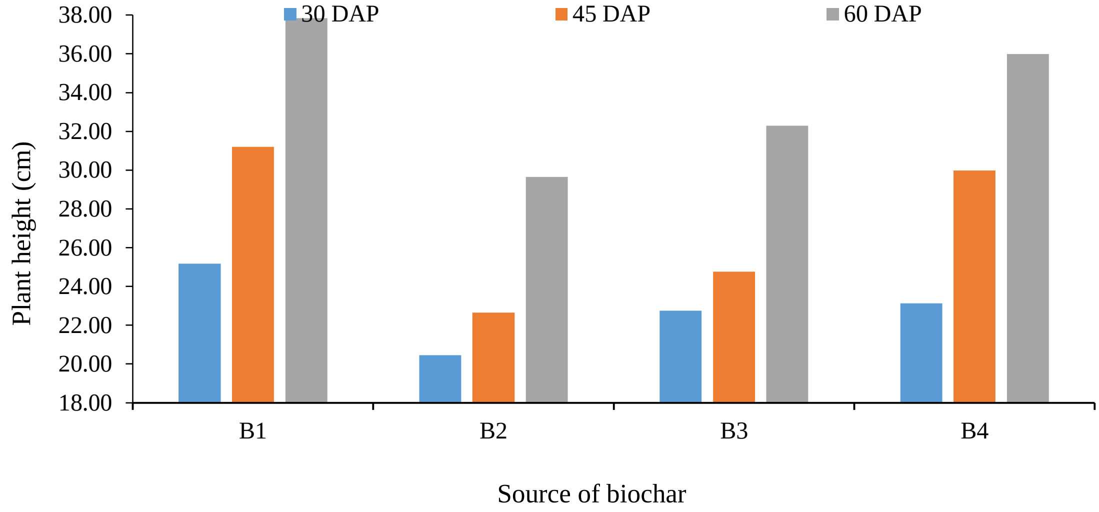


Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta) and V_3- BARI Alu-25 (Asterix).

Figure 1. Effect of variety on plant height (cm) of potato at different days after planting (LSD value = 1.03, 1.56 and 1.98 at 30, 45 and 60 DAP, respectively)

4.1.2 Effect of different sources of biochar

Plant height due to different sources of biochar applications was significantly influenced at days after planting (DAP) (Figure 2 and Appendix IV). At 30 DAP, the longest plant (25.18 cm) was recorded from B_1 (Cob) treatment whereas, the shortest plant (20.46 cm) was recorded from B_2 (Mahogany wood) treatment. At 45 and 60 DAP, the longest plant (31.20 and 37.84 cm, respectively) was recorded from B_1 (maize cob) treatment which was statistically identical to B_4 (29.98 and 35.99 cm, respectively) whereas, the shortest plant (22.64 and 29.64 cm, respectively) was recorded from B_2 (Mahogany wood) treatment. The results were conformity with the findings of Afrina (2017).



Note: B_1 – Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}) and B_4 - Cow dung (5.00 t ha^{-1}).

Figure 2. Effect of source of biochar on plant height (cm) of potato at different days after planting (LSD value = 1.03, 1.56 and 1.98 at 30, 45 and 60 DAP, respectively)

4.1.3 Interaction effect of variety and sources of biochar

Significant variation of plant height was found due to interactional effect of different varieties and sources of biochar in all the studied durations (Table 1 and Appendix IV). At 30, 45 and 60 DAP, the longest plant (27.07, 35.20 and 42.50 cm, respectively) was measured from V_2B_1 (Lady Rosetta with Maize Cob) combination. On the other hand, the shortest plant (17.17, 20.20 and 27.00 cm at 30, 45 and 60 DAP, respectively) from V_3B_2 (Asterix with Mahogany wood) treatment combination.

Table 1. Interaction effects of variety and source of biochar on plant height of potato at different days after planting

Treatment combination	Plant height (cm) at		
	30 DAP	**45 DAP**	**60 DAP**
V_1B_1	25.13 bc	30.53 c	36.10 c
V_1B_2	21.33 e	23.20 g	30.83 e
V_1B_3	23.07 d	24.87 f	32.10 de
V_1B_4	23.13 d	30.20 c	36.33 c
V_2B_1	27.07 a	35.20 a	42.50 a
V_2B_2	22.87 d	24.53 f	31.10 de
V_2B_3	24.63 c	26.20 e	35.77 c
V_2B_4	25.67 b	33.20 b	39.00 b
V_3B_1	23.33 d	27.87 d	34.93 cd
V_3B_2	17.17 f	20.20 h	27.00 g
V_3B_3	20.53 e	23.20 g	29.00 f
V_3B_4	20.57 e	26.53 e	32.63 d
LSD $_{(0.05)}$	**0.93**	**1.24**	**1.71**
CV (%)	**10.27**	**13.62**	**15.92**

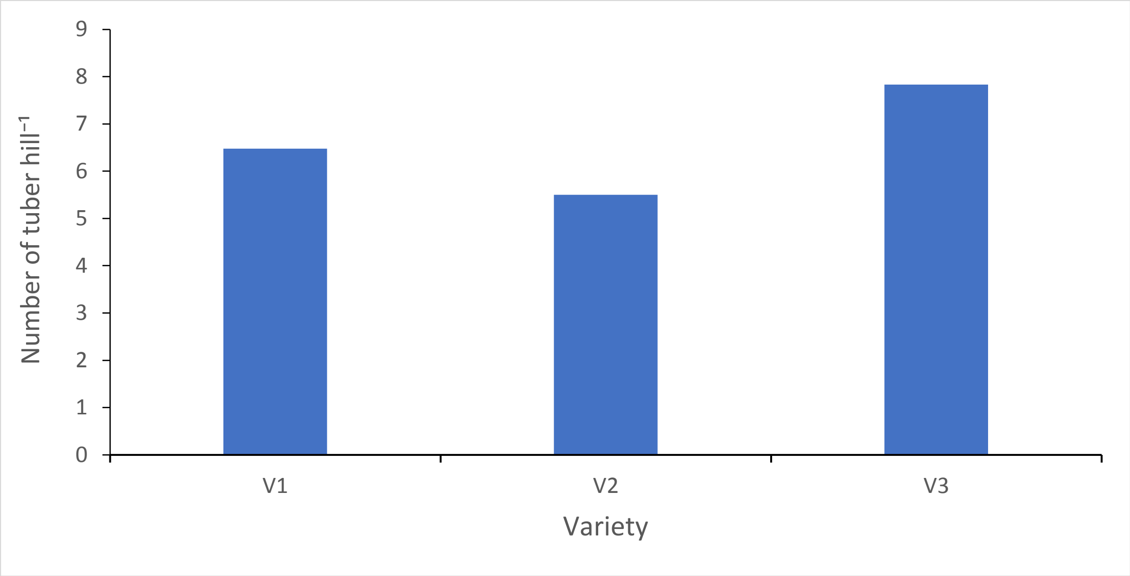
In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta), V_3- BARI Alu-25 (Asterix) and B_1 - Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}), B_4 - Cow dung (5.00 t ha^{-1}).

4.2 Number of tubers hill^{-1}

4.2.1 Effect of variety

Number of tubers hill^{-1} significantly influenced by the potato varieties (Appendix V and Figure 3). The maximum number of tubers hill^{-1} (7.83) was recorded from the 'Asterix' and the minimum (5.50) was found from BARI Alu-28 (Lady Rosetta)

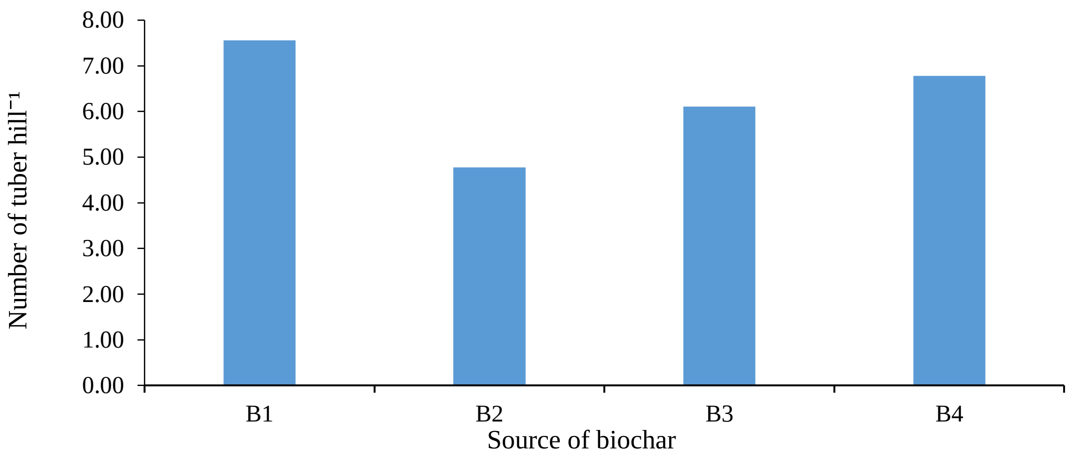


Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta) and V_3- BARI Alu-25 (Asterix).

Figure 3. Effect of variety on number of tuber hill^{-1} of potato (LSD value = 0.63)

4.2.2 Effect of different sources of biochar

Number of tubers hill^{-1} significantly influenced by the different sources of biochar applications (Figure 4 and Appendix V). The maximum (7.56) number of tubers was produced from B_1 (Maize Cob) treatment whereas the minimum (4.78) was produced from B_2 (Mahogany wood) treatment. The results were conformity with the findings of Afrina (2017).



Note: B_1 – Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}) and B_4 - Cow dung (5.00 t ha^{-1}).

Figure 4. Effect of source of biochar on number of tuber hill^{-1} of potato (LSD value = 0.63)

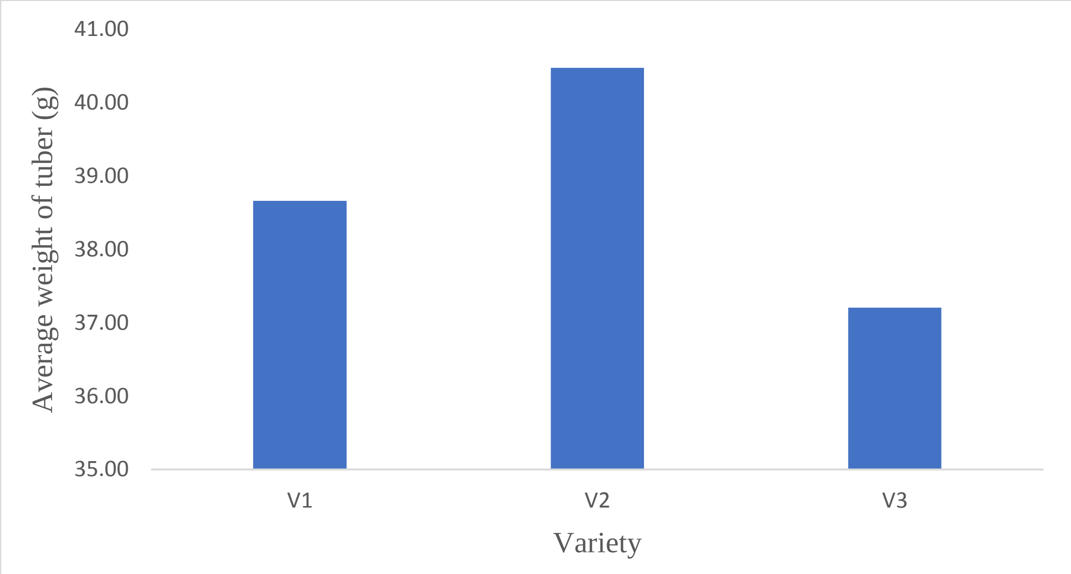
4.2.3 Interaction effect of variety and sources of biochar

In respect of number of tuber hill^{-1} due to different varieties and sources of biochar was found statistically significant (Table 2 and Appendix V). The maximum (9.33) number of tubers was found from V_3B_1 (Asterix with Maize Cob) treatment combination. On the other hand, the minimum (3.67) number of tubers was from V_1B_2 (Courage with Mahogany wood) treatment combination.

4.3 Average weight of tuber (g)

4.3.1 Effect of variety

The average weight of tuber varied significantly due to different potato varieties (Appendix V and Figure 5). The maximum average tuber weight (40.48 g) was recorded from the ‘Lady Rosetta’ which was statistically similar with ‘Courage’ (38.66 g) whereas, the minimum (37.21 g) was obtained from the ‘Asterix’ variety.

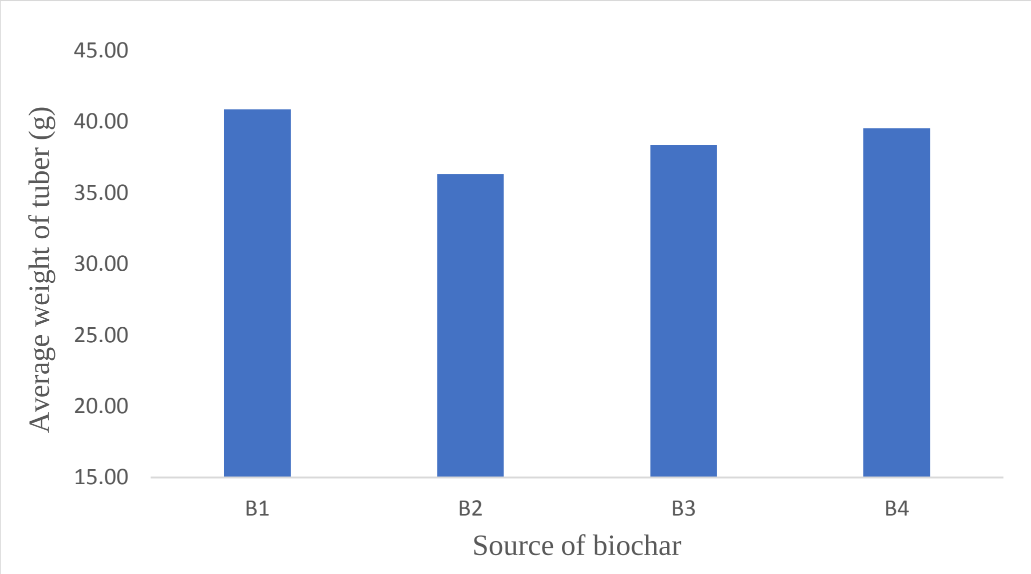


Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta) and V_3- BARI Alu-25 (Asterix).

Figure 5. Effect of variety on average weight of tuber of potato (LSD value = 1.86)

4.3.2 Effect of different sources of biochar

Average weight of tuber significantly varied among the different sources of biochar applications (Figure 6 and Appendix V). The maximum average weight of tuber (40.87 g) was observed from B_1 (Maize Cob) which was statistically similar to B_4 (39.54 g) while the lowest (36.33 g) was observed from B_2 (Mahogany wood) treatment. The result obtained from the present study was dissimilar with Afrina (2017).



Note: B_1 – Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}) and B_4 - Cow dung (5.00 t ha^{-1}).

Figure 6. Effect of source of biochar on average weight of tuber of potato (LSD value = 1.86)

4.3.3 Interaction effect of variety and sources of biochar

Interaction of different varieties and sources of biochar had significant effect on average weight of tuber (Table 2 and Appendix V). The maximum average weight of tuber (42.70 g) was recorded in V_2B_1 treatment combination which was statistically similar to V_2B_4 (41.48 g). On the other hand, the minimum average weight of tuber (34.53 g) was observed in V_3B_2 treatment combination.

Table 2. Interaction effects of variety and source of biochar on number of tuber hill^{-1}, average weight of tuber (g) and weight of tuber hill^{-1} (g) of potato

Treatment combination	No. of tuber hill^{-1}	Average weight of tuber (g)	Weight of tuber hill^{-1} (g)
V_1B_1	7.00 c	40.29 bc	282.03 cd
V_1B_2	3.67 g	36.12 e	156.52 i
V_1B_3	6.00 d	38.55 cd	231.30 f
V_1B_4	7.00 c	39.68 c	277.76 de
V_2B_1	6.33 d	42.70 a	270.43 e
V_2B_2	4.33 f	38.35 cd	140.62 j
V_2B_3	4.67 f	39.38 c	183.77 h
V_2B_4	5.33 e	41.48 ab	221.23 fg
V_3B_1	9.33 a	39.61 c	369.69 a
V_3B_2	6.33 d	34.53 f	218.69 g
V_3B_3	7.67 b	37.22 de	285.35 c
V_3B_4	8.00 b	37.47 de	299.76 b
LSD $_{(0.05)}$	**0.37**	**1.43**	**10.25**
CV (%)	**5.28**	**8.27**	**7.27**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

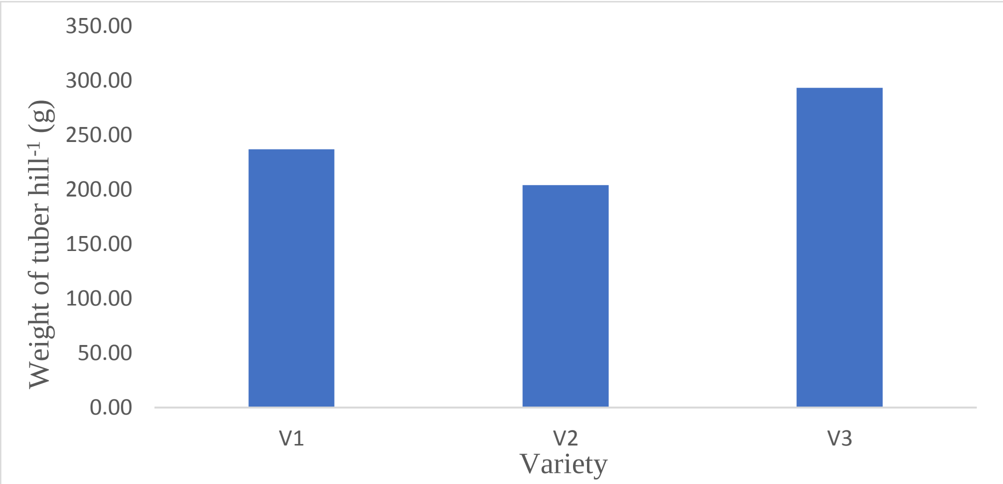
Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta), V_3- BARI Alu-25 (Asterix) and B_1 - Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}), B_4 - Cow dung (5.00 t ha^{-1}).

4.4 Weight of tuber hill^{-1} (g)

4.4.1 Effect of variety

Variety had significant effect on the weight of tuber hill^{-1} of potato (Appendix V and Figure 7). The highest weight of tuber hill^{-1} (293.37 g) was obtained from the variety ‘Asterix’ while the lowest (204.01 g) was found from the ‘Lady Rosetta’. The yields of different cultivars of potato were significantly different from each other reported by

Kundu *et al.* (2012). Similar trend of yield performance was also reported by Hossain (2011) and Das (2006). The probable reason for variation in yield due to the heredity of the variety, difference in agro-ecological condition and soils of the experimental site.

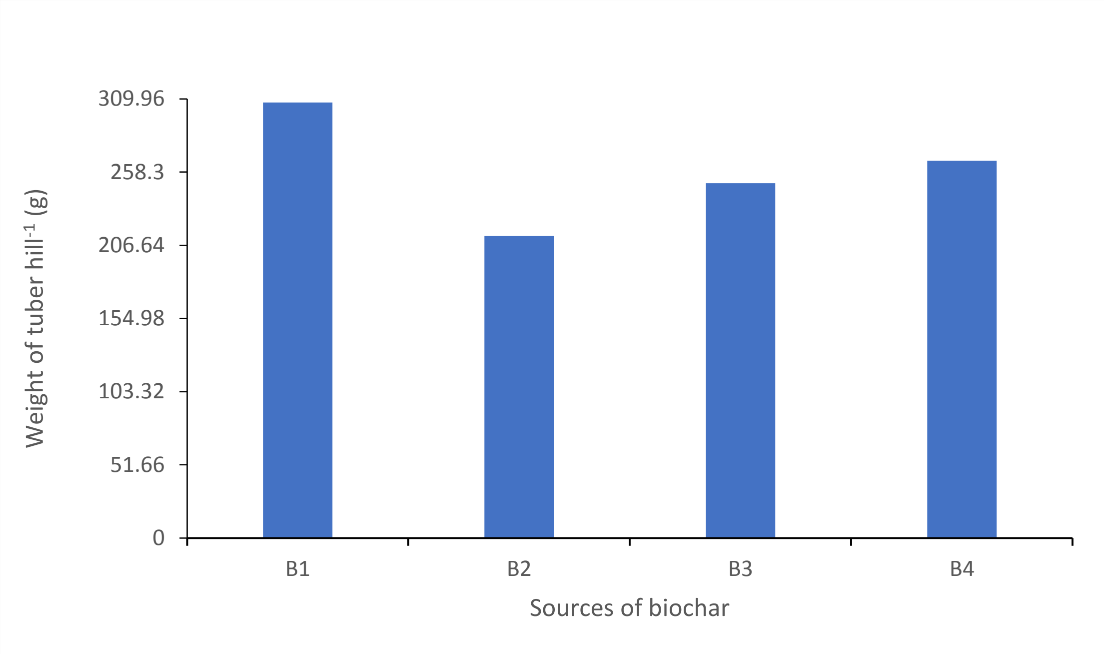


Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta) and V_3- BARI Alu-25 (Asterix).

Figure 7. Effect of variety on weight of tuber hill^{-1} of potato (LSD value = 13.28)

4.4.2 Effect of different sources of biochar

Different sources of biochar had significant effect on the weight of tuber hill^{-1} (Figure 8 and Appendix V). Results revealed that, treatment B_1 (Maize Cob) produced highest weight of tuber hill^{-1} (307.39 g) whereas, the lowest (213.13 g) one was obtained from B_2 (Mahogany wood). 44.23 % more weight of tuber was obtained from the plot treated with Maize Cob biochar (B_1) than the plot treated with Mahogany wood biochar (B_2). The higher yield might be attributed to vigorous plant growth, more tuber plant^{-1} and large tuber size. Indawan *et al.* (2018) reported that tobacco biochar application increased storage root weight, storage root dry weight and storage root yield.



Note: B_1 – Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}) and B_4 - Cow dung (5.00 t ha^{-1}).

Figure 8. Effect of source of biochar on weight of tuber hill^{-1} of potato (LSD value = 13.28)

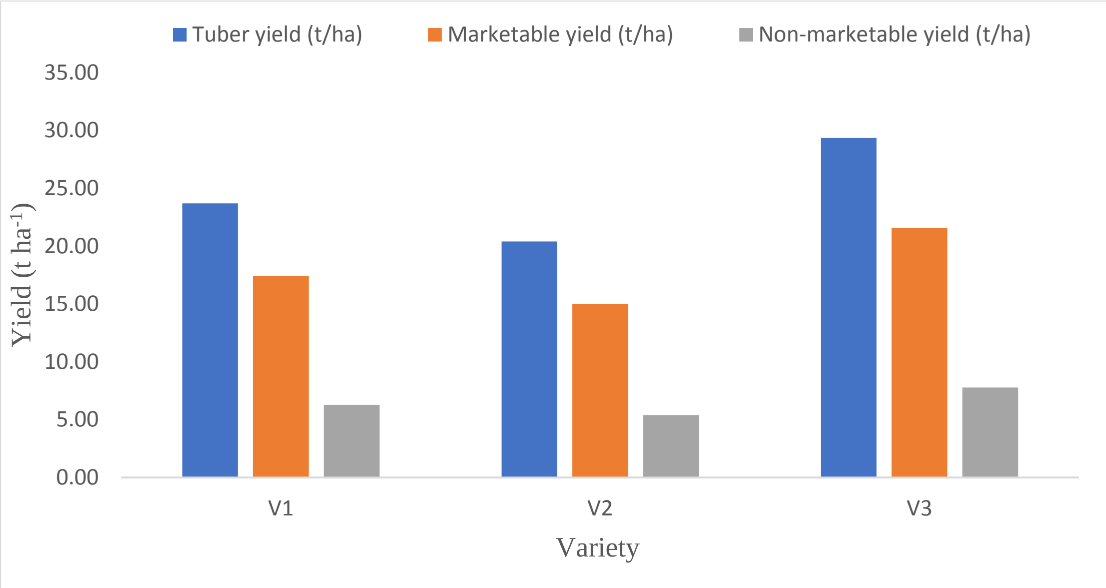
4.4.3 Interaction effect of variety and sources of biochar

Interaction of different varieties and sources of biochar had significant effect on weight of tuber hill^{-1} (g) (Table 2 and Appendix V). The highest weight of tuber hill^{-1} (369.69 g) was recorded in V_3B_1 treatment combination. On the other hand, the lowest weight of tuber hill^{-1} (140.62 g) was observed in V_2B_2 treatment combination.

4.5 Tuber yield (t ha^{-1})

4.5.1 Effect of variety

Potato tuber yield was significantly influenced by varietal variation (Figure 9 and Appendix VI). Results showed that, the V_3 (Asterix) produced maximum potato (29.34 t ha^{-1}) followed by V_1 (23.69 t ha^{-1}) and V_2 (Lady Rosetta) produced the minimum one (20.40 t ha^{-1}). 'Asterix' variety produced (28.35%) more potato than 'Lady Rosetta' variety. The variation in the production of potato might be due to genetic constituents of the crops. This might be due to genetic potentiality of potato cultivars. The results of our findings were also in line with the findings of Youseef *et al.* (2017) and Vakis (1990) who found that potato yield varied with varietal variation.

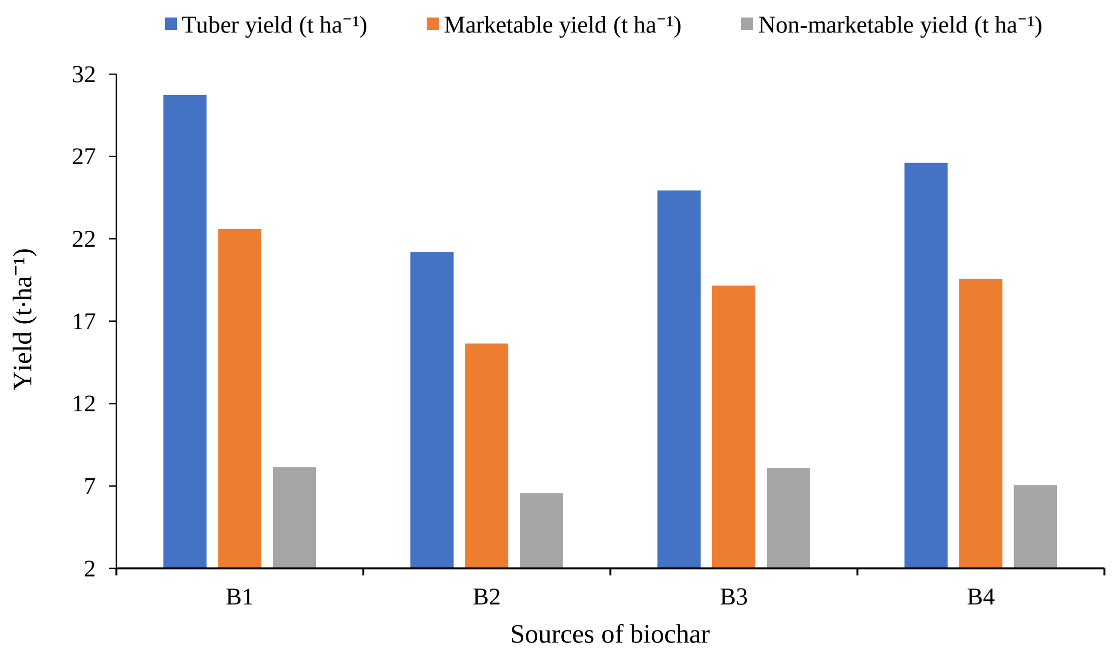


Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta) and V_3- BARI Alu-25 (Asterix).

Figure 9. Effect of variety on the yield (t ha^{-1}) of potato (LSD value = 1.61, 1.49 and 0.94)

4.5.2 Effect of different sources of biochar

Application of different sources of biochar had significant effect on the yield of tuber (Figure 10 and Appendix VI). Results revealed that, treatment B_1 (Maize Cob) produced maximum tuber yield (30.74 t ha^{-1}) whereas, the minimum (21.19 t ha^{-1}) one was obtained from B_2 (Mahogany wood). Gautam *et al.* (2017) indicated that the application of biochar along with FYM in fertile soils in hill farming systems of small holder farmers generally increased the crop yields in biochar and compost amended soils (Getachew, 2016 and Claudia, 2014). This might be due to biochar amendment being more effective in enhancing the vegetative growth of plants (Vaccari, 2015). Yang *et al.* (2015) reported that, the yield of the corn on the control soils without biochar weighed 0.5 t ha^{-1}. Study conducted by Olmo *et al.* (2014) revealed that biochar increased the yield by about 20%. Yilangai *et al.* (2014) reported that application of biochar together with nitrogen fertilizer enhanced biochar effect on crop growth and yield. This may be because biochar serves as a carrier substrate for nitrogen (N) which increases the effectiveness of biochar by retaining and preventing the leaching of N beyond the reach of plants. Biochar has also a potential to significantly improve durability of soil aggregates (Sun and Lu, 2014; Hale, 2013; Jeffery *et al*., 2011; Jha *et al*., 2010 and Lehmann *et al*., 2009). Another study on maize reported by Major *et al.* (2010) showed that maize increased to about 140% during the fourth year of biochar application and this was attributed to increased pH and nutrient retention in soil. Chan *et al*. (2008) reported 96% increase in radish yields from application of biochar in a greenhouse experiment and suggested that this increased yield was largely due to the ability of biochar to increase N availability. In addition, Yamato *et al.* (2006) revealed that with 2 t ha^{-1} RB addition, sweet potato yield was 37.62 t ha^{-1} and with 4 t ha^{-1} biochar that was 38.94 t ha^{-1} while without biochar the yield was only 33 t ha^{-1}.



Note: B_1 – Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}) and B_4 - Cow dung (5.00 t ha^{-1}).

Figure 10. Effect of biochar on the yield (t ha^{-1}) of potato (LSD value = 1.61, 1.49 and 0.94 for V_1, V_2, V_3 variety)

4.5.3 Interaction effect of variety and sources of biochar

Interaction between different varieties and sources of biochar played an important role for promoting the yield. Yield of tuber was significantly influenced by the interaction effects of different varieties and sources of biochar (Appendix VI and Table 3). Among the treatments, the maximum (36.97 t ha^{-1}) tuber yield was observed in Asterix variety with maize cob biochar (V_3B_1) treatment combination. On the other hand, the minimum (14.6 t ha^{-1}) tuber yield was found from Lady Rosetta and Mahogany wood biochar (V_2B_2) treatment combination.

4.6 Marketable yield (t ha^{-1})

4.6.1 Effect of variety

Marketable potato yield was significantly differed by different potato varieties (Figure 9 and Appendix VI). Results revealed that, the V_3 (Asterix) produced highest marketable potato (21.56 t ha^{-1}) and V_2 (Lady Rosetta) produced the lowest marketable potato (14.99 t ha^{-1}). 'Asterix' variety produced (26.08 %) more marketable potato than 'Lady Rosetta'. The variation in the production of potato might be due to genetic constituents of the crops.

4.6.2 Effect of different sources of biochar

Different sources of biochar had significant influenced on the marketable yield of potato (Figure 10 and Appendix VI). Results revealed that, treatment B_1 (Maize Cob) produced highest marketable yield (22.59 t ha^{-1}) whereas, the lowest (15.64 t ha^{-1}) one was obtained from B_2 (Mahogany wood). 44.43% more marketable yield of potato was obtained from the plot treated with maize cob biochar (B_1) than the plot treated with Mahogany wood biochar (B_2). Gautam *et al.* (2017), Alburquerque *et al*. (2013) and Asai *et al*. (2009) reported that higher AP levels of the biochar amended soils could be due to improved availability of phosphorous as a result of biochar addition which also could be the reason for better production of marketable potato. Timilsina *et al*. (2017) and Collins *et al*. (2013) also reported that increased biochar application had increased quality potato tuber. Youseef *et al.* (2017) reported that marketable yield was significantly increased with increasing biochar application rates up to 5 m^3 ha^{-1}. Ding *et al.* (2016) reported that organic matter and inorganic salt, such as humic-like and fluvic-like substances and available N, P, and K, can serve as fertilizer and be assimilated by plants and microorganisms. Chan *et al.* (2008) reported significant increase in radish yields from application of biochar and this increased yield was due to the biochar's ability to increase N availability to plants.

4.6.3 Interaction effect of variety and sources of biochar

Interaction of different varieties and sources of biochar had significant effect on marketable yield of potato (Table 3 and Appendix VI). The highest marketable yield (27.17 t ha^{-1}) was recorded in V_3B_1 (Asterix with Maize Cob biochar) combination treatment. On the other hand, the lowest marketable yield (10.34 t ha^{-1}) was observed in V_2B_2 (Lady Rosetta with Mahogany wood) combination treatment which followed by V_1B_2 (11.50 t ha^{-1}).

4.7 Non-marketable yield (t ha^{-1})

4.7.1 Effect of variety

Non-marketable potato yield was significantly differed by different potato varieties (Figure 9 and Appendix VI). Results revealed that, the 'Asterix' (V_3) produced highest non-marketable potato (7.77 t ha^{-1}). On the other hand, the 'Lady Rosetta' (V_2) produced the lowest non-marketable potato (5.41 t ha^{-1}). The variation in the production of potato might be due to genetic constituents of the crops.

4.7.2 Effect of different sources of biochar

Different sources of biochar had significant influenced on the non-marketable yield of potato (Figure 10 and Appendix VI). Results exposed that, treatment B_1 (Maize Cob) produced height non-marketable potato (8.15 t ha^{-1}). On the other hand, the lowest non-marketable potato (6.56 t ha^{-1}) one was obtained from B_2 (Mahogany wood) treatment.

4.7.3 Interaction effect of variety and sources of biochar

Interaction of different potassium sources and biochar levels had significant effect on non-marketable yield of potato (Table 3 and Appendix VI). The highest non-marketable potato (9.80 t ha^{-1}) was recorded in V_3B_1 combination treatment. On the other hand, the lowest non-marketable yield of potato (3.73 t ha^{-1}) was observed in V_2B_2 combination treatment.

Table 3. Interaction effects of variety and source of biochar on the yield (t ha)of potato

Treatment combination	Tuber yield (t ha^{-1})	Marketable yield (t ha^{-1})	Non-marketable yield (t ha^{-1})
V_1B_1	28.20 cd	20.73 cd	7.47 c
V_1B_2	15.65 g	11.50 g	4.15 h
V_1B_3	23.13 e	17.00 e	6.13 e
V_1B_4	27.78 cd	20.42 cd	7.36 cd
V_2B_1	27.04 d	19.88 d	7.17 d
V_2B_2	14.06 h	10.34 h	3.73 i
V_2B_3	18.38 f	13.51 f	4.87 g
V_2B_4	22.12 e	16.26 e	5.86 f
V_3B_1	36.97 a	27.17 a	9.80 a
V_3B_2	21.87 e	16.07 e	5.80 f
V_3B_3	28.54 c	20.97 c	7.56 c
V_3B_4	29.98 b	22.03 b	7.94 b
LSD $_{(0.05)}$	**1.34**	**1.04**	**0.27**
CV (%)	**7.37**	**6.72**	**7.03**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta), V_3- BARI Alu-25 (Asterix) and B_1 - Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}), B_4 - Cow dung (5.00 t ha^{-1}).

4.8 Specific gravity (g cm^{-3})

4.8.1 Effect of variety

In present study varieties had insignificant effect on specific gravity (Appendix VII and Table 4). The numerically highest specific gravity (1.059 g cm^{-3}) was obtained from the 'Asterix' variety followed by 'Courage' (1.052 g cm^{-3}) whereas, the lowest (1.048 g cm^{-3}) specific gravity was found from the 'Lady Rosetta' variety. Asmamaw *et al.* (2010) and Elfnesh *et al.* (2011) reported a specific gravity ranging them 1.06 to 1.09 and 1.08 to 1.10, respectively in two separate experiments with nine potato varieties during evaluated their processing quality. Ekin (2011) also reported specific gravity values ranging from 1.07 to 1.08 from a study of eight potato varieties over two consecutive years.

4.8.2 Effect of different sources of biochar

Specific gravity of tuber varied significantly with different sources of biochar application (Table 5 and Appendix VII). The highest specific gravity of tuber was recorded (1.067 g cm^{-3}) from B_1 treatment while, the lowest (1.048 g c m^{-3}) was found from B_2, B_3 and B_4 treatment. Similar findings were also reported by Bethee (2018) and Afrina (2017) who reported that biochar at 10.00 t ha^{-1} increased specific gravity in potato.

4.8.3 Interaction effect of variety and sources of biochar

The specific gravity of tuber due to different varieties and sources of biochar application was found statistically significant of potato (Table 6 and Appendix VII). The highest specific gravity of tuber (1.070 g cm^{-3}) exhibited by V_1B_1 and V_3B_1 combined treatment which was statistically similar to V_2B_1 (1.061 g cm^{-3}) and V_3B_3 (1.060 g cm^{-3}). On the other hand, the lowest specific gravity of tuber (1.041 g cm^{-3}) was exhibited by V_2B_3 combined treatment which was statistically similar to V_1B_3 (1.043 g cm^{-3}), V_2B_4 (1.043 g cm^{-3}), V_2B_2 (1.045 g cm^{-3}), V_1B_4 (1.046 g cm^{-3}), V_1B_2 (1.047 g cm^{-3}) and V_3B_2 (1.052 g cm^{-3}).

4.9 Dry matter content (%)

4.9.1 Effect of variety

Dry matter content showed insignificant variations among the potato varieties (Appendix VII and Table 4). The numerically maximum dry matter content of tuber (21.02 %) was recorded from the variety 'Axterix'. On the other hand, the numerically minimum tuber dry matter content (20.31 %) was recorded from 'Lady Rosetta'. The variation in dry matter content among the potato varieties were also observed by Suyre *et al.* (1975), Lana *et al.* (1970) and Capezio (1987). Variation in tuber dry matter content may be attributed to cultivars inherent difference in the production of total solids. Burton (1966) reported that genetic differences among varieties play a role in their ability to produce high solids when grown on the same test plot. Dry matter content is subjected to the influence of both the environment and genotypes (Miller *et al.*, 1975; Tai and Coleman, 1999).

4.9.2 Effect of different sources of biochar

Tuber dry matter content (%) of potato significantly influenced different sources of biochar application (Table 5 and Appendix VII). The maximum tuber dry matter (22.27 %) was recorded from B_1 treatment and the minimum tuber dry matter (18.99 %) was recorded from B_2 treatment. This result had agreements with the findings of Afrina (2017) and Youseef *et al.* (2017) who reported that the increases of potato dry matter may be attributed to that fertilizing with biochar positively increased number of main stems, leaves and tubers, as well as leaf area plant^{-1}.

4.9.3 Interaction effect of variety and sources of biochar

Interaction effect of variety and sources of biochar application had significant effect of tuber dry matter content (%) of potato (Table 6 and Appendix VII). The maximum tuber dry matter of (22.67 %) was recorded in V_3B_1 (Asterix variety with Maize Cob biochar) combination treatment which was statistically similar to V_1B_1 (22.13 %). On the other hand, the minimum tuber dry matter of potato (18.37 %) was observed in V_2B_2 (Lady Rosetta variety with Mahogany wood biochar) combination treatment.

Table 4. Effects of variety on the processing qualities of potato

Varieties	Specific gravity (g cm^{-3})	Dry matter content (%)	Total soluble solid (˚brix)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
V_1	1.052	20.74	5.39	14.60 b	0.278 c
V_2	1.048	20.31	5.61	16.13 a	0.478 a
V_3	1.059	21.02	5.49	15.50 ab	0.388 b
LSD $_{(0.05)}$	**NS**	**NS**	**NS**	**1.49**	**0.035**
CV (%)	**2.93**	**8.27**	**3.51**	**6.82**	**7.82**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta) and V_3- BARI Alu-25 (Asterix).

4.10 Total soluble solid (˚brix)

4.10.1 Effect of variety

Varieties differed insignificantly between themselves regarding total soluble solid (TSS) (Appendix VII and Table 4). The numerically highest TSS (5.61 %) was recorded from the variety 'Lady Rosetta' (V_2) and followed by 'Asterix' (5.49 %) whereas, the numerically lowest (5.39 %) was obtained from the variety 'Courage'. Study referred that the variety 'Lady Rosetta' expressed best result in terms of TSS.

4.10.2 Effect of different sources of biochar

Biochar sources had insignificant influenced on the total soluble solid (TSS) (Table 5 and Appendix VII). Results exposed that, treatment B_1 (Maize Cob) produced numerically the highest TSS (5.72 %) followed by B_4 (5.61 %) and B_3 (5.42 %) whereas, the numerically lowest one (5.25 %) with B_2 (Mahogany wood). Similar findings were reported by Youseef *et al.* (2017) who reported that biochar at 2.5 $m^3 fed^{-1}$ decreasedthe total soluble solid content in potato. Akhtar *et al*. (2014) found that biochar addition improved quality of tomato fruits.

4.10.3 Interaction effect of variety and sources of biochar

Significant variation was found among different varieties and sources of biochar application on total soluble solid of tuber (Table 6 and Appendix VII). The highest total soluble solid of tuber (5.81%) exhibited by V_2B_1 treatment combination which was statistically identical to V_2B_4 (5.80%) and statistically similar to V_3B_1 (5.73 %), V_1B_1 (5.63 %), V_3B_4 (5.59 %), V_2B_3 (5.52 %), V_1B_4 (5.43 %) and V_3B_3 (5.41 %). On the other hand, the lowest total soluble solid (5.18 %) was exhibited by V_1B_2 combination treatment which was statistically similar to V_3B_2 (5.25 %), V_2B_2 (5.32 %) and V_1B_3 (5.33 %).

Table 5. Effects of source of biochar on the processing qualities of potato

Source of biochar	Specific gravity (g cm^{-3})	Dry matter content (%)	Total soluble solid (°brix)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
B_1	1.067 a	22.27 a	5.72	16.73 a	0.413 a
B_2	1.048 b	18.99 d	5.25	14.00 c	0.333 c
B_3	1.048 b	20.30 c	5.42	14.90 bc	0.373 b
B_4	1.048 b	21.19 b	5.61	16.00 ab	0.403 ab
LSD $_{(0.05)}$	**0.013**	**0.72**	**NS**	**1.49**	**0.035**
CV (%)	**2.93**	**8.27**	**3.51**	**6.82**	**7.82**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

Note: B_1 – Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}) and B_4 - Cow dung (5.00 t ha^{-1}).

4.11 Starch content (mg g^{-1} FW)

4.11.1 Effect of variety

Significant variation was found on starch content on potato due to varietal variation (Appendix VII and Table 4). The maximum starch content on potato (16.13 mg g^{-1} FW) was attained by potato variety 'Lady Rosetta' (V_2) which was statistically similar to V_3 (15.50 mg g^{-1} FW) and the minimum starch content on potato (14.60 mg g^{-1} FW) was attained by potato variety 'Courage' (V_1).

4.11.2 Effect of different sources of biochar

Significant variation was found on starch content on potato due to different biochar sources (Table 5 and Appendix VI). The maximum starch content on potato (16.73 mg g^{-1} FW) was attained by B_1 (Maize Cob) which was statistically similar to B_4 (16.00 mg g^{-1} FW). On the other hand, the minimum starch content on potato (14.00 mg g^{-1} FW) was attained by B_2 (Mahogany wood) which was statistically similar to B_3 (14.90 mg g^{-1} FW). Similar findings were also reported by Bethee (2018) and Youseef *et al.* (2017) who reported that biochar at 2.5 $m^3 fed^{-1}$ increased starch content in potato. Akhtar *et al.* (2014) found that biochar addition improved quality of tomato fruits.

4.11.3 Interaction effect of variety and sources of biochar

Significant variation was found on starch content on potato due to interaction effect of different potato varieties and sources of biochar application (Table 6 and Appendix VII). The maximum starch content on potato (17.50 mg g^{-1} FW) was attained by V_2B_4 treatment combination which was statistically similar to V_3B_1 (16.90 mg g^{-1} FW), V_2B_3 (16.50 mg g^{-1} FW) and V_3B_4 (16.40 mg g^{-1} FW). On the other hand, the minimum starch content on potato (13.70 mg g^{-1} FW) was attained by V_1B_2 treatment combination which was statistically similar with V_1B_3 (13.80 mg g^{-1} FW), V_3B_2 (14.10 mg g^{-1} FW), V_2B_2 (14.20 mg g^{-1} FW), V_3B_3 (14.60 mg g^{-1} FW) and V_1B_4 (15.10 mg g^{-1} FW).

4.12 Reducing sugar (mg g^{-1} FW)

4.12.1 Effect of variety

Significant variation was found on reducing sugar (mg g^{-1} FW) on potato due to varietal variation (Table 4 and Appendix VII). The highest reducing sugar on potato (0.478 mg g^{-1} FW) was attained by potato variety 'Lady Rosetta' (V_2) and the lowest ones (0.278 mg g^{-1} FW) was attained by potato variety 'Courage' (V_1).

4.12.2 Effect of different sources of biochar

Reducing sugar (mg g^{-1} FW) has significantly influenced different sources of biochar application (Table 5 and Appendix VII). The highest reducing sugar value (0.413 mg g^{-1} FW) was recorded from the "Maize Cob biochar" (B_1) treatment which was statistically similar with B_4 (0.403 mg g^{-1} FW) whereas, the lowest (0.333 mg g^{-1} FW) was found from the "Mahogany wood biochar" (B_2) treatment.

4.12.3 Interaction effect of variety and sources of biochar

Interaction of different potato varieties and sources of biochar had significant effect of reducing sugar content (mg g^{-1} FW) of potato (Table 6 and Appendix VII). The highest reducing sugar content (0.510 mg g^{-1} FW) was recorded in V_2B_1 which was statistically identical with V_2B_3 (0.490 mg g^{-1} FW) and V_2B_4 (0.490 mg g^{-1} FW) whereas, the lowest value of potato (0.230 mg g^{-1} FW) was observed in V_1B_2 combination treatment which was statistically identical with V_1B_3 (0.250 mg g^{-1} FW).

Table 6. Interaction effects of variety and source of biochar on the processing qualities of potato

Treatment combination	Specific gravity (g cm^{-3})	Dry matter content (%)	Total soluble solid (°brix)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
V_1B_1	1.070 a	22.13 ab	5.63 a-c	15.80 bc	0.320 e
V_1B_2	1.047 cd	19.23 f	5.18 d	13.70 d	0.230 f
V_1B_3	1.043 cd	20.50 d	5.33 b-d	13.80 cd	0.250 f
V_1B_4	1.046 cd	21.09 cd	5.43 a-d	15.10 cd	0.310 e
V_2B_1	1.061 ab	22.00 b	5.81 a	17.50 a	0.510 a
V_2B_2	1.045 cd	18.37 g	5.32 b-d	14.20 cd	0.420 b
V_2B_3	1.041 d	19.88 e	5.52 a-d	16.30 b	0.490 a
V_2B_4	1.043 cd	21.00 cd	5.80 a	16.50 ab	0.490 a
V_3B_1	1.070 a	22.67 a	5.73 ab	16.90 ab	0.410 b
V_3B_2	1.052 b-d	19.38 ef	5.25 cd	14.10 cd	0.350 d
V_3B_3	1.060 a-c	20.54 d	5.41 a-d	14.60 cd	0.380 c
V_3B_4	1.054 bc	21.48 c	5.59 a-c	16.40 ab	0.410 b
LSD $_{(0.05)}$	**0.011**	**0.61**	**0.43**	**1.24**	**0.026**
CV (%)	**2.93**	**8.27**	**3.51**	**6.82**	**7.82**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta), V_3- BARI Alu-25 (Asterix) and B_1 - Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}), B_4 - Cow dung (5.00 t ha^{-1}).

4.13 Grading of potato (t ha^{-1})

4.13.1 Yield of potato for canned production (t ha^{-1}) (< 30 mm)

4.13.1.1 Effect of variety

Potato variety exerted significant difference on yield of potato for canned production (< 30 mm) (Appendix VIII and Figure 11). The highest canned potato (8.51 t ha^{-1}) was produced by the 'Asterix' variety and the lowest canned potato (5.10 t ha^{-1}) was produced by the 'Lady Rosetta' variety which was statistically similar to V_1 (5.21 t ha^{-1}).

4.13.1.2 Effect of different sources of biochar

The yields of potato for canned production (< 30 mm) was significantly varied by the different biochar sources (Appendix VIII and Figure 12). The highest canned production (7.90 t ha^{-1}) was obtained from B_1 treatment and the lowest (4.43 t ha^{-1}) was obtained from B_2 treatment.

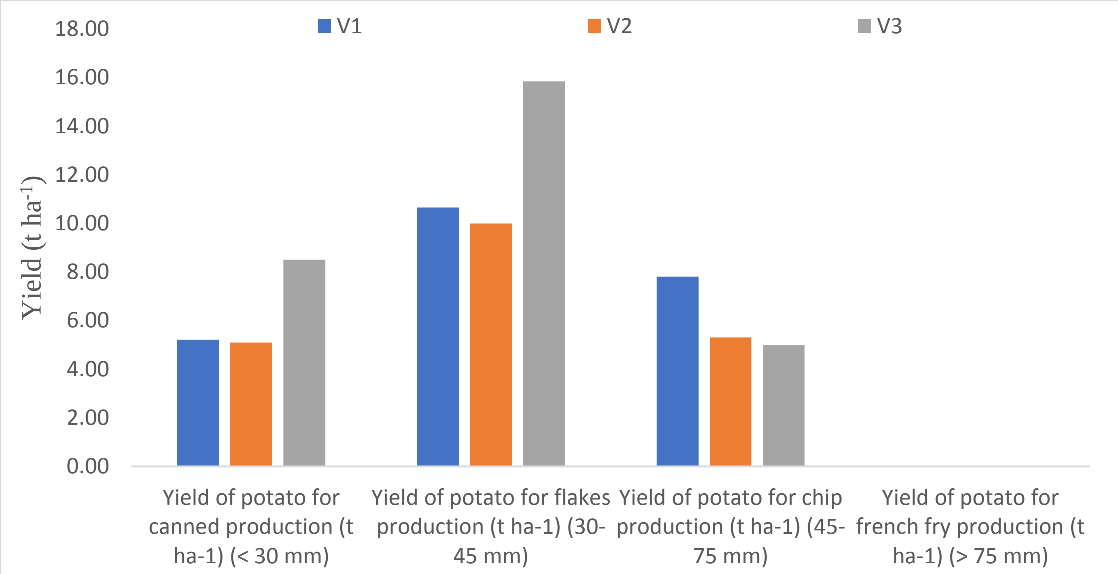
4.13.1.3 Interaction effect of variety and sources of biochar

The yields of potato for canned production (< 30 mm) due to different potato varieties and sources of biochar application was found statistically significant (Table 7 and Appendix VIII). The highest canned production (10.37 t ha^{-1}) exhibited by V_3B_1 treatment combination whereas, the lowest (3.44 t ha^{-1}) was exhibited by V_1B_2 treatment combination which was statistically similar to V_2B_2 (3.52 t ha^{-1}).

4.13.2 Yield of potato for flakes production (t ha^{-1}) (30-45 mm)

4.13.2.1 Effect of variety

The yield of potato for flakes production (30-45 mm) was significantly differed by the varietal difference (Appendix VIII and Figure 11). The highest flakes potato yield (15.84 t ha^{-1}) was recorded from the 'Asterix' (V_3) whereas the lowest one (10.00 t ha^{-1}) was recorded from 'Lady Rosetta' (V_2).



Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta) and V_3- BARI Alu-25 (Asterix).

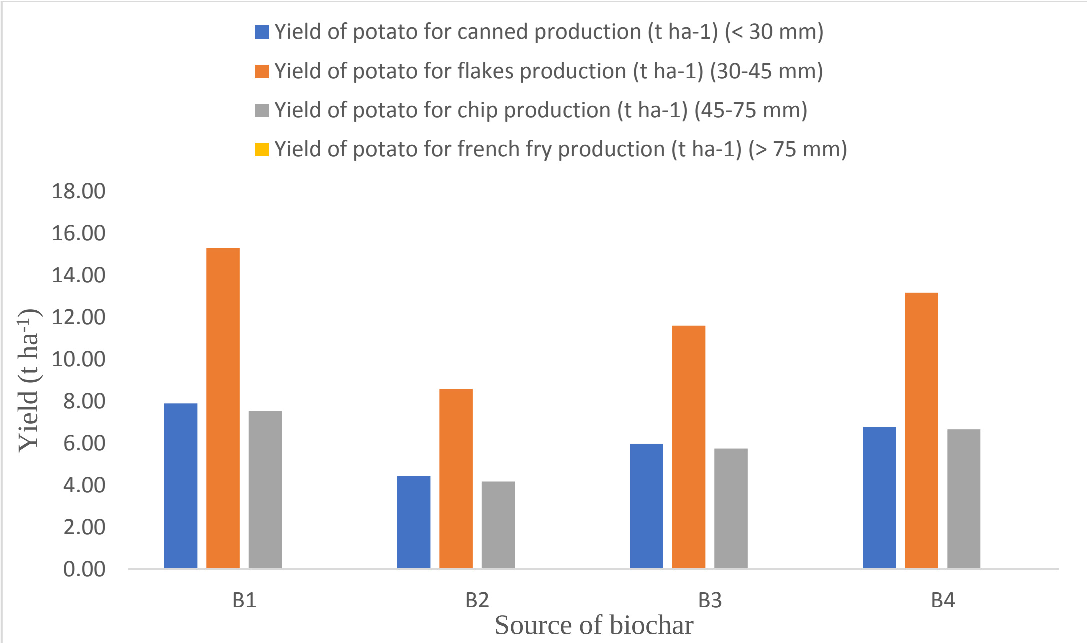
Figure 11. Effect of variety on the yield of potato for different processing purpose (LSD value = 0.34, 0.47, 0.59 and Non-significant for V_1, V_2, V_3 variety)

4.13.2.2 Effect of different sources of biochar

The yields of potato for flakes production (30-45 mm) was significantly influenced by the different sources of biochar (Figure 11 and Appendix VIII). The highest flakes production (15.30 t ha^{-1}) was obtained from B_1 treatment and the lowest ones (8.58 t ha^{-1}) was obtained from B_2 treatment. This result had agreements with the findings of Youseef *et al.* (2017) who reported that potato yield for flakes production was significantly increased with increasing biochar application rates up to 5 m^3 ha^{-1}.

4.13.2.3 Interaction effect of variety and sources of biochar

The yields of potato for flakes production (30-45 mm) due to different potato varieties and sources of biochar application was found statistically significant (Table 7 and Appendix VIII). The highest flakes production (19.96 t ha^{-1}) exhibited by V_3B_1 treatment combination whereas, the lowest ones (6.89 t ha^{-1}) was exhibited by V_2B_2 treatment combination.



Note: B_1 – Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}) and B_4 - Cow dung (5.00 t ha^{-1}).

Figure 12. Effect of biochar the yield of potato for different processing purpose (LSD value = 0.34, 0.47, 0.59 and Non-significant for B_1, B_2, B_3, B_4 biochar)

4.13.3 Yield of potato for chips production (t ha^{-1}) (45-75 mm)

4.13.3.1 Effect of variety

Potato variety exerted significant influence on yield of potato for chips production (Figure 11 and Appendix VIII). The maximum chips potato (7.82 t ha^{-1}) was produced by the 'Courage' (V_1) variety. On the other hand, the minimum chips potato (4.99 t ha^{-1}) was produced by the 'Asterix' (V_3) variety which was statistically identical to V_2 (5.30 t ha^{-1}).

Table 7. Interaction effects of variety and source of biochar on the yield of potato for different processing purpose

Treatment combination	Yield of potato for canned production (t ha^{-1}) (< 30 mm)	Yield of potato for flakes production (t ha^{-1}) (30-45 mm)	Yield of potato for chip production (t ha^{-1}) (45-75 mm)	Yield of potato for French fry production (t ha^{-1}) (> 75 mm)
V_1B_1	6.20 ef	12.69 e	9.31 a	NF
V_1B_2	3.44 j	7.04 j	5.17 f	NF
V_1B_3	5.09 h	10.41 h	7.63 b	NF
V_1B_4	6.11 f	12.50 e	9.17 a	NF
V_2B_1	6.76 d	13.25 d	7.03 c	NF
V_2B_2	3.52 j	6.89 k	3.66 h	NF
V_2B_3	4.59 i	9.00 i	4.78 g	NF
V_2B_4	5.53 g	10.84 g	5.75 e	NF
V_3B_1	10.72 a	19.96 a	6.28 d	NF
V_3B_2	6.34 e	11.81 f	3.72 h	NF
V_3B_3	8.28 c	15.41 c	4.85 g	NF
V_3B_4	8.69 b	16.19 b	5.10 f	NF
LSD $_{(0.05)}$	0.22	0.23	0.35	-
CV (%)	3.71	4.28	6.29	-

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta), V_3- BARI Alu-25 (Asterix) and B_1 - Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}), B_4 - Cow dung (5.00 t ha^{-1}).
NF = Not found

4.13.3.2 Effect of different sources of biochar

The yields of potato for chips production (45-75 mm) was significantly affected by the different sources of biochar (Figure 12 and Appendix VIII). The maximum chips production (7.54 t ha^{-1}) was obtained from B_1 (Maize Cob biochar) treatment. On the other hand, the minimum chips production (4.18 t ha^{-1}) was obtained from B_2 (Mahogany wood biochar) treatment. This result had agreements with the findings of Youseef *et al.* (2017) who reported that chips production was significantly increased with increasing biochar application rates up to 5 m^3 fed^{-1}.

4.13.3.3 Interaction effect of variety and sources of biochar

The yields of potato for chips production (45-75 mm) due to different potato varieties and sources of biochar application was found statistically significant (Table 7 and Appendix VIII). The maximum chips production (9.31 t ha^{-1}) exhibited by V_1B_1 treatment combination which was statistically identical to V_1B_4 (9.17 t ha^{-1}). On the other hand, the minimum (3.66 t ha^{-1}) was exhibited by V_2B_2 treatment combination which was statistically identical to V_3B_2 (3.72 t ha^{-1}).

4.14 Soil pH

4.14.1 Effect of different sources of biochar

Significant variation was found on soil pH of the soils collected from the experimental plot due to different sources of biochar (Table 8 and Appendix IX). The highest soil pH (6.48) was recorded when the plots treated with cow dung biochar (B_4) and the lowest one (5.90) was recorded when the plot treated with Cow dung + saw dust (B_3). Biochar with a high liming equivalence typically increases the pH value in acidic soils, whereas the actual increase is dependent on the pH-buffering capacity of the respective soil (Mukherjee and Lal, 2014). The liming effect of biochar is positive for acidic soils, especially if they are affected by metal toxicity or nutrient deficiencies. Further, pH in soil increases more when biochar rich in ash is used. In case of disproportionally high soil pH values, liming effect can also have adverse effects (Alburquerque *et al.*, 2014). The increase in pH value following biochar application is usually higher in sandy and loamy soils than in clayey soils (De Gryze, 2010). The buffering capacity of a finely textured clay soil is usually higher than that of a coarse-textured soil. This entails that larger amounts of liming resources for clayey soils are required in order to raise the pH to a certain value when compared to a soil with low buffering capacity. Increases in soil pH have been observed in response to peanut biochar addition under greenhouse conditions (Chang *et al*., 2016; Jiang *et al*., 2014; Wang *et al*., 2014; Yuan *et al.*, 2011 and Novak *et al.*, 2009) and in response to pine biochar (Wang *et al.*, 2016 and Robertson *et al*., 2012). Gautam *et al.* (2017) and Barrow, (2012) reported that the increase in soil pH could be due to the alkaline nature of biochar which, upon addition to the soil could have contributed towards reducing the acidic level of soil. The alkaline nature of biochar resulted in a rise of soil pH (Streubel *et al*., 2011, Shinogi and Kanri, 2003 and Abe *et al*., 1998). Most biochars have high pH (8-10) which has been shown to have a liming effect, increasing pH in sandy soils 0.5 to 1 unit following additions of 5 to 20 Mg ha^{-1} (Streubel *et al*., 2011; Collins, 2009; Novak *et al*., 2009 and Rodriquez *et al*., 2009). Rodriguez *et al*. (2009) used biochar produced from sugarcane bagasse to increase soil pH from 4.0-4.5 to 6.0-6.5 in a maize trial in Colombia. The result of our experiment was in line with the findings of Indawan *et al.* (2018); Yang *et al.* (2015); Collins *et al.* (2013); Dou *et al*. (2012) and Moses (2011) reported that Biochar had the potentiality to increase soil pH.

4.14.2 Interaction effect of variety and sources of biochar

Significant variation was found on soil pH of the soils collected from the experimental plot due to interaction effect of variety and different sources of biochar (Table 9 and Appendix IX). The highest soil pH (6.61) was attained by treatment combination V_3B_4 and the lowest one (5.56) was attained by treatment combination V_1B_2.

Table 8. Effects of source of biochar on the soil characters of experimental plots

Source of biochar	Soil pH	Soil organic carbon	Nitrogen content (%)	Potassium content (%)
B_1	6.26 b	0.66 b	0.041	0.170 b
B_2	6.19 c	0.65 b	0.039	0.164 c
B_3	5.90 d	0.53 c	0.040	0.149 d
B_4	6.48 a	0.70 a	0.042	0.178 a
$LSD_{(0.05)}$	**0.06**	**0.03**	**NS**	**0.004**
CV (%)	**7.25**	**8.93**	**4.56**	**3.86**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

Note: B_1 – Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}) and B_4 - Cow dung (5.00 t ha^{-1}).

4.15 Soil organic carbon

4.15.1 Effect of different sources of biochar

The organic carbon content in soil collected from the experimental plot was significantly influenced by the different sources of biochar (Table 8 and Appendix IX). The highest organic carbon (0.70) was obtained where Cow dung biochar (B_4) was applied and the lowest organic carbon (0.53) was obtained where (Cow dung + saw dust) (B_3) was applied. Diatta (2016) reported that biochar application to soils significantly increased total soil C compared to un-amended soils. Xu *et al*. (2015) found that addition of peanut shell biochar increased total soil C while Wang *et al.* (2016) observed similar results after application of pine biochar. The increases in total soil C in biochar-amended soils are readily explained by the large addition of C with biochar treatments. High inputs of C also may limit the decomposition of native soil organic matter because of change in C/N ratio, contributing to the greater concentrations of C in soil (Krapfl *et al*., 2014 and Lehmann *et al*., 2006). Timilsina *et al*. (2017) reported that the highest (2.915%) soil organic matter was obtained from 20 Mg ha^{-1} biochar application which was significantly higher than other treatments, and it was the lowest (1.165%) from no biochar application. Lehmann (2007) and Van Zwieten *et al.* (2010) reported high organic carbon in soil treated with biochar. The results of our findings were in line with the findings of Indawan *et al.* (2018); Yang *et al.* (2015); Borchard *et al.* (2014); Zheng *et al*. (2013) and Baronti *et al*. (2010) who reported that soil amended with biochar increased the soil organic carbon.

4.15.2 Interaction effect of variety and sources of biochar

The organic carbon content in soil collected from the experimental plot was significantly influenced by the interaction effect of variety and different biochar levels (Table 9 and Appendix IX). The highest organic carbon (0.88) was obtained from V_3B_4 treatment combination and the lowest value for organic carbon (0.43) was obtained from treatment combination V_1B_2 which was statistically identical to V_3B_1 (0.45) and V_1B_4 (0.52).

4.16 Nitrogen content (%) in soil

4.16.1 Effect of different sources of biochar

The nitrogen content in soil was not significantly affected by the different sources of biochar (Table 8 and Appendix IX). Numerically the maximum nitrogen content in soil (0.042 %) was obtained from B_4 treatment whereas, numerically the minimum ones (0.039 %) was obtained from B_2 treatment. Similar results were not also reported by Timilsina *et al*. (2017) who concluded that the effects of biochar application on nitrogen content in soil were highly significant. Addition of different doses of biochar had higher nitrogen contents of soil compared with without addition of biochar. The highest nitrogen content (1.2 g kg^{-1}) was found from 20 kg ha^{-1} biochar application. The lowest (0.7 g kg^{-1}) nitrogen content was obtained from without biochar amended soil. The observed increase in N contents of soil due to application of biochar could be due to the presence of high contents of N in biochar. Chan *et al*. (2008) and Lehmann *et al.* (2003) also reported the addition of biochar to soil increased total N in soil. Diatta (2016) reported that biochar application to soils significantly increased total soil N compared to un-amended soils. Xu *et al.* (2015) revealed that addition of peanut shell biochar increased total soil N while Wang *et al.* (2016) observed similar results after application of pine biochar. Greater total soil N in biochar-amended soils also could be a result of N immobilization (Lehmann *et al*., 2003; Rajkovich *et al*., 2012 and Wang *et al*., 2015) due to the high C/N ratio of the peanut shell and mixed pine wood biochars inducing enhanced microbial biomass and activity (Brantley *et al*., 2015). The results was also coincide with the findings of Indawan *et al.* (2018); Yang *et al.* (2015); Collins *et al.* (2013); Dou *et al*. (2012); Streubel *et al*. (2011); Novak *et al*. (2009); Warnock *et al*. (2007); DeLuca *et al*. (2006); Liang *et al.* (2006); Oguntunde *et al.* (2004) and Glaser *et al.* (2002).

4.16.2 Interaction effect of variety and sources of biochar

The nitrogen content in soil was not significantly affected by the interaction effect of variety and different sources of biochar (Table 9 and Appendix IX). Numerically, the maximum nitrogen content in soil (0.047 %) was obtained from treatment combination V_3B_4 whereas, numerically the minimum ones (0.037 %) was obtained from V_3B_3 treatment combinations.

4.17 Potassium content (%) in soil

4.17.1 Effect of different sources of biochar

The potassium content in soil was significantly varied by the different sources of biochar (Table 8 and Appendix IX). The maximum potassium content in soil (0.178%) was obtained from B_4 treatment. On the other hand, the minimum potassium content in soil (0.149%) was obtained from B_3 treatment. This result had agreements with the findings of Timilsina *et al*. (2017) and Diatta (2016) who reported that peanut shell biochar application resulted in increased plant available K. Wang *et al*. (2014) reported that addition of peanut shell biochar resulted in decreased soil exchangeable acidity and Al saturation and also increased in exchangeable cations specially K. The increase in available K is explained by the high content of K in peanut shell biochar. Indawan *et al.* (2018) showed that the biochar application increased K_2O content in soil (2.5%) compare to that of no biochar treated soil. Biochar induced changes in soil properties such as cation exchange capacity and exchangeable cations (Kim *et al*., 2016). Application of biochar 5.00 t ha^{-1} in this trial improved potassium exchangeable in their study. Timilsina *et al*. (2017) reported that the highest available potassium content (12.30 mg kg^{-1}) in soil was found from 20 Mg ha^{-1} biochar application the lowest available potassium content (7.70 g kg^{-1}) was found from without biochar amended soil. The observed increase in K contents of soil due to application of biochar could be due to the presence of high contents of K in biochar. Chan *et al.* (2008) also reported the addition of biochar to soil increased available K of soil. The result of our investigation also reported by Yang *et al.* (2015); Zheng *et al*. (2013); Dou *et al*. (2012) and Baronti *et al*. (2010) who reported that biochar application in soil increased available K in soil.

Table 9. Interaction effects of variety and source of biochar on the soil characters of experimental plots

Treatment combination	Soil pH	Soil organic carbon	Nitrogen content (%)	Potassium content (%)
V_1B_1	6.45 bc	0.77 bc	0.040	0.198 b
V_1B_2	5.56 f	0.43 f	0.040	0.111 i
V_1B_3	6.41 bc	0.59 de	0.039	0.146 g
V_1B_4	5.96 e	0.52 ef	0.040	0.184 c
V_2B_1	6.35 c	0.78 b	0.040	0.172 de
V_2B_2	5.97 e	0.55 e	0.040	0.160 f
V_2B_3	6.20 d	0.63 d	0.040	0.167 ef
V_2B_4	6.36 c	0.69 c	0.040	0.148 g
V_3B_1	6.49 b	0.45 f	0.043	0.127 h
V_3B_2	6.18 d	0.62 d	0.040	0.176 c-e
V_3B_3	5.96 e	0.72 c	0.037	0.178 cd
V_3B_4	6.61 a	0.88 a	0.047	0.213 a
$LSD_{(0.05)}$	**0.09**	**0.05**	**NS**	**0.009**
CV (%)	**7.25**	**8.93**	**4.56**	**3.86**

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

Note: V_1- BARI Alu-29 (Courage), V_2- BARI Alu-28 (Lady Rosetta), V_3- BARI Alu-25 (Asterix) and B_1 - Maize cob (5.00 t ha^{-1}), B_2 - Mahogany wood (5.00 t ha^{-1}), B_3 – (Cow dung + saw dust) (5.00 t ha^{-1}), B_4 - Cow dung (5.00 t ha^{-1}).

4.17.2 Interaction effect of variety and sources of biochar

The potassium content in soil was significantly varied by the interaction effect of variety and different sources of biochar (Table 9 and Appendix IX). The maximum potassium content in soil (0.213 %) was obtained from V_3B_4 treatment combination. On the other hand, the minimum potassium content in soil (0.111 %) was obtained from V_1B_2 treatment combination.

CHAPTER V

SUMMARY AND CONCLUSION

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The field experiment was conducted at the experimental plot of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2019 to March, 2020 in Rabi season to find out the response of different types of biochars and potato varieties on growth, yield and quality of potato. The experiment had two factors. Factor A: Four different types of biochar, i. B_1:Maize Cob (10.00 t ha^{-1}), ii. B_2: Mahogany wood (10.00 t ha^{-1}), iii. B_3: Cow dung + Sawdust (10.00 t ha^{-1}) and iv. B_4: Cow dung (10.00 t ha^{-1}) and Factor B: Three different types of potato, i. V_1: BARI Alu-29 (Courage), ii. V_2: BARI Alu-28 (Lady Rosetta) and iii. V_3: BARI Alu-25 (Asterix). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three (3) replications. Total 36 unit plots was made for the experiment with 12 treatments. Each plot was of required size. Data on different growth and yield parameter of potato were recorded and significant variation was recorded for different treatment.

In case of different potato varieties, at 30, 45 and 60 DAP, 'Lady Rosetta' showed the tallest plant (25.06, 29.78 and 37.09 cm, respectively) whereas, the shortest plant (20.40, 24.45 and 30.89 cm, respectively) was found from the variety 'Asterix'. The maximum number of tubers $hill^{-1}$ (7.83) was recorded from the 'Asterix' and the minimum number of tubers $hill^{-1}$ (5.50) was found from the 'BARI Alu-28'. The maximum average tuber weight (30.48 g) was recorded from the 'Lady Rosetta' whereas, the minimum average tuber weight (27.21 g) was obtained from the 'Asterix' variety. The highest weight of tuber $hill^{-1}$ (215.04 g), the maximum yield of potato (15.91 t ha^{-1}), the highest amount of marketable potato (9.74 t ha^{-1}) and the highest amount of non-marketable potato (6.17 t ha^{-1}) was obtained from the variety 'Asterix' (V_3) while the lowest weight of tuber $hill^{-1}$ (154.01 g), the minimum yield of potato (11.40 t ha^{-1}), the lowest amount of marketable potato (7.20 t ha^{-1}) and the lowest amount of non-marketable potato (4.19 t ha^{-1}) was found from the 'Lady Rosetta' (V_2). Numerically the highest specific gravity (1.059 g cm^{-3}) and was the maximum dry matter content of tuber (21.02%) obtained from the 'Asterix' variety whereas, the lowest specific gravity (1.048 g cm^{-3}) and the minimum tuber dry matter content (20.31%) was found from the 'Lady Rosetta' variety. Numerically, the highest TSS (5.61%), the maximum starch content on potato (16.13 mg g^{-1} FW) and the highest reducing sugar on potato (0.478 mg g^{-1} FW) was recorded from the potato variety 'Lady Rosetta' (V_2) whereas, numerically the lowest TSS (5.39 %), the minimum starch content on potato (14.60 mg g^{-1} FW) and the lowest reducing sugar on potato (0.278 mg g^{-1} FW) was obtained from the variety 'Courage' (V_1). The highest canned potato (4.61 t ha^{-1}) and the highest flakes potato yield (8.59 t ha^{-1}) was produced by the 'Asterix' variety (V_3) whereas the lowest canned potato (2.85 t ha^{-1}) the lowest flakes potato yield (5.58 t ha^{-1}) was recorded from 'Lady Rosetta' (V_2) variety. The maximum chips potato (4.30 t ha^{-1}) was produced by the 'Courage' (V_1) variety. On the other hand, the minimum chips potato (2.71 t ha^{-1}) was produced by the 'Asterix' (V_3) variety.

In case of different types of biochar, at 30 DAP, 45 DAP and 60 DAP, the tallest plant (25.18 cm, 31.20 and 37.84 cm, respectively) was recorded from B_1 (Maize Cob) treatment whereas, the shortest plant (20.46 cm, 22.64 and 29.64 cm, respectively) was recorded from B_2 (Mahogany wood) treatment. The maximum number of tubers (7.56), the maximum average weight of tuber (40.87 g), the highest weight of tuber $hill^{-1}$ (307.39 g), maximum tuber yield (30.74 t ha^{-1}), the highest marketable yield (22.59 t ha^{-1}) and the highest non-marketable potato (8.15 t ha^{-1}) was produced from B_1 (Maize Cob) treatment; whereas the minimum number of tubers (4.78), the lowest average weight of tuber (36.33 g), the lowest weight of tuber $hill^{-1}$ (213.13.16 g), the minimum tuber yield (21.19 t ha^{-1}), the lowest marketable yield (15.64 t ha^{-1}) and the lowest non-marketable potato yield (6.56 t ha^{-1}) was produced from B_2 (Mahogany wood) treatment. The highest specific gravity of tuber was recorded (1.067 g cm^{-3}) from B_1 treatment while, the lowest specific gravity of tuber (1.048 g c m^{-3}) was found from B_2, B_3 and B_4 treatment. The maximum tuber dry matter content (22.27%), numerically the highest TSS (5.72%), the maximum starch content on potato (16.73 mg g^{-1} FW) and the highest reducing sugar value (0.413 mg g^{-1} FW) was recorded from “Maize Cob biochar” (B_1) treatment and the minimum tuber dry matter content (18.99%), numerically the lowest TSS (5.25%), the minimum starch content on potato (14.00 mg g^{-1} FW) and the lowest reducing sugar value (0.333 mg g^{-1} FW) was recorded from the “Mahogany wood biochar” (B_2) treatment. The highest canned production (4.40 t ha^{-1}), the maximum chips production (4.21 t ha^{-1}) and the highest flakes production (8.54 t ha^{-1}) was obtained from B_1 (Maize Cob biochar) treatment while the lowest canned production (2.37 t ha^{-1}), the lowest flakes production (4.58 t ha^{-1}) and the minimum chips production (2.24 t ha^{-1}) was obtained from B_2 (Mahogany wood biochar) treatment. The highest soil pH (6.48), the highest organic carbon (0.70) and the maximum potassium content in soil (0.178%) was recorded when the pots were treated with Cow dung biochar (B_4) and the lowest soil pH (5.90), the lowest organic carbon (0.53) and the minimum potassium content in soil (0.149%) was recorded when the pots were treated with (Cow dung + saw dust) (B_3). Numerically the maximum nitrogen content in soil (0.042 %) was obtained from B_4 treatment whereas, numerically the minimum nitrogen content in soil (0.039%) was obtained from B_2 treatment

Interaction effect of different potato varieties and different types of biochar was significant in most of the parameters under study. At 30, 45 and 60 DAP, the tallest plant (27.07, 35.20 and 42.50 cm, respectively) was measured from V_2B_1 (Lady Rosetta with Cob) combination. On the other hand, the shortest plant (17.17, 20.20 and 27.00 cm at 30, 45 and 60 DAP, respectively) from V_3B_2 (Asterix with Mahogany wood) treatment combination. The maximum number of tubers (9.33) was found from V_3B_1 (Asterix with Maize Cob) treatment combination. On the other hand, the minimum number of tubers (3.67) was from V_1B_2 (Courage with Mahogany wood) treatment combination. The maximum average weight of tuber (32.70 g) was recorded in V_2B_1 treatment combination. On the other hand, the minimum average weight of tuber (24.53 g) was observed in V_3B_2 treatment combination. The highest weight of tuber $hill^{-1}$ (276.36 g), the maximum tuber yield (20.45 t ha^{-1}), the highest marketable yield (13.70 t ha^{-1}) and the highest non-marketable potato yield (6.75 t ha^{-1}) was recorded in Asterix variety with cob biochar (V_3B_1) treatment combination.

On the other hand, the lowest weight of tuber hill^{-1} (103.95 g), the minimum tuber yield (7.69 t ha^{-1}), the lowest marketable yield (5.15 t ha^{-1}) and the lowest non-marketable yield of potato (2.54 t ha^{-1}) was observed from Lady Rosetta and Mahogany wood biochar (V_2B_2) treatment combination. The highest specific gravity of tuber (1.070 g cm^{-3}) exhibited by V_1B_1 and V_3B_1 combined treatment. On the other hand, the lowest specific gravity of tuber (1.041 g cm^{-3}) was exhibited by V_2B_3 combined treatment. The maximum tuber dry matter content of potato (22.67 %) was recorded in V_3B_1 (Asterix variety with Maize Cob biochar) treatment combination and, the minimum tuber dry matter content of potato (18.37%) was observed in V_2B_2 (Lady Rosetta variety with Mahogany wood biochar) treatment combination. The highest total soluble solid of tuber (5.81%) exhibited by V_2B_1 treatment combination. On the other hand, the lowest total soluble solid of tuber (5.18%) was exhibited by V_1B_2 treatment combination. The maximum starch content on potato (17.50 mg g^{-1} FW) was attained by V_2B_4 treatment combination. On the other hand, the minimum starch content on potato (13.70 mg g^{-1} FW) was attained by V_1B_2 treatment combination. The highest reducing sugar content of potato (0.510 mg g^{-1} FW) was recorded in V_2B_1 whereas, the lowest reducing sugar content of potato (0.230 mg g^{-1} FW) was observed in V_1B_2 combination treatment. The highest canned production (5.93 t ha^{-1}) exhibited by V_3B_1 treatment combination whereas, the lowest canned production (1.84 t ha^{-1}) was exhibited by V_1B_2 treatment combination. The highest flakes production (11.04 t ha^{-1}) exhibited by V_3B_1 treatment combination whereas, the lowest flakes production (3.77 t ha^{-1}) was exhibited by V_1B_2 and V_2B_2 treatment combination. The maximum chips production (5.18 t ha^{-1}) was exhibited by V_1B_1 treatment combination. On the other hand, the minimum chips production (1.96 t ha^{-1}) was exhibited by V_3B_2 treatment combination. The highest soil pH (6.61) was attained by treatment combination V_3B_4 and the lowest soil pH (5.56) was recorded from treatment combination V_1B_2. The highest organic carbon (0.88) was obtained from V_3B_4 treatment combination and the lowest value for organic carbon (0.43) was obtained from treatment combination V_1B_2. Numerically, the maximum nitrogen content in soil (0.047%) was obtained from treatment combination V_3B_4 whereas, numerically the minimum nitrogen content in soil (0.037%) was obtained from V_3B_3

treatment combinations. The maximum potassium content in soil (0.213 %) was obtained from V_3B_4 treatment combination. On the other hand, the minimum potassium content in soil (0.111%) was obtained from V_1B_2 treatment combination.

Based on the experimental results, it may be concluded that-

1. The effect of potato variety and different source of biochar had positive effect on morphological and growth characters, yield and qualitative attributes of potato.

2. The combination of V_3B_1 (Asterix and Maize cob) exhibited highest specific gravity, dry matter content. This combination also shows the positive effects on soil health. So the application of maize cob biochar as the source of biochar with potato variety BARI Alu-25 (Asterix) seemed to be more suitable for getting higher yield and good quality tuber of potato for the farmers

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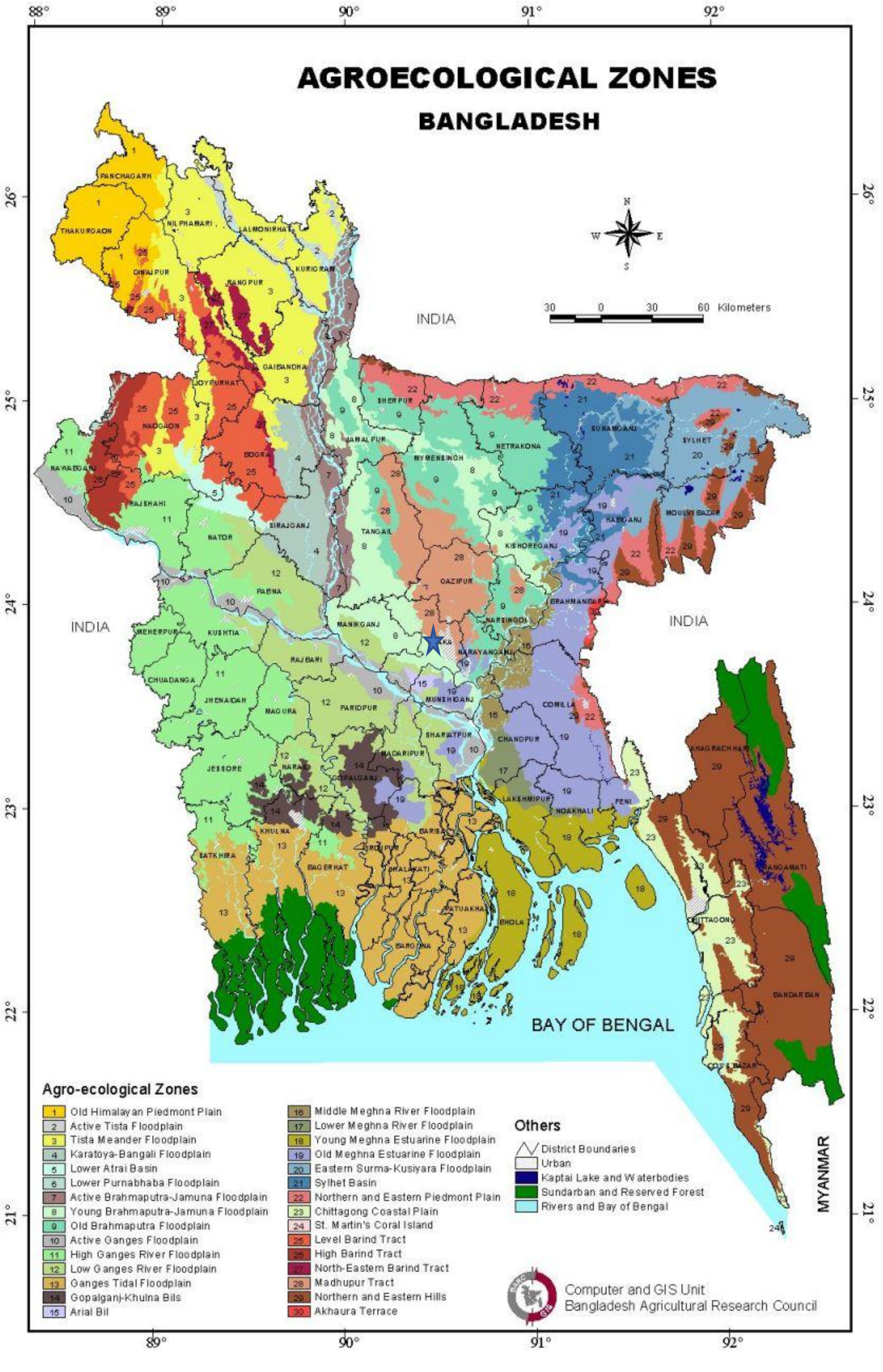
APPENDICES

APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh



Appendix II. Monthly average temperature, relative humidity and total rainfall of the experimental site during the period from November, 2019 to February, 2020

Month	Air temperature (^0C)		R. H. (%)	Total rainfall (mm)
	Maximum	Minimum		
November, 2019	31.82	14.04	81	24
December, 2019	23.40	10.50	87	5
January, 2020	20.18	7.04	88	0
February, 2020	18.20	9.70	82	15

Source: Bangladesh Metrological Department (Climate and weather division) Agargaon, Dhaka.

Appendix III. Characteristics of experimental fields soil was analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Agronomy Farm, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping Pattern	Boro rice-Fallow-Aman rice

B. Physical properties of the initial soil

Characteristics	Value
%Sand	27
%Silt	43
%clay	30

C. Chemical properties of the initial soil

Characteristics	Value
Textural class	Silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.077
Available P (ppm)	20.00
Exchangeable K (meq/ 100 g soil)	0.10
Available S (ppm)	45

Source: Soil Resource Development Institute (SRDI), Farmgate, Dhaka.

Appendix IV. Analysis of variance (mean square) of plant height at different DAP

Source of variation	Degrees of freedom	Plant height		
		30 DAP	45 DAP	60 DAP
Replication	2	1.970	41.200	149.040
Variety (A)	2	50.408*	119.856*	205.300*
Biochar (B)	3	9.672*	26.023*	79.191*
A×B	6	0.577*	6.475*	3.825*
Error	22	2.327	13.856	25.211

*** and ** indicate significant at 5% and 1% level of probability, respectively.**

Appendix V. Analysis of variance (mean square) of yield components

Source of variation	Degrees of freedom	No. of tuber $hill^{-1}$	Average weight of tuber	Weight of tuber $hill^{-1}$
Replication	2	0.723	3.862	4.298
Variety (A)	2	28.392*	829.628*	294.822*
Biochar (B)	3	19.333**	874.629**	193.637**
A×B	6	0.936*	3.977**	0.251**
Error	22	0.739	1.293	2.964

* and ** indicate significant at 5% and 1% level of probability, respectively

Appendix VI. Analysis of variance (mean square) of yield

Source of variation	Degrees of freedom	Tuber yield	Marketable yield	Non-marketable yield
Replication	2	1.970	73.428	187.040
Variety (A)	2	53.933*	125.833*	238.363*
Biochar (B)	3	7.526*	22.403*	87.537*
A×B	6	0.482*	6.527*	4.272*
Error	22	4.282	14.282	29.562

*** and ** indicate significant at 5% and 1% level of probability, respectively**

Appendix VII. Analysis of variance (mean square) of processing qualities

Source of variation	Degrees of freedom	Specific gravity	Dry matter content	Total soluble solid	Starch content	Reducing sugar
Replication	2	183.208	82.330	31.342	28.073	35.054
Variety (A)	2	92.519^{NS}	52.135^{NS}	8.090^{NS}	46.212*	37.946*
Biochar (B)	3	3.822**	14.272**	2.122^{NS}	25.339*	27.845**
A×B	6	3.7282**	3.829**	1.673**	2.480*	2.737**
Error	22	35.272	28.373	20.423	10.007	14.829

*** and ** indicate significant at 5% and 1% level of probability, respectively, NS = non-significant**

Appendix VIII. Analysis of variance (mean square) of yield of potato for different processing purpose

Source of variation	Degrees of freedom	Yield of potato for canned production (< 30 mm)	Yield of potato for flakes production (30-45 mm)	Yield of potato for chip production (45-75 mm)	Yield of potato for french fry production (> 75 mm)
Replication	2	4.596	1.356	7.477	0.583
Variety (A)	2	169.548*	772.850**	184.473**	0.007^{NS}
Biochar (B)	3	858.401**	206.604**	108.251**	0.007^{NS}
A×B	6	3.429*	18.522**	0.010**	0.001^{NS}
Error	22	30.629	40.774	1.655	0.208

* and ** indicate significant at 5% and 1% level of probability, respectively

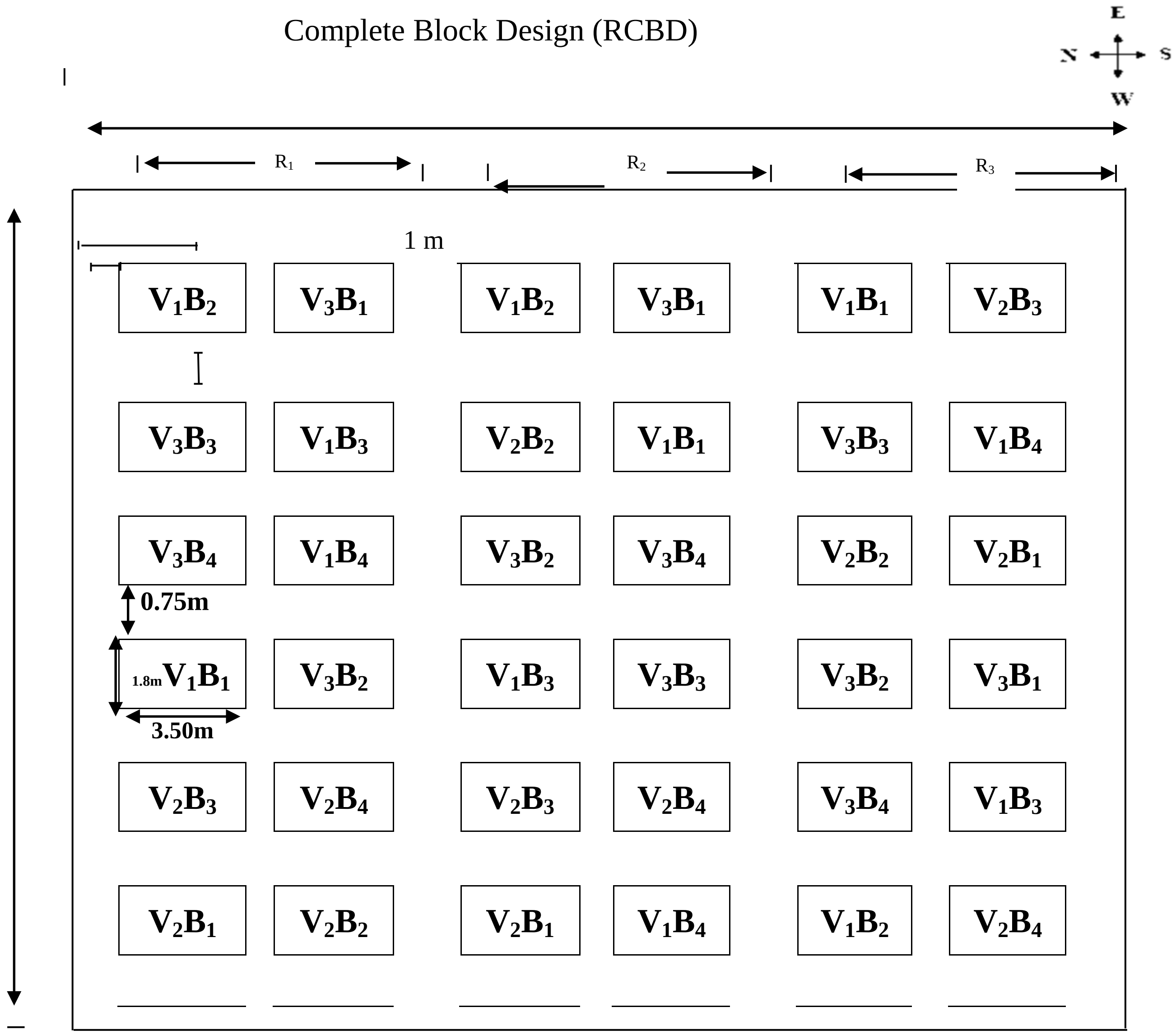
NS = Non-significant

Appendix IX. Analysis of variance (mean square) of soil characters of experimental plots

Source of variation	Degrees of freedom	Soil pH	Soil organic carbon	Nitrogen content	Potassium content
Replication	2	0.030	0.043	0.007	0.030
Variety (A) Biochar (B)	3	0.040*	0.213*	0.645^{NS}	1.924**
A×B	6	0.007*	0.070*	0.051^{NS}	0.328**
Error	29	0.017	0.039	0.045	0.062

* and ** indicate significant at 5% and 1% level of probability, respectively, NS = Non-significant

Appendix X: Field layout of the two-factor experiment in Randomized Complete Block Design (RCBD)



Number of treatment combinations = 12
Between replication = 1.0 m

Factor A: Types of Biochar

B_1: Maize cob (5.00 t ha^{-1}),

B_2: Mahogany wood (5.00 t ha^{-1}),

B_3: (Cow dung + Sawdust) (5.00 t ha^{-1})

B_4: Cow dung (5.00 t ha^{-1})

Factor B: Types of Potato

V_1: BARI Alu-29

V_2: BARI Alu-28

V_3: BARI Alu-25