IMPROVING GROWTH, YIELD AND QUALITY OF POTATO THROUGH BIOCHAR AND VERMICOMPOST MANAGEMENT

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CERTIFICATE

*This is to certify that the thesis entitled, "**IMPROVING GROWTH, YIELD AND QUALITY OF POTATO THROUGH BIOCHAR AND VERMICOMPOST MANAGEMENT**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka-1207, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **AGRONOMY**, embodies the result of a piece of bona fide research work carried out by **BIJAYA RANI BISWAS,** Registration No. **15-06672** 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.

Date:

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Dedicated to

My

Beloved Parents

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ABSTRACT

Increasing tuber yield and ensuring good quality potato are challenging in Bangladesh. Combined application of biochar and vermicompost along with recommended dose of chemical fertilizers may improve the yield and quality of potato. From this aspect, a field experiment was carried out at the Agronomy Research Field, Sher-e-Bangla Agricultural University, Dhaka during the period from November 2021 to February 2022 in the Rabi season for improving growth, yield and quality of potato through biochar and vermicompost management. The experiment comprised two factors and followed split plot design with three replications. Factor A, doses of biochar application *viz*., (4) B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1} and Factor B, doses of vermicompost application *viz*., (4) Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}. In case of levels of biochar application, the B_4 treatment had the highest tuber yield, marketable tuber yield, dry matter content of potato and starch content which were statistically similar to B_3 treatment, however the lowest yield and qualities of potato were observed in B_0 treatment. Number of tubers $hill^{-1}$, average tuber weight, yield, different categories of potato tuber, dry matter content, specific gravity and starch content increased with increasing the vermicompost level. The highest marketable tuber yield, the highest chips potato yield, dry matter content of potato and starch content of potato were observed from Vm_4 treatment, which was statistically similar to Vm_3 treatment. In respect of the interaction effect, the highest tuber yield (32.47 t ha^{-1}), marketable tuber yield (32.07 t ha^{-1}), french fry potato yield (6.37 t ha^{-1}), specific gravity of potato (1.068 g cm^{-3}) and starch (18.45 mg g^{-1} FW) were observed in B_4Vm_4 interaction whereas, the lowest was recorded from B_1Vm_1 treatment. However, B_4Vm_3, B_3Vm_4 and B_3Vm_3 interaction treatments showed statistically similar results in terms of yield and quality attributes of potato. So, the combination of biochar and vermicompost at the rate of each of 3 t ha^{-1} (B_3Vm_3) along with recommended dose of chemical fertilizers would be used for producing maximum yield and good processing quality potato without sacrificing yield.

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ABBREVIATIONS

Full word	Abbreviation
Agriculture	Agri.
Agro-Ecological Zone	AEZ
Bangladesh Bureau of Statistics	BBS
Biology	Biol.
Biotechnology	Biotechnol.
Botany	Bot.
Cultivar	Cv.
Dry weight	DW
Editors	Eds.
Emulsifiable concentrate	EC
Entomology	Entomol.
Environments	Environ.
Food and Agriculture Organization	FAO
Fresh weight	FW
International	Intl.
Journal	J.
Least Significant Difference	LSD
Liter	L
Triple super phosphate	TSP
Science	Sci.
Soil Resource Development Institute	SRDI
Technology	Technol.
Serial	Sl.

CHAPTER I

INTRODUCTION

Potato (*Solanum tuberosum* L.) is widely grown around the world because of its rich nutrition, ease of cultivation and high yield (Wang *et al*., 2020). It is now the fourth most important food crop in the world after wheat, rice, and maize, covering 19.3 million hectares and producing 388.2 million tons (Waqas *et al*., 2021). It is now grown in more than 100 countries and feeds more than a billion people worldwide (Islam *et al*., 2020). In Bangladesh, production of potato is gradually increasing. Bangladesh experienced much progress in area, production and yield of potato in the last decade, as its area, production and yield increased to 461 thousand hectares, 9605 thousand Metric Ton (MT) and 20.8 MT ha^{-1} in 2019-20 from 435 thousand hectares, 7930 thousand MT and 18.25 MT ha^{-1} in 2009-10, with the corresponding growth rates 6%, 21% and 14%, during the period, respectively. It has happened due to the suitable environment and use of high yielding varieties in potato production. As the currently production exceeds demand, Bangladesh started exporting fresh potato in the world market and exported 45000 MT of fresh potato in 2019-20 (Sabur *et al*., 2021). Annual potato consumption per capita had also increased and reached 25.66 Kg in 2016 from 23.65 kg in 2010, bringing the growth rate 8.5% during the only six-year period (HIES, 2016).

In Bangladesh, the annual demand for potato is 6.5 million tons against its production of 9.65 million tons (BBS, 2020). So, about 3 million tons are surplus. This surplus amount of potato needs to be used either in processing industries or to export in foreign countries. But only 2% of the potatoes are processed to chips and crackers mainly as most of the potatoes does not meet the requirements for processing. Dry matter, starch, reducing sugar, non-reducing and total sugar content of 40 varieties of potatoes in Bangladesh 13.56% – 24.6%, 6.8% – 18.93%, 0.02% – 0.61%, 0.09% – 0.53%, 0.27% – 0.78% respectively (Roy *et al*., 2017). Potato tuber quality is one of the essential quality attributes for consumers and industrial demand (Pedreschi and Moyano, 2005). Quality of potato depends on its dry matter content (≥20%), specific gravity (≥1.06%), starch content (≥13%), reducing sugar content (<0.30%). (Kirkman, 2007). Potato product manufacturers prefer high specific gravity potatoes for baking, frying, mashing and French fry production as well as to obtain a higher crisp yield (Pedreschi and Moyano, 2005).

Potato tubers provide a large amount of dietary carbohydrates and protein, most of which are represented by starch and organic acids, whose content is significantly affected by variety, soil environment and their interactions (Romano *et al*., 2018). Currently, potato yields have stagnated between 5 and 9 t ha^{-1} compared to the achievable farmer yields of about 20 t ha^{-1} (Otieno, 2019). The low yields could be attributed to soil infertility, improper use of fertilizers, foliar pests and diseases, use of poor quality tuber seeds and low yielding varieties, weed control and within-season droughts (Mugo *et al*., 2020). Therefore, it is a key measure to improve yield and quality of potato tubers to identify and integrate different agronomic managements.

Potato being nutrients exhaustive crop has higher requirement of nitrogen, phosphorus, potassium and other nutrients (Kahsay, 2019), the balanced nutrition at planting ensures a good start for the potato crop with higher productivity. However, excessive use of chemical fertilizers to meet the crop demand has badly affected the soil health and productivity and is also adding high economic load but at present condition it is not possible to eliminate the use of chemical fertilizers completely. On the other hand, reliance on organic fertilizers and biofertlizers alone is also not feasible because they are comparatively low in nutrient amount and can better serve as a supplement rather than substitute (Chojnacka *et al*., 2020). Therefore, combined use of inorganic and organic sources of plant nutrients is the most effective approach to manage long-term soil fertility as well as soil productivity.

Biochar, a solid product of pyrolysis, which is also known as black-carbon, is a recalcitrant carbon rich compound that, when added to soil, has the capacity to restore as much as 9 to 11 Gt (Giga tonne) of carbon per year (Wang *et al.* 2013). This recalcitrance property of biochar enables its permanence in soil 10-1000 times longer than the most soil organic matter residence time (Lehmann and Joseph, 2015). Lin *et al.* (2017) investigated the potential effect of biochar on improving the soil properties and reported increase in soil pH, CEC, various enzymatic activities and available nutrients (N, P, K, Ca, Mg) in the amended soil. Nurida and Rachman (2011) stated that biochar application in soil at doses of 5.0-7.5 t ha^{-1} was capable of improving crop productivity by enhancing soil physio-chemical properties, and improving soil microbial community and diversity. Addition of biochar in soil could result in net microbial immobilization of nutrients as biochar contains small amount of native labile carbon with high C:N ratio (Deluca *et al.,* 2009). Therefore, combined application of biochar with inorganic fertilizers has been shown to enhance agronomic benefits in terms of growth and production of crops especially in low fertile soil, either by acting as a direct source of available nutrients or by increasing nutrient availability in soil (Hameeda *et al.,* 2019).

Vermicompost is a highly efficient organic manure, which is made from the farm waste and involves the advantages of increase in production and improves the quality of agricultural produce. Vermicompost increases the value of land by increasing the NPK content, water holding capacity and productivity of land (Cao *et al*., 2021). Vermicompost provides macro and micronutrients to the soil and enhances soil aeration for growth and development of crop (Lamichhane, 2017). Higher growth and yield values were recorded when vermicompost were applied at 12.5 t ha^{-1} (Jatav and Jatav*,* 2020). The organic carbon in vermicompost releases the nutrients slowly and steadily into the system and enables the plant to absorb these nutrients. The soil enriched with vermicompost provides additional substances that are not found in chemical fertilizers (Ramnarain *et al.,* 2019). Therefore, emphasis is to be given on growing agronomic crops supplied with organic inputs and thereby increasing the soil productivity for maintaining sustainable crop yield and quality. Therefore, the present investigation is undertaken with following objectives.

Objectives:

i. to study the effect of biochar and/or vermicompost on growth, yield and quality of potato and

ii. to select the suitable combination of biochar and vermicompost for maximizing yield with good quality potato tuber.

CHAPTER II

REVIEW OF LITERATURE

A brief review of literature on important aspects pertaining to present study entitled "Improving growth, yield and quality of potato through biochar and vermicompost management" is presented in this chapter. An attempt has been made to cite all available literatures on potato. But due to paucity of adequate published information, research work on other crops has also been reviewed.

2.1 Effect of biochar on growth, yield and quality of potato

Roy *et al*. (2021) conducted a field experiment at to find out the response of biochar on yield of potato for different processing categories. The experiment comprised Potato varieties (3): V_1: BARI Alu-29 (Courage), V_2: BARI Alu-28 (Lady Rosetta) and V3: BARI Alu-25 (Asterix) and Biochar level (5): B_0: 0 (Control), B_1: 2.50 t ha^{-1}, B_2: 5.00 t $ha^{-1,}$ B_3: 7.50 t ha^{-1} and B_4: 10 t ha^{-1}. The study was laid out in a randomized complete block design with 3 replications. The results showed that biochar amendment enhanced the yield of processing category of potato. The total yield and marketable yield of potato gradually increased with increasing biochar level. The results also revealed that the processing category potato *viz*., canned, chips and french fry potato yields progressively increased with advancing biochar level irrespective of varieties except the dehydrated category.

Kaur and Sharma (2020) evaluated the significance of mixed wood biochar application on the growth parameters of berseem crop. The study indicated that application of 5% biochar increased plant height by 28-50% and plant biomass by 30-60% in a period of 180 days over no application of biochar.

Mollick *et al*. (2020) conducted a field experiment to observe the effect of biochar on the yield and quality of potato tuber and to find out the optimum dose of biochar along with inorganic fertilizers for achieving the maximum yield of potato. The results indicated that biochar application significantly ($p<0.05$) increased plant height, weight of tubers, yield of tubers, tuber dry matter content, tuber specific gravity, soil organic carbon. Results suggested that biochar application had significant positive effect on plants and soils.

Adekiya *et al.* (2019) revealed that there was an increase in yield components of radish by the application of biochar and poultry manure either as sole or in a combination. The highest yield was obtained from the combined application of biochar and poultry manure.

Haque *et al*. (2019) conducted an experiment to study the effectiveness of biochar on soil fertility and yields of brinjal and cauliflower with five treatments *viz*., control, recommended inorganic fertilizer (RF), biochar 1 t ha^{-1} + RF, biochar 3 t ha^{-1} + RF and biochar 5 t ha^{-1} + RF laid out in a randomized complete block design with four replications. Result indicated that biochar at the rate of 5 t ha^{-1} along with RF provided maximum yields of brinjal (67 t ha^{-1}) and cauliflower (42 t ha^{-1}). The pH, nutrients and moisture contents of the study soils increased and bulk density decreased with the higher rates of biochar application.

Khan *et al.* (2019) compared the effect of mesquite biochar (MB, 10 tons ha^{-1}), farmyard manure (FYM, 10 tons ha^{-1}), and NPK fertilizers (120:80:80 kg ha^{-1}) on soil fertility and growth of onion. The maximum onion bulb weight (6.13 kg $plot^{-1}$), leaf length (32.38 cm), total onion yield (268.55 kg ha^{-1}) were observed in the plots treated with MB as compared with FYM and NPK fertilizers.

Gamareldawla *et al.* (2017) carried out a study to analyze the influence of biochar application e.g., 0%, 2% and 4% w/w on the soil properties, growth, yield and water productivity of tomato plant under poor silt loam soil. The result of the experiment revealed that biochar amendments significantly increased all yield components except fruit diameter and color index were not affected by biochar addition. 14% w/w biochar and 2% w/w biochar gave the highest fruit number $plant^{-1}$, fruit weight, fruit water content and total yield $plant^{-1}$ compared to those under no biochar (control). This attributed to the improvement of soil properties and plant growth parameters under biochar additions.

Gautam *et al.* (2017) reported that higher 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.

Rageendrathas and De Silva (2017) reported that yield of onion was significantly increased by the application of paddy husk biochar. Biochar application increased the plant height compared to the fertilizer alone treatments.

Trupiano *et al*. (2017) studied the effects of biochar amendment, compost addition and their combination on lettuce plants grown in a soil poor in nutrients. Results showed that compost amendment had clear and positive effects on plant growth and yield. The research demonstrated that biochar alone stimulated lettuce leaves number, leaves length and breadth and total biomass. As per the research, combining biochar and compost had no positive synergies and summative effect. The research demonstrated that in a soil the biochar alone could be used effectively to enhance soil fertility and plant growth and biomass yield. The results showed that, combined application and single application biochar or compost additions increased the plant height, stem girth, and dry matter yields of maize.

Vista *et al.* (2017) reported that excessive dose of biochar is not beneficial for vegetable crops. They found that application of 30 t ha^{-1} of biochar was most satisfactory for overall improvement of yield and growth parameters of vegetable crops.

Youseef *et al.* (2017) revealed that the number of main stems and number of tubers significantly increased with increasing biochar application rates up to 12 m^3 ha^{-1}.

Akca and Namli (2015) reported that the fresh and dry weight of tomatoes, pepper, and lettuce were recorded to increase after biochar treatment than other treatments.

Vinh *et al.* (2014) reported that yield of rice increased by 4.7-25.5% with biochar as compared to unamended control plot.

Akhtar *et al*. (2014) investigated the effects of biochar on physiology, yield and quality of tomato under different irrigation regimes. The results showed that addition of biochar increased the soil moisture contents in deficit irrigation and partial root zone drying, which consequently improved physiology, yield and quality of tomato as compared with the non biochar control.

Nair *et al.* (2014) found that marketable potato yield increased with increasing biochar.

Rahila *et al.* (2014) conducted a research to study the effect of charcoal on the growth of tomato. The application of biochar at the rate of 30 kg on super vegetable garden bed increased the stem growth and fruit yield compared to untreated beds.

Yilangai *et al.* (2014) investigated the effect of charcoal (biochar) on the growth of tomato (*Lycopersicum esculentus*). Four Super Vegetable Garden (SVG) growing beds and four traditional vegetable beds each measuring 15 m^2 (12.5 m by 1.2 m) and 1 m gap between beds were laid out. After preparing the subsoil, 30 kg of biochar was spread on the four SVG beds as evenly as possible. Results obtained from this research showed that stem growth was significantly higher (35%) in tomatoes grown on SVG beds treated with charcoal than traditional beds without charcoal. Number of fruits $plant^{-1}$, individual fruit weight and fruit yield in tomato plant was also significantly higher on beds with charcoal than beds without charcoal.

Carter *et al.* (2013) reported that application of rice husk biochar, showed significant change in final biomass, plant height, root biomass and number of leaves in lettuce and cabbage in comparison to no biochar treatment.

Collins *et al.* (2013) reported that increased biochar application had increased quality potato tuber.

Schulz *et al.* (2013) reported the positive impacts of application of mixture of biochar prepared from beech wood at 350–450°C and compost prepared by 50% sewage sludge, 25% freshly chaffed lop and 25% sieve leftovers of earlier composting on plant growth of Oat crop. The application of composted biochar significantly increased the plant height, above ground biomass ($p< 0.01$) and grain yield ($p<0.001$) as compared to control. This increase was only due to the addition of biochar while compost did not significantly contribute to this effect.

Varela *et al.* (2013) reported that the positive effects of capturing radiation by biochar in winter sown crop could be attributed larger canopy size and greater chlorophyll content in chick-pea with application of biochar.

Cui *et al*. (2012) extended a field study involving wheat production in order to study the effect of biochar (BC) amendment in paddy soil that had long-term contamination of Cd. The BC was used as an amendment in Cd-contaminated soil for its special property. BC was amended at rates of 10 to 40 t ha^{-1} during the rice season before rice transplantation in 2009. BC amendments increased grain yield of wheat as compared to control where BC was not applied.

Poorter *et al.* (2012) reported that application of bamboo biochar showed the significant effect on plant height and fresh weight, but it had no significant effect on the number of leaves and oven dry weight of economic yield. Plant height, larger stem diameter, root mass fraction and root mass increased due to nitrogen and phosphorus availability in soil because of stimulation of accumulated dry matter in vegetative parts by the application of biochar in soil.

Haefele *et al.* (2011) observed clear positive effect of biochar application on yield and fertilizer use efficiency only in the site where the natural soil fertility was very low. Biochar application improved the CEC and soil water holding capacity and thereby increased the emergence of potato seedlings and improved 16-35% in grain yield over control.

Jeffery *et al.* (2011) evaluated the evidences regarding the relationship between biochar and crop productivity by conducting a meta-analysis. The greatest positive effects were seen with biochar application rates of 100 t ha^{-1} (39%). Other positive effects were seen in acidic (14%) and neutral pH soils (13%) and soils with coarse (10%) or medium (13%). These results suggest main two mechanisms for yield improvement *viz*., liming effect and improved water holding capacity.

Clough *et al.* (2010) confirmed the direct role of biochar in nutrient supply to plants.

Gaskin *et al.* (2010) noted a decrease in grain yield with increasing rates of biochar application. Increased crop yield is a mostly recognized benefit of biochar application;

however, crop responses are highly variable and reliant on biochar type and application rates.

Graber *et al.* (2010) emphasized that treating plants by biochar positively enhanced plant height of tomato crop.

Hossain *et al.* (2010) investigated and quantified the effects of waste water sludge biochar on soil quality, growth, yield and bio availability of metals in cherry tomatoes, pot experiments were carried out in a temperature controlled environment and under four different treatments consisting of control soil, soil with biochar; soil with biochar and fertilizer, and soil with fertilizer only. The results revealed significant effect of biochar on the height of the plant, increase in fruits size and grain yield of the plant.

Purakayastha (2010) reported that application of biochar prepared from wheat straw at 1.9 t ha^{-1} along with recommended doses of NPK (NPK:180:80:80) significantly increased the yield of maize in Inceptisol of IARI farm and this treatment was superior to either crop residue incorporation or crop residue burning.

Asai *et al.* (2009) studied the effect of biochar application on grain yield of upland rice at ten different sites, combining different rate of biochar and fertilizer application (N and P) and two cultivars. Biochar application resulted in higher grain yields at the sites with low P availability. In the absence of N fertilizer and at the highest rate of biochar application, there was reduction in leaf chlorophyll content indicating biochar application is highly dependent on soil fertility and fertilizer management.

Chan *et al.* (2008) evaluated two biochar produced from poultry litter under different conditions in a pot experiment by assessing yield of radish. The yield increase was largely due to the ability of biochar to increase nutrient availability, particularly N and other beneficial effects of biochar on soil quality. In this regard, the non-activated (450°C) poultry litter biochar was more effective than the activated (550°C) biochar. These results highlight the importance of feedstock and process conditions during pyrolysis in determining the soil amendment values of biochar.

Chan *et al.* (2007) conducted a pot culture study to investigate the effect of biochar produced from green waste on the yield of radish. In the absence of N fertilizer, application of biochar to the soil did not increase radish yield even at the highest rate of 100 t ha^{-1}. However, a significant interaction between biochar and N fertilizer was observed in that yield increased with increasing rates of biochar application, highlighting the role of biochar in improving N fertilizer use efficiency of the plant.

Rondon *et al.* (2007) demonstrated the potential for increasing the N input by BNF (Biological Nitrogen Fixation) into agro-ecosystems in highly weathered and acid soils by biochar applications. Nitrogen fixation was significantly improved by moderate rates of biochar additions. The reason for the improved BNF was mostly an effect of the improved availability of B and likely of Mo and to a lesser extent, a decreased N availability and increased availability of K, Ca, and P and higher pH as well as lower Al saturation.

2.2 Effect of vermicompost on growth, yield and quality of potato

Alamayo *et al*. (2022) conducted a study to investigate the effect of integrated vermicompost and blended NPS fertilizer application on soil physio-chemical properties and potato tuber yield. The treatment levels consisted of 4 rates of blended NPS fertilizers (0, 150, 200 and 250 kg NPS ha^{-1}) and 4 rates of vermicompost (0, 4, 6 and 8 t ha^{-1}) in factorial combination in randomized complete block design with 3 replications. Soil analysis before planting and after harvesting revealed the incorporation of vermicompost and NPS fertilizer increased OC, CEC, available P and K and total N content of the soil. The organic carbon, available P and available K were increased by 8.7, 14.9 and 13.0% over the initial status respectively. Furthermore, the integrated use of various rates of vermicompost (VC) and low rates of inorganic fertilizer is better than independent use of inorganic fertilizer. The organic carbon, soil pH, available P and K, CEC and exchangeable bases (Na, K, Ca and Mg) increased due to the application of vermicompost. Here combined application of 250 kg ha^{-1} blended NPS fertilizer and 8 t ha^{-1} vermicompost that gave significantly maximum yield for marketable tuber yield (27.4 t ha^{-1}) and total tuber yield (27.9 t ha^{-1}).

Wagari *et al.* (2022) reported that the combined application of 250 kg ha^{-1} blended NPS fertilizer and 8 t ha^{-1} vermicompost gave significantly maximum yield for marketable tuber yield (27.4 t ha^{-1}) and total tuber yield (27.9 t ha^{-1}).

Abou El-Goud *et al.* (2021) conducted two field experiments to evaluate the performance of three potato cultivars (Sponta, Cara and Elbieda) under different fertilizer treatments. The results showed that compared to the NPK inorganic fertilizer, organic fertilizers significantly improved the vegetative growth characteristics of potato in all treatments. Among the organic treatments, the highest growth parameters were recorded with the application of mixed organic fertilizer, vermicompost, and *Azolla pinnata* (T_1). The highest yield, *viz*., tuber yield, number of tubers $plant^{-1}$, and tuber weight, and yield quality characteristics, *viz*., total carbohydrates, starch, and TSS were also recorded in T_1. The results demonstrate that the Sponta cultivar grown with the application of mixed organic fertilizer, vermicompost, and *Azolla pinnata* (T_1) produced the highest growth, yield and quality of potato tubers.

Badrunnesa *et al*. (2021) carried out an experiment to assess the effect of potassium sources and vermicompost level on yield and grading of potato tuber. The potato tuber of variety BARI Alu-25 (Asterix) was used as the planting material for this experiment. The experiment consisted of two factors: Factor A: 3 sources of Potassium such as- K_1: KCl, K_2: KNO_3 and K_3: K_2SO_4. Factor B: 4 levels of vermicompost such as- Vm_0: 0 (Control), Vm_1: 4 t ha^{-1} , Vm_2: 8 t ha^{-1} and Vm_3: 12 t ha^{-1}. The highest yield of potato tubers (27.86 t ha^{-1}) was recorded from K_2SO_4 whereas the lowest (26.02 t ha^{-1}) was found from KNO_3. The number of tubers $hill^{-1}$, average tuber weight, yield and different categories of potato tuber were increased with the increasing of vermicompost level.

Mostofa *et al.* (2021) conducted an experiment to find out the effect of vermicompost and seed tuber size on the yield of potato. The experiment consisted of two factors, i.e., factor A: Vermicompost level (Vc-4): Vc_1: 0 t ha^{-1}, Vc_2: 3 t ha^{-1}, Vc_3: 6 t ha^{-1} and Vc_4: 9 t ha^{-1}; factor B: Tuber size (T-5): T_1: 5 - 10 g, T_2: 10 - 20 g, T_3: 20 - 30 g, T_4: 30 - 40 g and T_5: >40 g. Vermicompost was found to have a significant effect on most of the yield contributing parameters. Results showed that yield parameters increased with increasing vermicompost level irrespective of tuber size.

Hensh *et al*. (2020) conducted a field experiment with potato to study on integrated nutrient management in productivity and economics of potato Among the treatments, maximum yield (12.85 t ha^{-1} and 14.15 t ha^{-1} respectively) of larger size tubers i.e., grade A (>100 g) tubers and medium size i.e., grade B (50-99 g) tubers was recorded with treatment T_{10}-80% RDN through chemical fertilizer + 20% through vermicompost + biofertilizer. Crop receiving treatment T_{10} also showed highest total tuber yield (32.05 t ha^{-1}) of potato. The higher tuber yield with T_{10} treatment could be attributed to increased availability of nutrients including micro nutrients in the soil which led to enhanced absorption of nutrients by the crop resulting in increased tuber production. An increase in tuber yield with the combined application of vermicompost and biofertilizers might have positive impact due to its richness in both macro and micronutrients.

Kumar *et al.* (2020) carried out an experiment to study the effect of organic and biofertilizers on growth and yield parameters in potato cultivar Kufri Chipsona-3. Growth parameters like plant height, number of compound leaves $plant^{-1}$, number of shoots $plant^{-1}$, diameter of stem and number of stolon $plant^{-1}$, number of branches $plant^{-1}$, fresh and dry weight of shoot and yield attributing parameters like fresh and dry weight of tubers $plant^{-1}$, number of tuber $plant^{-1}$, diameter of tuber $plant^{-1}$ and total yield ha^{-1} increased with the application of vermicompost in different combination rates with biofertilizers was much better than applying vermicompost only and using phosphate solubilizing bacteria with them combinedly were the most effective treatments comparing with the others. However, the highest values for number of tuber $plant^{-1}$ and $plot^{-1}$ as well as tuber yield $plot^{-1}$ and $hectare^{-1}$ were recorded on application of Vermicompost @ 6 t ha^{-1} + PSB @ 10 kg ha^{-1} was the most effective treatment both the years followed by Vermicompost @ 6 t ha^{-1} respectively.

Li *et al.* (2020) found that vermicompost not only contributes to improve soil texture, aeration, and soil compaction, enhancing plant water and nutrient uptake, but also produces hormones, vitamins, plant regulators, antibiotics, and beneficial microbes that further improve plant health.

Ferdous *et al.* (2019) implemented an experiment at and vermicompost on the starch and sugar content activity of potato and their performance under ambient storage condition.

The experiment consisted of two factors, i.e., factor A:- Potato varieties (V-4): V_1: BARI TPS-1, V_2: BARI Alu-28 (Lady Rosetta), V_3: BARI Alu-25 (Asterix) and V_4: BARI Alu-29 (Courage); factor B:- Vermicompost level (M-4): M_1: 0 t ha^{-1} (Control), M_2: 2 t ha^{-1}, M_3: 4 t ha^{-1} and M_4: 6 t ha^{-1}. The research revealed that vermicompost had a remarkable effect on most of the processing quality contributing parameters. Results also exhibited those processing parameters improved with increasing vermicompost level. Among the sixteen treatment combinations, Asterix with vermicompost at 6 t ha^{-1} showed the highest glucose, sucrose content. These two combinations also showed a little bit higher concentration of glucose and sucrose compared to those of other combinations.

Hindersah *et al.* (2019) conducted a field experiment to determine the effect of vermicompost with and without NPK fertilizer on soil acidity, soil phosphorus (P) availability and P uptake in potato shoots, as well as tuber yield and quality. They found that vermicompost and NPK fertilizer increased plant height as well as soil P availability and acidity when compared to controls.

Barman *et al*. (2018) reported that maximum number of tuber hill^{-1}, plant height and number of compound leaves was recorded under treatment (Vermicompost @ 2.5 t ha^{-1} + half NPK through inorganic fertilizer).

Koodi *et al.* (2017) reported the effect of NPK, FYM and vermicompost on growth, yield and quality of sweet potato. Vine length, leaf area, chlorophyll content in leaves, tuber weight, tuber length, tuber diameter, tuber yield (kg plot^{-1}), tuber yield (q ha^{-1}), NPK content, starch, protein, TSS and ascorbic acid content significantly differed at different fertility levels. The maximum vine length (172.9 cm), leaf area (185.3 cm^2), chlorophyll content (1.178 mg g^{-1}), tuber weight (323.62 g), tuber length (15.20 cm), tuber diameter (8.57 cm), tuber yield (12.32 kg plot^{-1}), tuber yield (228.16 q ha^{-1}), TSS content (4.56%), NPK content (0.348%, 0.310% and 0.646% respectively), starch (13.03%), protein (2.17%) and ascorbic acid content (43.49 mg 100 g^{-1}) were found in F_3 (100% RDF + 2.5 t VC ha^{-1}) fertility level.

Ram *et al.* (2017) carried out an experiment to study the impact of various organic treatments on growth, yield and quality parameters of potato. The experimental findings revealed that higher dry matter content (19.66%) and starch content (17.81%) were achieved in T_4 treatment (Crop residue incorporation + biofertilizers (*Azotobacter* and *Phosphobacteria* + Vermicompost @ 5 t ha^{-1} + microbial culture) which might be due to application of vermicompost that played a positive role in affecting dry matter of tubers.

Shrimal and Khan (2017) performed a field experiment to determine the effects of vermicompost on Chickpea (*Cicer arietinum* L.) var. RSG-896. Seeds of Chickpea (*Cicer arietinum* L.) var. RSG-896 were exposed to different treatment levels of vermicompost i.e., T_1 which was control level (soil without vermicompost), T_2, T_3, T4, T_5 and T_6. Plants were harvested at three stages i.e., pre-flowering, peak-flowering and post-flowering stages. With the increase in vermicompost level the root length, shoot length, root dry weight, shoot dry weight and total dry weight were increased to 39.36, 38.55, 36.92, 67.94, 64.26% respectively. Chlorophyll-a, chlorophyll-b and total chlorophyll contents also increased with increasing level of vermicompost to 86.95, 77.61 and 89.95% respectively.

Taha *et al.* (2017) obtained highest dry matter (18.84%) and maximum specific gravity (1.093) with the application of 50% recommended nitrogen + 25% recommended nitrogen through FYM @ 7.5 t ha^{-1} + 25% recommended nitrogen through VC @ 2.25 t ha^{-1}.

Bhat *et al.* (2016) revealed the most suitable organic source and pruning pattern for optimum growth, yield and quality of sweet pepper in Kashmir valley against four different nutrient treatments (S_1: Farmyard manure @ 2.5 kg m^{-2}, S_2: 25 Vermicompost @ 0.5 kg m^{-2}, S_3: Sheep manure @ 1.65 kg m^{-2} and S_4: Recommended fertilizer dose (20 t FYM + NPK @ 120:90:60 kg ha^{-1}) under two pruning levels P_1 : One shoot and P_2: three shoot. Data with regards to main effect revealed that organic manures through vermicompost (S_2) resulted in maximum plant height (117.18 cm). Most of the yield parameters also recorded higher values due to vermicompost (S_2).

Kumar and Singh (2016) conducted an experiment to study the effect of inorganic fertilizers and various organic manures on productivity, nutrient uptake and profitability of processing type autumn potato (*Solanum tuberosum* L.). Result revealed that the large sized (> 40g) potato tubers and total tuber yield was statistically as per with inorganic fertilizers and 100% nitrogen through vermicompost. With inorganic fertilizers applications, the large sized potato tubers and total potato tuber yield was observed 5.82 and 6.86 % more than application of 100 % N through vermicompost. These organic source of nutrients were statistically comparable with inorganic sources of nutrients. Sole application of organic sources of nutrients was equally efficient to inorganic fertilizers in improving the nutrients uptake and tuber yield.

Meena *et al*. (2016) conducted a field experiment during 2008–2009 and 2009–2010 to investigate the effect of organic sources of nutrients on tuber bulking rate, grades and specific gravity of potato tubers. The results revealed that the application of organic manures (FYM, LC and VC) recorded significantly higher tuber bulking rate as compared to RDF ($N_{120}P_{25}K_{35}$ kg ha^{-1}) and control plots.

Mondal *et al*. (2016) showed that the crop receives 80% RDN (N:P:K=200:150:150 kg ha^{-1}) through chemical fertilizer + 20% RDN through vermicompost recorded greater plant height, dry matter accumulation, crop growth rate, tuber growth rate and tuber bulking rate at different growth stages than 100% RDN through chemical fertilizer.

Srimathi (2015) reported that organic mode of nutrient through various combinations of bio regulators was found to be superior over chemical fertilizers, in terms of increased plant height, number of leaves and average yield of curd. The best combination was 100% recommended dose of fertilizers through vermicompost @ 3.1 t ha^{-1} along with foliar spray of humic acid (0.1%).

Dubey *et al.* (2014) observed that application of 75% NPK through chemical fertilizers along with 5 t ha^{-1} vermicompost gave the highest tuber yield of 336 q ha^{-1} with 41.17% higher yield of potato as compared to farmer's practice followed by 75% NPK through chemical fertilizers along with 20 t ha^{-1} compost and FYM.

Najar and Khan (2013) reported a significant increase in vegetative plant growth of tomato in plots amended with 6 t ha^{-1} vermicompost. The macro-nutrients provided by vermicompost improve crop yield via activation of enzymes involved in chlorophyll synthesis, growth, yield and enzyme system maintenance.

Narayan *et al.* (2013) showed that integrated approach of nutrient management, particularly 75% RDF + 8 t ha^{-1} vermicompost + *Azotobacter* and PSB can be recommended for getting the enhanced yield of potato under temperate condition of Kashmir valley.

Sarkar *et al*. (2011) reported positive effect of applying nutrients from organic and inorganic sources and their combinations on plant height, leaf area index (LAI), dry matter production, number of shoots, number of tubers, tuber yield of potato and net return treatment of 40% organic + 60% inorganic recorded significantly higher effect followed by 50% organic + 50% inorganic over other treatments.

Mirdad (2010) reported that organic fertilizer application increases the availability of soil macro and micro-nutrients and provides nutrients to meet crop requirements, supporting crop production.

Suthar (2009) studied the growth and yield of garlic (*Allium sativum*) on application of vermicompost and Farm Yard Manure. Different doses of vermicompost, compost and chemical fertilizers were applied alone and in combinations. It was found that there was excellent plant growth as well as yield in garlic plants that received vermicompost as main nutrient supplier. So, vermicompost proved to be better than Farm Yard Manure while combined treatment of vermicompost and chemical fertilizers proved to be the best.

Ansari (2008) studied the effect of vermicompost and vermiwash in reclaimed sodic soils on the productivity of onion (*Allium cepa*) and potato (*Solanum tuberosum*). Among the combinations of vermicompost @ 6 tonnes and vermiwash (different concentrations), there has been significant improvement in soil qualities in plots treated with vermicompost and vermiwash (1:10 v/v in water), vermicompost and vermiwash (natural) and vermicompost and vermiwash (1:5 v/v in water). The yield of onion was significantly higher in plots treated with vermiwash (1:10 v/v in water) whereas the average weight of onion bulbs was significantly greater in plots amended with vermicompost and vermiwash (1:5 v/v in water). The yield of potato and the average weight of potato tubers were significantly higher in plots treated with vermicompost.

Alam *et al*. (2007) conducted a field experiment and showed that application of various amounts of vermicompost (2.5, 5, 10 t ha^{-1}) with NPKS fertilizers (50% and 100%) increased the vegetative growth and yield of potato.

Bongkyon (2004) reported that the effect of vermicompost application was favourable than the effect of chemical fertilizers on potato crop.

Das *et al*. (2004) found that the highest dry matter accumulation, number of tubers $plant^{-1}$, tuber weight $plant^{-1}$ and tuber yield in the treatment having 60% recommended N as vermicompost + 40% recommended dose of N as urea rather than in the treatments using 100% recommended dose of N as urea or farmers' practice or other combinations of vermicompost and urea.

Kumaraswamy *et al*. (2002) reported that application of vermicompost 20 t ha^{-1} was found to be significantly superior in number of leaves $plant^{-1}$, leaf length, diameter of stem over vermicompost (0 t ha^{-1}). This one could be due to presence of enzymes, hormones, growth regulators along with plant nutrient in vermicompost which improves the nutrient uptake and provide better condition for improvement of growth character of potato.

CHAPTER III

MATERIALS AND METHODS

The field experiment was conducted during the Rabi season of 2021-2022. The details regarding soil, climate, weather and method adopted for the present investigation are summarized in this chapter under appropriate heads.

3.1 Experimental period

The experiment was conducted during the period from November 2021 to February 2022.

3.2 Description of the experimental site

3.2.1 Geographical location

The experiment was carried out at Sher-e-Bangla Agricultural University's (SAU) Agronomy farm. The experimental site is located 8.6 meters above sea level at a latitude and longitude of 23°77 N and 90°33 E, respectively. In Appendix I Map of Bangladesh's AEZ, the experimental site has been highlighted for easier understanding.

3.2.2 Climate and weather

The experimental site's climate was subtropical, with the winter season lasting from November to February, the pre-monsoon period, also known as the hot season, lasting from March to April, and the monsoon season lasting from May to October. Appendix-II contains meteorological information about the temperature, relative humidity and rainfall during the experiment period that was gathered from the Bangladesh Meteorological Department's Climate Division in Sher-e-Bangla Nagar, Dhaka.

3.2.3 Soil characteristics

The soil of experimental plot was medium deep black having uniform topography. In order to know the physio-chemical properties of the experimental site, the soil samples to the depth of 0-30 cm were randomly collected from the experimental site before planting and further analysis. The soil analysis was done at Soil Resource and Development

Institute (SRDI), Dhaka. The morphological and physio-chemical properties of the soil are presented in Appendix-II.

3.3 Planting materials

BARI Alu-25 (Asterix) was used as planting material in this experiment. The main characteristics of this variety was given below-

BARI Alu-25 (Asterix)

BARI Alu-25 (Asterix) was developed by Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh. The origin of this variety came from Netherlands and in the year of 2005, it was then officially released for cultivation of potato. Plant is straight and average 3-4 stem plant^{-1}; leaf large, green and bushy, plant structure and leaf orientation is attractive; potato oval shape to tall, medium to large size; skin red and smooth, flesh pale yellow, shallow eye, sprout violet color and hairy, crop duration 90-95 days. It was cultivated in Rabi season and the average yield between 25-30 t ha^{-1}. This variety is suitable for food processing.

3.4 Experimental design and layout

The experiment was laid out in split-plot design having 3 replications. In main plot there was biochar treatment and in sub plot there was vermicompost treatment. There were 16 treatment combinations and 48 unit plots. The unit plot size was 5.0 m^2 (2.5 m × 2 m). The blocks and unit plots were separated by 1.0 m and 0.50 m spacing respectively. Line to line and hill to hill spacing was 0.50 m and 0.20 m respectively.

3.5 Experimental treatment

There were two factors in the experiment namely different doses of biochar and vermicompost application as mentioned below:

Factor A. 4 doses of biochar

B_1: 0 (Control)
B_2: 1.5 t ha^{-1}
B_3: 3.0 t ha^{-1} and
B_4: 4.5 t ha^{-1}

Factor B. 4 doses of vermicompost

Vm_1: 0 (Control)
Vm_2: 1.5 t ha^{-1}
Vm_3: 3.0 t ha^{-1} and
Vm_4: 4.5 t ha^{-1}.

Treatment combinations- Sixteen treatment combinations: B_1Vm_1, B_1Vm_2, B_1Vm_3, B_1Vm_4, B_2Vm_1, B_2Vm_2, B_2Vm_3, B_2Vm_4, B_3Vm_1, B_3Vm_2, B_3Vm_3, B_3Vm_4, B_4Vm_1, B_4Vm_2, B_4Vm_3, B_4Vm_4.

3.6 Tuber collection

For conducting the present experiment, the tuber of the test crop i.e., BARI Alu-25 was collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.7 Land preparation

Initially, the field was prepared with the help of tractor drawn implement. After giving one deep ploughing, the experimental field was cross harrowed and levelled properly to break the clods and bring the soil to the desired tilth. The plots were prepared manually for sowing the subsequent crops of the experimental study.

3.8 Application of manures and fertilizers

Potato, with its sparse root system, responds well to applied nutrients. The potato crop requires a large amount of nutrients, specifically nitrogen, phosphorus, and potassium, for proper growth and development. The full amount of organic fertilizer, biochar and vermicompost, was applied in accordance with the treatment requirement and inorganic fertilizers MoP, TSP, Gypsum, and Zinc Suphate were applied as a basal dose at the time of planting. A half dose of Urea was applied as a basal dose with the remainder applied at 50 DAP. Following amounts of fertilizers were applied in all plots.

Manures and fertilizers	Dose ha^{-1}	Application (%)	
		Basal	50 DAP
Biochar	As per treatment	100	--
Vermicompost	As per treatment	100	--
Urea	325 kg	50	50
TSP	200 kg	100	
MoP	250 kg	100	--
Gypsum	100 kg	100	--
Zinc Suphate	8 kg	100	--

(Source: BARI, 2019)

3.9 Planting of tubers

Well sprouted seed tubers were selected and placed maintaining 50 cm line to line spacing and 20 cm hill to hill spacing. Planting of tubers was done on 21 November 2021. To protect crop from sucking pest at initial stage, granules of Thimet 10 G were applied uniformly in row @ 10 kg ha^{-1}. Irrigation was given immediately after planting of tubers.

3.10 Intercultural operations

3.10.1 Weeding and mulching

To keep the plots free of weeds, manual weeding was done when needed. For easy aeration and to store soil moisture as needed, the soil crusts were broken and then mulched. Mulching also assisted in preventing the growth of weeds such as Bathua plants (*Chenopodium album*). These two procedures were properly carried out without endangering the health of the test crop.

3.10.2 Earthing up

Earthing up was done twice during the crop growing period. The first earthing up was done at 25 DAP on 15 December 2021 and second earthing up done after 15 days of the first earthing up on 30 December 2021.

3.10.3 Irrigation

Irrigation was given before planting and 10 days after planting on 30 November 2021 and 30 days after planting on 20 December 2021 for good emergence of tuber and establishment of crop.

3.10.4 Plant protection

Other than cutworm, no other insect was found to be detrimental to potato growth. During the last stage of field preparation, Furadan 5G was applied @ 10 kg ha^{-1} to protect soil-borne insects. To suppress the cutworm, Dursban was applied @ 2 ml L^{-1} after 20 DAP. As a defense against potato late blight (*Phytophthora infestans*), Dithane M-45 was applied @ 2 g L^{-1} at 10 day intervals. In some plots, poisonous bait was employed to keep rats away from the tubers.

3.11 Haulm cutting

Haulm cutting was done at maturity level at 77 days after planting on 6 February 2022. After haulm cutting, the tubers were kept under the soil for skin hardening.

3.12 Harvesting

Harvesting was done at physiological maturity. First of all, the border was harvested. Then net plot was marked. Harvesting was done at 90 days after planting on 19 February 2022 manually with the help of spade.

3.13 Collection of data

The following parameters were recorded and their mean values were calculated from the sample plants.

i. 1^{st} emergence
ii. 80% emergence
iii. Plant height
iv. Number of leaves $plant^{-1}$
v. Number of stem $plant^{-1}$
vi. Number of tuber $plant^{-1}$
vii. Tuber yield $plant^{-1}$
viii. Tuber yield (t ha^{-1})
ix. Marketable yield (t ha^{-1})
x. Category of potato tubers for different uses
xi. Dry matter content (%)

xii. Specific gravity

xiii. Reducing sugar content

xiv. Starch content

3.14 Procedure of data collection

i. 1st emergence

To determine the number of days needed for the 1st emergence of potato seedlings, each experiment plot was closely monitored beginning rates at 1 December 2021 on day 10 after planting. The total number of days between the planting date and the visible emergence were counted and recorded.

ii. 80% emergence

For the purpose of keeping track of the number of days needed for 80% of the potato seedlings to emerge, each experiment plot was closely monitored. Total number of days from planting to 80% emergence was recorded.

iii. Plant height

The height of the main stem from the ground level to the apical bud (leaf apex) was measured with the meter scale at 15 days' interval from 30 to 75 days after planting.

iv. Number of leaves plant^{-1}

From each of the selected potato plants, the total number of plant^{-1} leaves was counted. The average of five randomly chosen plants from the inner rows of each plot were used to calculate the data, which were recorded at 15 days' interval from 30 to 75 days after planting.

v. Number of stems plant^{-1}

The total number of stems plant^{-1} was counted from each selected plants. Data were recorded as the average of 5 plants selected at random from the inner rows of each plot at 15 days' interval from 30 to 75 days after planting.

vi. Number of tuber plant^{-1}

Number of tubers from three randomly uprooted plants was counted and the mean value computed to indicate the number of tubers plant^{-1}.

vii. Tuber yield plant^{-1}

The weight of tubers plant^{-1} was calculated from the average of 5 randomly selected plants from each unit plot at harvest and was expressed in gram.

viii. Tuber yield (t ha^{-1})

The yield of tuber received from each net plot was recorded and converted on hectare basis by multiplying with hectare factor.

ix. Marketable yield

The total tubers obtained from each plot were sorted out into different grades according to weight i.e., small size < 50 g, medium size 50 – 100 g and big size > 100g. The total weight of medium and big size tubers were recorded separately for marketable tuber yield plot^{-1}. Marketable tuber yield plot^{-1} was converted to tons ha^{-1} by multiplying with the appropriate factor.

x. Category of potato tubers for different uses

The harvested potato tubers from 1 m^2 area of each unit plot were classified for different purposive uses i.e., Canned (25-45 mm), Chips (45-75 mm) and French fry (>75 mm), potato and expressed in percentage. Then category wise potato tubers yield plot^{-1} was converted to ton ha^{-1} by multiplying with necessary factor.

xi. Tuber dry matter content (%)

Tuber samples were collected from each treatment. The samples after being peeled were dried in an oven at 72 degrees Celsius for 72 hours. The weights of tuber flesh dry matter content % were then recorded. The dry matter percentage of tuber was calculated using the formula below.

$$\text{Dry matter content (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

xii. Specific gravity

Specific gravity of potato tubers was measured by using the following formula (Gould, 1995). Five tubers were taken from each plot after harvest of treatment and then the means were taken.

$$\text{Specific gravity} = \frac{\text{Weight of tuber in air}}{\text{Weight of tuber (g) in fresh water at } 4^0\text{C}}$$

xiii. Starch content

The starch content of potato tuber was estimated using the standard procedure (Sawhney and Randhir, 2001) and expressed in percentage on dry weight basis.

xiv. Reducing sugar content

Reducing sugar content was determined following the method of Nelson (1944).

3.15 Statistical analysis

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program Statistix 10 software. The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

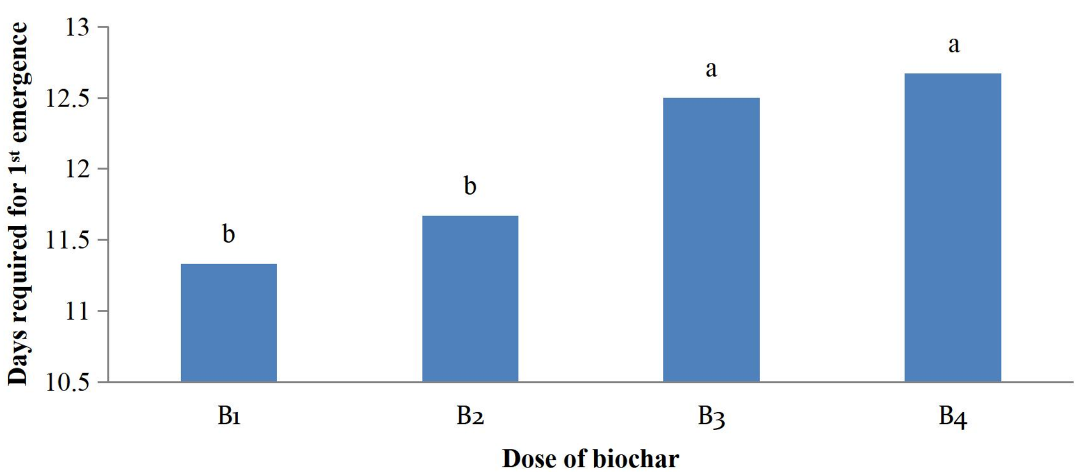
RESULTS AND DISCUSSION

This section contains a presentation and discussion of the study's findings on improving growth, yield and quality of potato through biochar and vermicompost management. The information are presented in various tables and figures. The findings have been discussed, and possible interpretations are provided under the headings listed below.

4.1 Days required for 1st emergence

Effect of biochar

Different biochar doses resulted in significant differences in the number of days required for the 1st emergence of potato seedlings (Figure 1). The maximum number of days required for 1st emergence (12.67) was obtained from the B_4 treatment which was statistically similar to B_3 (12.50) treatment. While the minimum number of days for the 1st emergence of potato (11.33) was obtained from the B_1 treatment which was statistically similar to B_2 (11.67) treatment. Haefele *et al.* (2011) also reported that biochar application improved the cation exchange capacity (CEC) and soil water holding capacity, thereby improved emergence of potato seedlings.

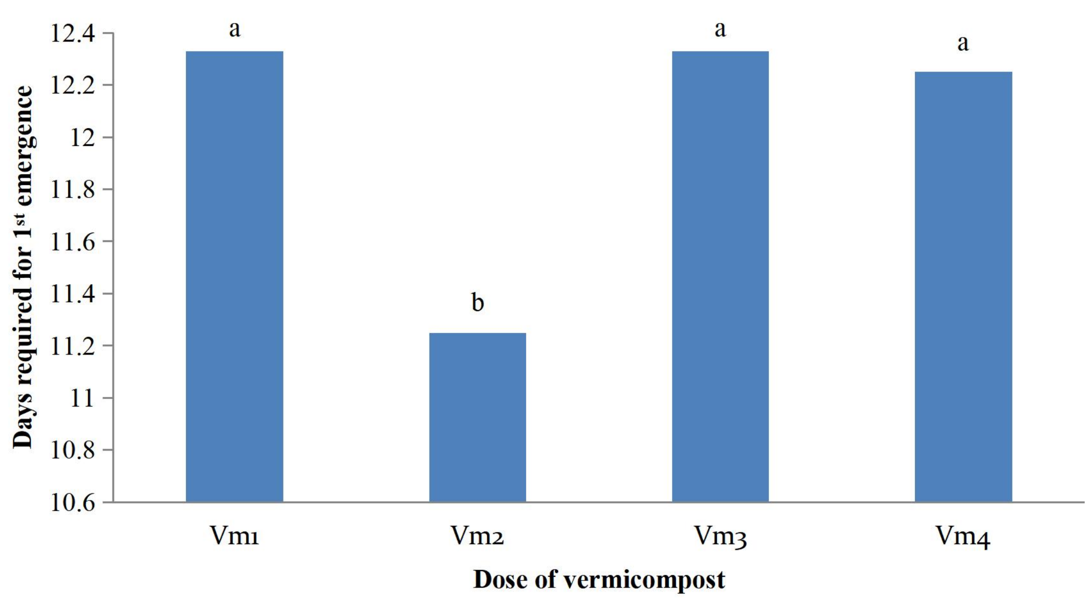


Note: B_1: 0 (Control) , B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 1. Effect of doses of biochar on the days required for 1st emergence of potato seedlings ($LSD_{0.05}$ = 0.60; the same letters indicate that there is no significant difference between the meanings from LSD test)

Effect of vermicompost

The number of days required for the 1st emergence of potato seedlings varied significantly when different doses of vermicompost were applied (Figure 2). The maximum number of days needed for 1st emergence (12.33) was obtained from the Vm_3 treatment which was statistically comparable with the Vm_1 (12.33) and Vm_4 (12.25) treatment. While the Vm_2 treatment provided the minimum number of days (11.25) required for 1st emergence. Vermicompost application stimulates soil microbial activity, increases oxygen availability, maintains normal soil temperature, increases soil porosity and water infiltration and improves nutrient content, thereby improved emergence of potato seedlings. Li *et al.* (2020) found that vermicompost not only contributes to improve soil texture, aeration, and soil compaction; enhancing plant water and nutrient uptake; but also produces hormones, vitamins, plant regulators, antibiotics and beneficial microbes that further improve plant health.



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 2. Effect of doses of vermicompost on the days required for 1st emergence of potato seedlings ($LSD_{0.05}$ = 0.87; the same letters indicate that there is no significant difference between the meanings from LSD test)

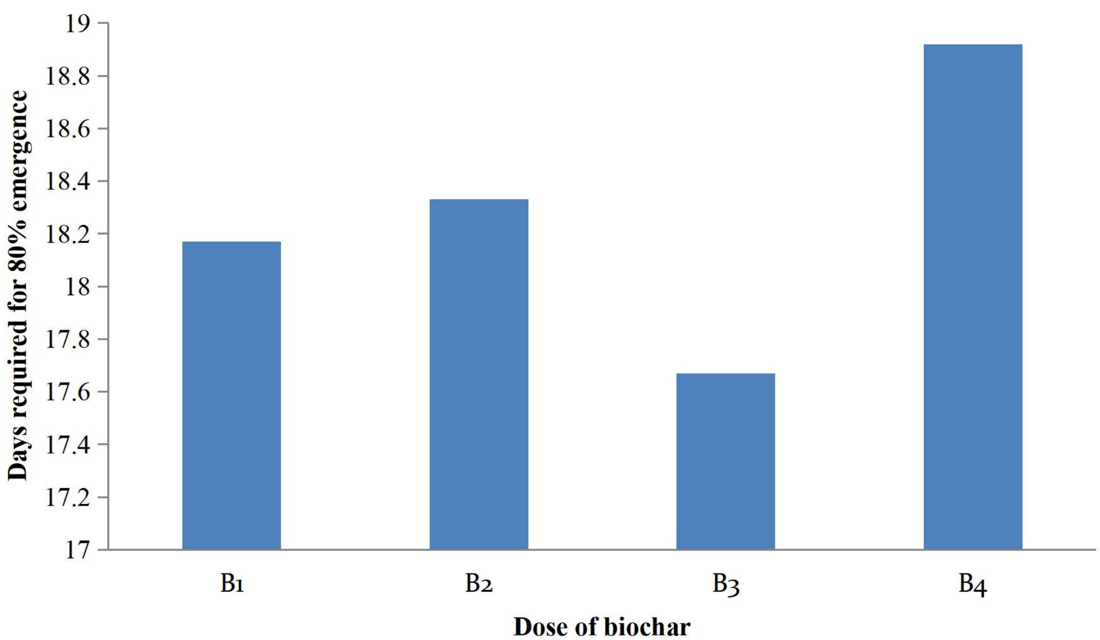
Interaction effect of biochar and vermicompost

The days required for the emergence of potato seedlings varied insignificantly due to the interaction effect of biochar and vermicompost doses (Table 1). The maximum number of days required for the 1st emergence (13.33) was found in the B_3Vm_4 interaction treatment while the minimum number of days (10.00) was found in the B_1Vm_2 interaction treatment.

4.2 Days required for 80% emergence

Effect of biochar

The number of days required for 80% emergence of potato seedlings varied insignificantly due to different biochar application doses (Figure 3). The maximum number of days required for 80% emergence (18.92) was observed in the B_4 treatment while the minimum number of days (17.67) was observed in the B_3 treatment.

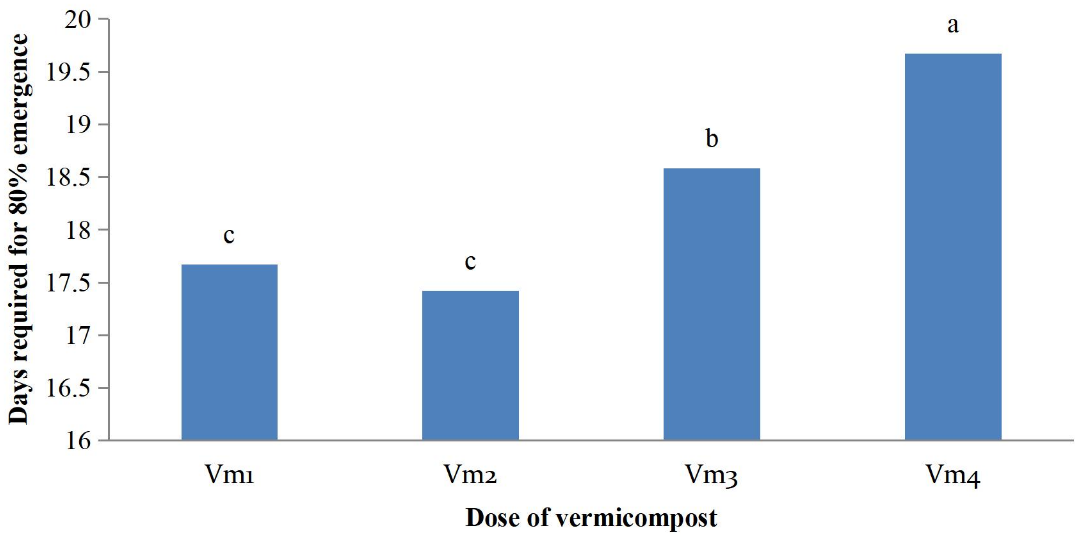


Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 3. Effect of doses of biochar on the days required for 80% emergence of potato seedlings ($LSD_{0.05}$= NS)

Effect of vermicompost

The number of days required for 80% emergence of potato seedlings varied significantly depending on the level of vermicompost used (Figure 4). The maximum days required for 80% emergence (19.67) were obtained from the Vm_4 treatment. While the minimum days (17.42) were obtained from the Vm_2 treatment which was statistically similar to the Vm_1 (17.67) treatment.



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 4. Effect of doses of vermicompost on the days required for 80% emergence of potato seedlings ($LSD_{0.05}$ = 0.85; the same letters indicate that there is no significant difference between the meanings from LSD test)

Interaction effect of biochar and vermicompost

The interaction effect of different doses of biochar and vermicompost resulted in statistically significant variation in the number of days required for 80% emergence (Table 1). The maximum number of days required for 80% emergence (20.00) was discovered in the B_4Vm_4 interaction treatment which was statistically similar to B_4Vm_3 (19.00), B_4Vm_2 (18.67), B_3Vm_4 (19.67), B_2Vm_4 (19.67), B_2Vm_3 (19.00), B_1Vm_4 (19.33) and B_1Vm_3 (18.33) interaction treatment. While the minimum number of days (15.67) was discovered in the B_3Vm_2 interaction treatment which was statistically similar to B_3Vm_1 (17.33) and B_1Vm_1 (17.33) interaction treatment.

Table 1. Interaction effect of doses of biochar and vermicompost on the days required for 1st and 80% emergence of potato seedlings

Interaction treatment	Days required for 1st emergence	Days required for 80% emergence
B_1Vm_1	11.33	17.33 def
B_1Vm_2	10.00	17.67 cde
B_1Vm_3	11.67	18.33 a-e
B_1Vm_4	12.33	19.33 abc
B_2Vm_1	12.67	17.00 ef
B_2Vm_2	10.67	17.66 cde
B_2Vm_3	12.33	19.00 a-d
B_2Vm_4	11.00	19.67 ab
B_3Vm_1	13.00	17.33 def
B_3Vm_2	11.33	15.67 f
B_3Vm_3	12.33	18.00 b-e
B_3Vm_4	13.33	19.67 ab
B_4Vm_1	12.33	18.00 b-e
B_4Vm_2	13.00	18.67 a-e
B_4Vm_3	13.00	19.00 a-d
B_4Vm_4	12.33	20.00 a
CV(%)	8.62	5.53
$LSD_{(0.05)}$	----	1.723
Significance level	NS	*

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.

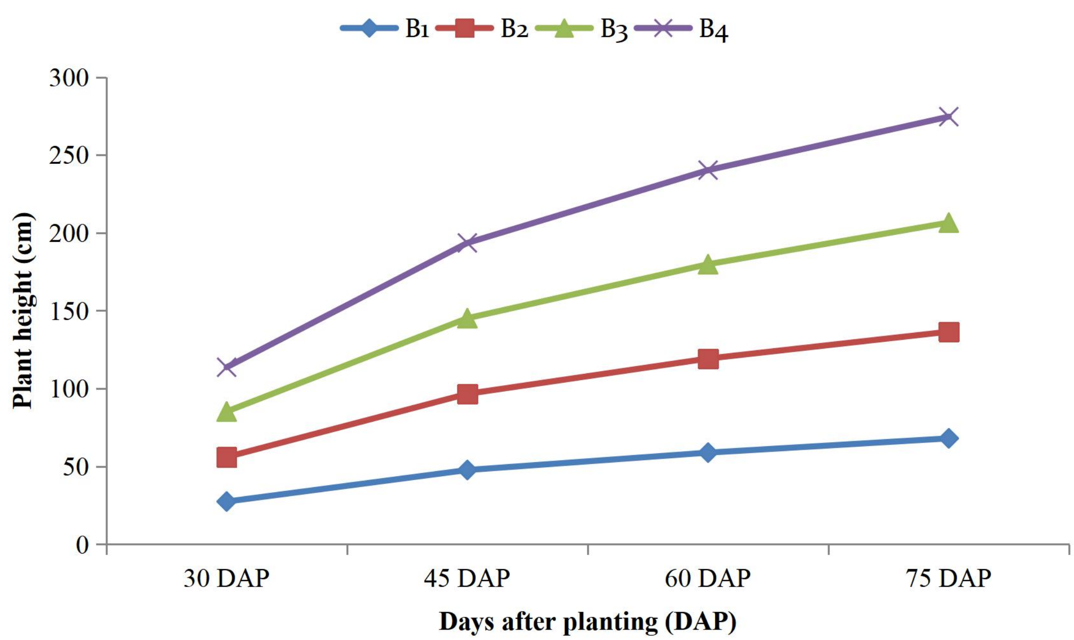
Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}, Vm_1: 0 (Control) , Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

* indicates 5% level of probability
NS means non-significance

4.3 Plant height

Effect of biochar

Plant height is an important aspect of the vegetative stage of the potato plant and has an indirect impact on yield. Plant height was measured 30, 45, 60 and 75 days after planting (DAP). The experimental results revealed that different doses of biochar application had shown non-significant effect on potato plant height at different DAP (Figure 5). At 30 DAP the highest plant height (29.25 cm) was observed in B_3 treatment while the lowest plant height (27.42 cm) was observed in B_1 treatment. At 45 DAP the B_2 treatment had the highest plant height (48.92 cm) while the lowest plant height (47.67 cm) was observed in B_1 treatment. At 60 and 75 DAP the highest plant height (60.58 cm and 70.08 cm) was observed in B_3 treatment while the lowest plant height (58.83 cm and 68.00 cm) was observed in B_1 treatment (Figure 5). The increase in the plant height might be due the biochar's ability to reduce leaching of nutrients, increase water and nutrient retention, increase microbial activity and aeration in the soil and thereby slow, steady and balanced nutrients were supplied. This result in support with the findings of Kaur and Sharma (2020) reported that in berseem crop, application of 5% biochar increased plant height by 28-50%. Rageendrathas and De Silva (2017) reported that biochar application increased the plant height of onion compared to the fertilizer alone treatments.

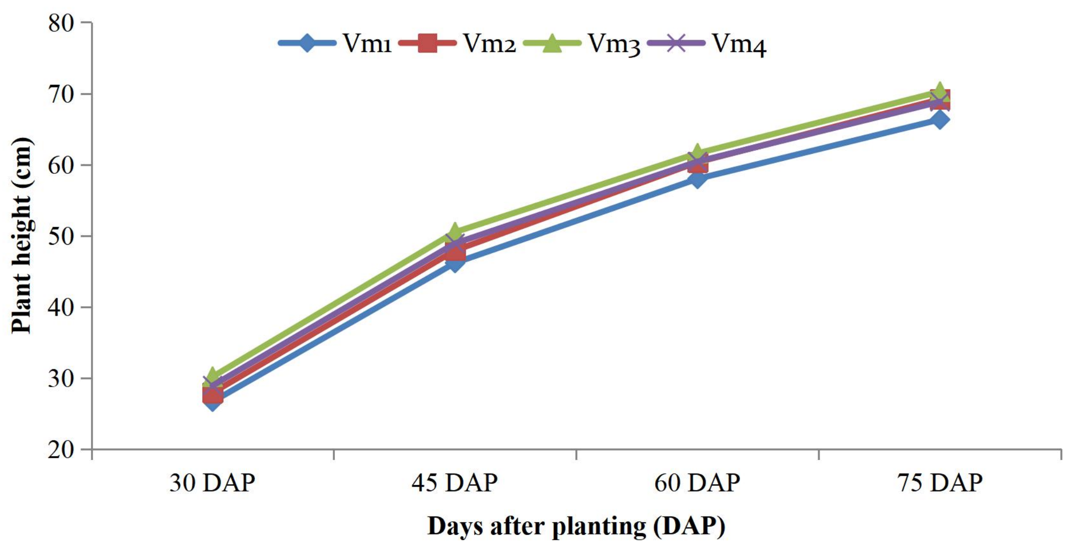


Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 5. Effect of doses of biochar on plant height of potato at different days after planting ($LSD_{0.05}$ = NS, NS, NS and NS)

Effect of vermicompost

Different levels of vermicompost application had shown significant effect on plant height of potato at different DAP (Figure 6). According to the experimental findings, the Vm_1 treatment had the lowest plant height (26.67, 46.17, 57.99 and 66.33 cm) at 30, 45, 60 and 75 DAP which was statistically similar to Vm_2 (27.92 cm) treatment at 30 DAP. While increased vermicompost application increased uptake of nutrients in the plants leading to enhanced chlorophyll content and carbohydrate synthesis that led to the increased cell division and enlargement of the cell size which helped in increasing plant height comparable to control treatment. As a result, the highest plant height (30.17, 50.50, 61.58 and 70.25 cm) at 30, 45, 60 and 75 DAP was observed in Vm_3 treatment which was statistically similar to Vm_4 (28.92 and 60.42 cm) treatment at 30 and 60 DAP. Similar results were found by Hindersah *et al.* (2019) supporting the current finding and reported that vermicompost and NPK fertilizer increased plant height as well as soil P availability and acidity when compared to controls.



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 6. Effect of doses of vermicompost on plant height of potato at different days after planting ($LSD_{0.05}$ = 1.69, 1.43, 1.83 and 2.02)

Interaction effect of biochar and vermicompost

Statistically significant variation was observed in potato plant height at 45 DAP, whereas non-significant variation was observed in potato plant height at 30, 60, and 75 DAP as a result of the interaction effect of different doses of biochar and vermicompost application (Table 2). Experimental result revealed that at 30 DAP, the highest plant height (32.00 cm) was observed in B_3Vm_4 interaction treatment while the lowest (26.00 cm) was observed in B_1Vm_2 interaction treatment. At 45 DAP, the B_2Vm_3 interaction treatment had the highest plant height (53.00 cm) which was statistically similar to B_2Vm_4 (50.67cm) and B_3Vm_3 (50.67cm) interaction treatments while the lowest plant height (44.00 cm) was observed in B_2Vm_1 interaction treatment which was statistically similar to B_1Vm (45.33 cm) and B_1Vm_2 (47.33 cm) interactions. At 60 DAP, the highest plant height (63.33 cm) was observed in B_2Vm_3 interaction treatment while the lowest one (58.00 cm) was observed in B_1Vm_3 treatment at 75 DAP. The B_3Vm_3 interaction treatment had the highest plant height (72.00 cm) while the lowest plant height (66.00 cm) was observed in B_2Vm_1 treatment.

Table 2. Interaction effect of doses of biochar and vermicompost on plant height of potato at different days after planting

Interaction treatment	Plant height at			
	30 DAP	45 DAP	60 DAP	75 DAP
B_1Vm_1	26.67	45.33 cd	58.67	66.33
B_1Vm_2	26.00	47.33 bcd	59.00	67.33
B_1Vm_3	28.33	49.00 b	58.00	68.67
B_1Vm_4	28.67	49.00 b	59.67	69.67
B_2Vm_1	25.33	44.00 d	57.33	66.00
B_2Vm_2	29.67	48.00 bc	63.33	69.00
B_2Vm_3	29.67	53.00 a	63.33	70.33
B_2Vm_4	28.67	50.67 ab	60.67	68.67
B_3Vm_1	26.33	47.33 b-d	57.33	66.67
B_3Vm_2	28.00	48.00 bc	61.33	70.67
B_3Vm_3	30.67	50.67 ab	62.33	72.00
B_3Vm_4	32.00	48.33 bc	61.33	70.00
B_4Vm_1	28.33	48.00 bc	58.33	66.33
B_4Vm_2	28.00	47.67 bc	60.67	68.67
B_4Vm_3	31.00	49.33 b	62.67	70.00
B_4Vm_4	26.33	47.67 bc	60.00	67.00
CV(%)	7.09	3.53	3.61	3.50
$LSD_{(0.05)}$	----	3.42	---	---
Significance level	NS	**	NS	NS

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: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}, Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

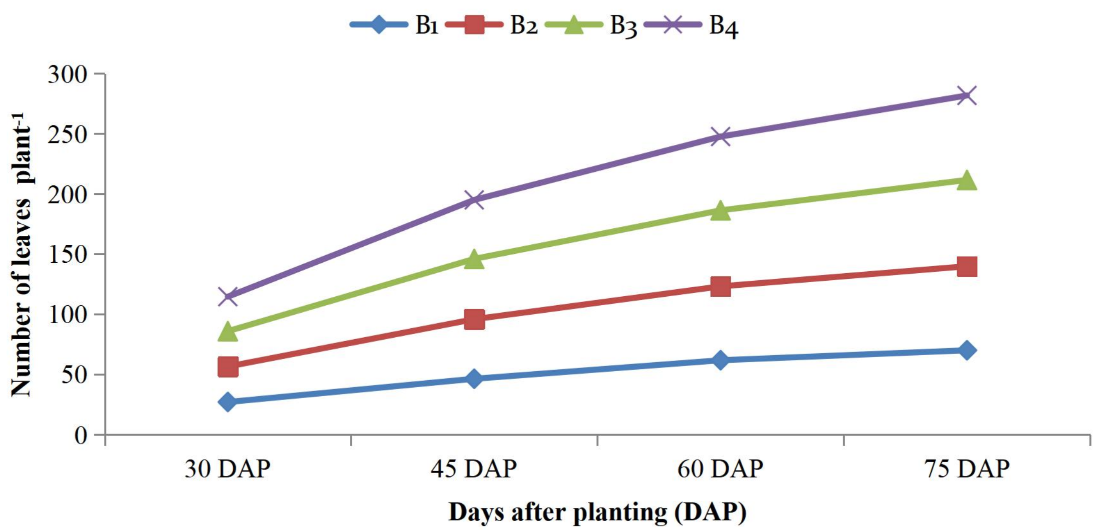
** indicates 1% level of probability
NS means non-significance

4.4 Number of leaves plant^{-1}

Effect of biochar

A leaf is the principal lateral appendage of the vascular plant stem, usually borne above ground and specialized for photosynthesis. The doses of biochar application had shown significant effect on number of leaves plant^{-1} of potato at different DAP (Figure 7). According to the experimental findings, B_1 treatment had the lowest number of leaves plant^{-1} (27.16 and 46.47) at 30 and 45 DAP. At 60 DAP, the lowest number of leaves plant^{-1} (61.28) was found at B_4 treatment which was statistically similar to B_1 (61.85) and B_2 (61.37). At 75 DAP, the lowest number of leaves plant^{-1} (69.82) was found at B_2

treatment which was statistically similar to B_1 (70.13) treatment. While the highest number of leaves plant^{-1} (29.47) at 30 DAP was found in B_2 treatment which was statistically similar to B_3 (29.37) and B_4 (28.65) treatment. At 45, 60 and 75 DAP, the highest number of leaves plant^{-1} (50.08, 63.16 and 71.69) was found in B_3 treatment which was statistically similar to B_2 (49.49) and B_4 (49.02) treatment at 45 DAP and B_4 (70.17) treatment at 75 DAP. Similar results were stated by Trupiano *et al*. (2017) supporting the current finding and reported that application of biochar alone stimulated lettuce leaves number. Carter *et al.* (2013) also concluded that application of rice husk biochar showed significant change in final biomass, plant height, root biomass and number of leaves in lettuce and cabbage in comparison to no biochar treatment.

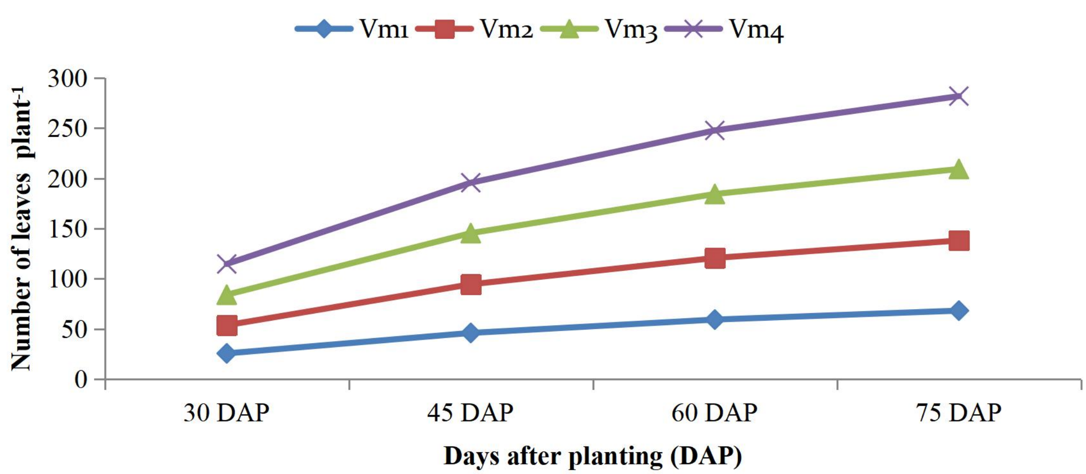


Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 7. Effect of doses of biochar on number of leaves plant^{-1} of potato at different days after planting ($LSD_{0.05}$ = 0.94, 1.36, 1.16, 0.77)

Effect of vermicompost

The number of leaves on plant^{-1} of the potato at different DAP responded significantly to various vermicompost application levels (Figure 8). According to the experimental findings, the Vm_1 treatment had the lowest number of leaves on plant^{-1} (25.59, 45.96, 59.26 and 68.18) at 30, 45, 60 and 75 DAP. While increased vermicompost application increased nutrient uptake in the plants and resulted in increased chlorophyll content and carbohydrate synthesis. This resulted in increased cell division and enlargement of cell size resulting in increased number of leaves on plant^{-1} when compared to the control treatment. As a result, the highest number of leaves on plant^{-1} (30.62) at 30 DAP was observed in Vm_4 treatment which was statistically similar to Vm_3 (30.34) treatment. At 45 and 60 DAP the highest number of leaves on plant^{-1} (50.96 and 63.68) was observed in Vm_3 treatment which was statistically similar to Vm_4 (50.19 and 63.32) treatment at 45 and 60 DAP. At 75 DAP the highest number of leaves on plant^{-1} (72.58) was observed in Vm_4 treatment which was statistically similar to Vm_3 treatment. Similar results were discovered by Barman *et al*. (2018) supporting the current finding and reported that maximum number of stems plant^{-1}, plant height and number of compound leaves were recorded under treatment (Vermicompost @ 2.5 t ha^{-1} + NPK through inorganic fertilizer). This one could be due to the presence of enzymes, hormones, growth regulators along with plant nutrient in vermicompost which improve the nutrient uptake and provide better condition for improvement of growth character of potato.



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 8. Effect of doses of vermicompost on number of leaves plant^{-1} of potato at different days after planting ($LSD_{0.05}$ = 1.29, 1.61, 1.48 and 1.43)

Interaction effect of biochar and vermicompost

As a result of the interaction effect of different doses of biochar and vermicompost application, statistically significant variation in the number of leaves on plant^{-1} of potato was observed at 30 and 75 DAP whereas non-significant variation was observed at 45 and 60 DAP (Table 3). Experimental result revealed that at 30 DAP the highest number of leaves on plant^{-1} of potato (32.37) was observed in B_2Vm_4 interaction treatment which was statistically similar to B_3Vm_4 (32.30), B_3Vm_3 (32.23) and B_2Vm_3 (30.57) while the lowest number of leaves on plant^{-1} (22.73) was observed in B_1Vm_1 interaction treatment. At 45 DAP the B_3Vm_3 interaction treatment had the highest number of leaves on plant^{-1} (53.10) while the lowest number of leaves on plant^{-1} (43.40) was observed in B_1Vm_1 interaction treatment. At 60 DAP the B_1Vm_4 interaction treatment had the highest number of leaves on plant^{-1} (67.40) while the lowest number of leaves on plant^{-1} (57.53) was observed in B_1Vm_1 interaction treatment. At 75 DAP the B_1Vm_4 interaction treatment had the highest number of leaves on plant^{-1} (75.97) which was statistically similar to B_3Vm_3 (74.70) interaction treatment while the lowest number of leaves on plant^{-1} (65.22) was observed in B_1Vm_1 interaction treatment.

Table 3. Interaction effect of doses of biochar and vermicompost on the number of leaves plant^{-1} at different days after planting

Interaction treatment	Number of leaves plant^{-1} at			
	30 DAP	45 DAP	60 DAP	75 DAP
B_1Vm_1	22.73 g	43.40	57.53	65.22 g
B_1Vm_2	27.00 def	47.37	61.47	69.77 def
B_1Vm_3	29.20 bcd	48.60	67.30	69.57 def
B_1Vm_4	29.70 bc	48.50	67.40	75.97 a
B_2Vm_1	26.63 ef	45.83	60.10	69.30 ef
B_2Vm_2	28.33 b-e	48.17	59.60	68.50 ef
B_2Vm_3	30.57 ab	51.23	61.67	68.47 ef
B_2Vm_4	32.37 a	52.73	64.10	73.60 bc
B_3Vm_1	25.17 f	47.40	60.47	70.37 def
B_3Vm_2	27.77 cde	48.43	62.90	70.77 cde
B_3Vm_3	32.23 a	53.10	65.93	74.70 ab
B_3Vm_4	32.30 a	51.40	63.33	70.93 cde
B_4Vm_1	27.83 cde	47.20	58.93	67.83 f
B_4Vm_2	29.30 bcd	49.83	61.60	70.27 def
B_4Vm_3	29.37 bcd	50.90	63.43	72.13 bcd
B_4Vm_4	28.10 cde	48.13	61.13	70.43 b-f
CV(%)	5.35	3.90	2.84	2.42
$LSD_{(0.05)}$	2.426	---	---	2.604
Significance level	*	NS	NS	**

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: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}, Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

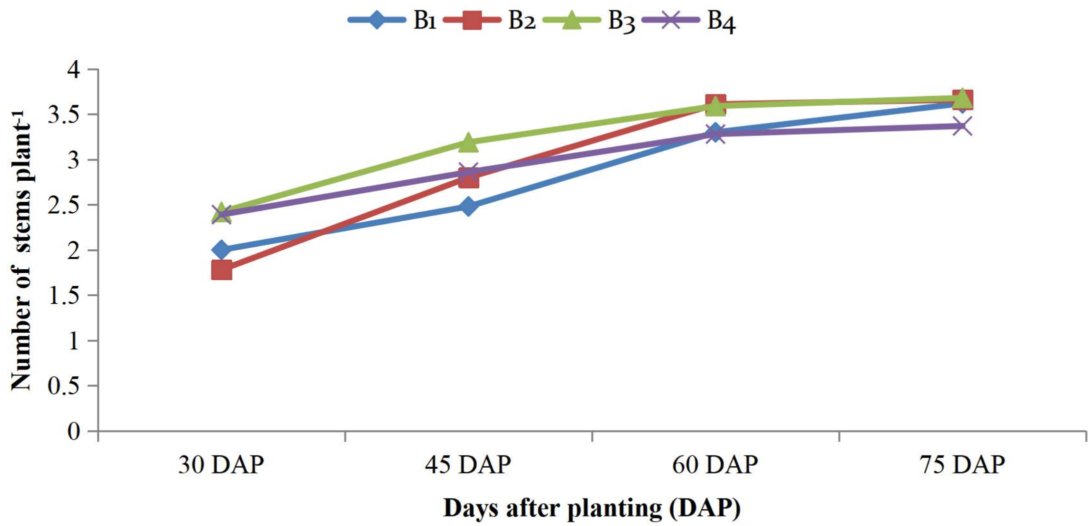
* and ** indicate 5% and 1% level of probability, respectively
NS means non-significance

4.5 Number of stems plant^{-1}

Effect of biochar

Due to biochar application doses, there was statistically non-significant variation in the number of stems plant^{-1} of potato at 30, 45, 60 and 75 DAP (Figure 9). At 30, 45, 60 and 75 DAP the B_3 treatment had the highest number of stems plant^{-1} (2.42, 3.19, 3.59 and 3.68). However, at 30 DAP the lowest number of stems plant^{-1} (1.78) was observed in B_2 treatment. At 45 DAP the B_1 treatment had the lowest number of stems plant^{-1} (2.48). At 60 and 75 DAP the lowest number of stems plant^{-1} (3.28 and 3.37) was observed in B_4

treatment. Youseef *et al.* (2017) revealed that the number of main stems and number of tubers significantly increased with increasing biochar application rates up to 12 m^3 ha^{-1}.

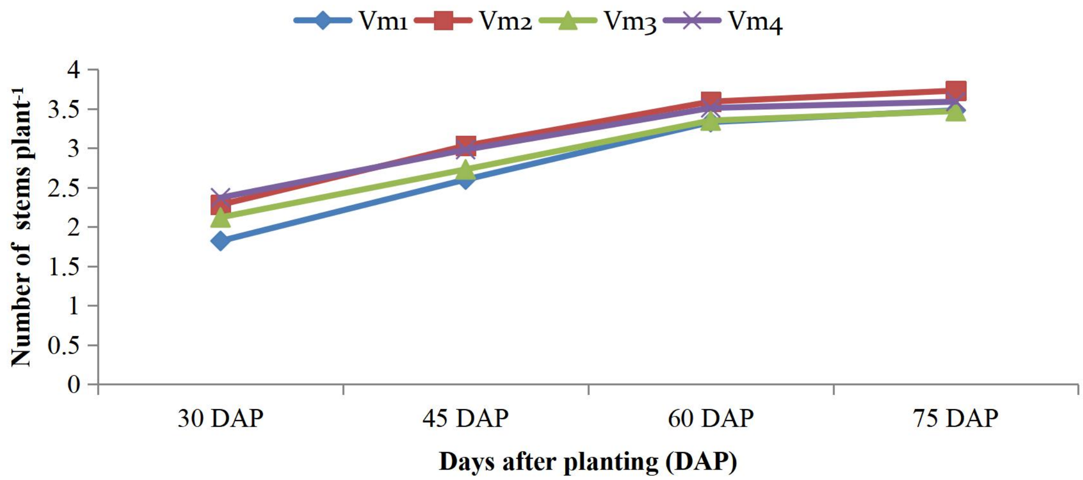


Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 9. Effect of doses of biochar on number of stems plant^{-1} of potato at different days after planting ($LSD_{0.05}$ = NS, NS, NS and NS)

Effect of vermicompost

Statistically significant variation was observed in the number of stems plant^{-1} of potato at 30 DAP, but not at 45, 60, or 75 DAP due to different doses of vermicompost application. (Figure 10). Experimental result revealed that at 30 DAP the highest number of stems plant^{-1} (2.37) was observed in Vm_4 treatment which was statistically similar to Vm_3 (2.12) and Vm_2 (2.28) treatment. At 45, 60 and 75 DAP the highest number of stems plant^{-1} (3.03, 3.59 and 3.73) was observed in Vm_2 treatment. However, at 30, 45, 60 and 75 DAP the Vm_1 treatment had the lowest number of stems plant^{-1} (1.82, 2.60, 3.33 and 3.48). Li *et al.* (2020) found that vermicompost not only contributes to improve soil texture, aeration and soil compaction enhancing plant water and nutrient uptake, but also produces hormones, vitamins, plant regulators, antibiotics, and beneficial microbes that further improve plant health.



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 10. Effect of doses of vermicompost on number of stems plant^{-1} of potato at different days after planting ($LSD_{0.05}$ = 0.35, NS, NS and NS)

Interaction effect of biochar and vermicompost

The interaction effect of doses of biochar and vermicompost application resulted in statistically significant variation in the number of stems plant^{-1} of potato at 30 DAP whereas non-significant variation was observed at 45, 60 and 75 DAP (Table 4). Experimental result revealed that at 30 DAP the highest number of stems plant^{-1} (3.37) was observed in B_4Vm_2 interaction treatment which was statistically similar to B_4Vm_4 (3.10), B_4Vm_3 (2.43), B_3Vm_3 (2.70) and B_3Vm_2 (2.67) interaction treatment while the lowest number of stems plant^{-1} of potato (1.20) was observed in B_2Vm_3 interaction treatment which was statistically similar to B_1Vm_1 (1.47), B_1Vm_2 (2.10), B_1Vm_3 (2.10), B_2Vm_1 (1.90), B_2Vm_2 (2.00), B_2Vm_4 (2.03), B_3Vm_1 (2.23), B_3Vm_4 (2.03) and B_4Vm_1 (1.67) interaction treatment. At 45, 60 and 75 DAP the B_2Vm_2 interaction treatment had the highest number of stems plant^{-1} (3.57, 4.20 and 4.20) while the lowest number of stems plant^{-1} (2.23) was observed in B_1Vm_2 interaction treatment at 45 DAP. While at 60 and 75 DAP the B_4Vm_1 interaction treatment had the lowest number of stems plant^{-1} (2.90 and 3.00).

Table 4. Interaction effect of doses of biochar and vermicompost on the number of stems plant^{-1} of potato at different days after planting

Interaction treatment	Number of stems plant^{-1} at			
	30 DAP	45 DAP	60 DAP	75 DAP
B_1Vm_1	1.47 de	2.77	3.23	3.57
B_1Vm_2	2.10 b-e	2.23	3.10	3.73
B_1Vm_3	2.10 b-e	2.27	3.40	3.60
B_1Vm_4	2.33 bcd	2.67	3.50	3.57
B_2Vm_1	1.90 cde	2.43	3.53	3.53
B_2Vm_2	2.00 cde	3.57	4.20	4.20
B_2Vm_3	1.20 e	2.57	3.47	3.33
B_2Vm_4	2.03 cde	2.67	3.23	3.57
B_3Vm_1	2.23 b-e	2.87	3.67	3.83
B_3Vm_2	2.67 abc	3.13	3.47	3.57
B_3Vm_3	2.70 abc	3.43	3.57	3.67
B_3Vm_4	2.03 cde	3.33	3.67	3.67
B_4Vm_1	1.67 cde	2.30	2.90	3.00
B_4Vm_2	3.37 a	3.20	3.60	3.43
B_4Vm_3	2.43 a-d	2.67	3.00	3.27
B_4Vm_4	3.10 ab	3.27	3.63	3.57
CV(%)	19.40	26.75	20.08	16.47
$LSD_{(0.05)}$	1.05	---	---	---
Significance level	*	NS	NS	NS

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.

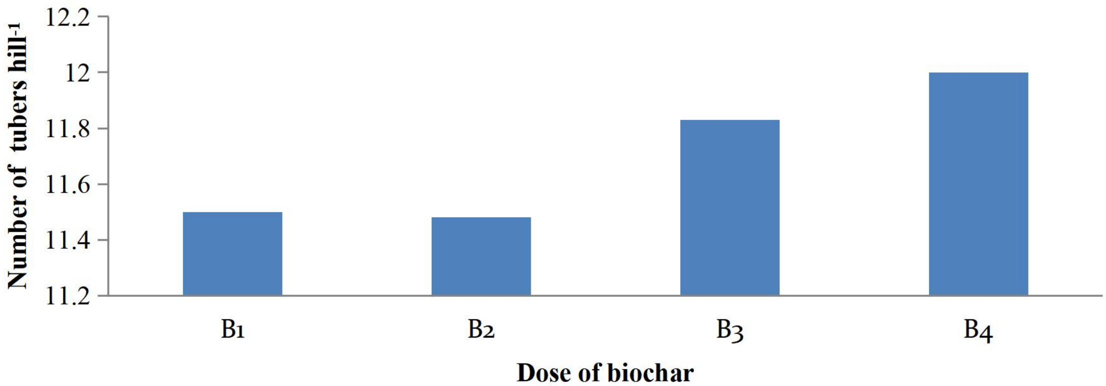
Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}, Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

* indicates 5% level of probability
NS means non-significance

4.6 Number of tubers hill^{-1}

Effect of biochar

The number of potato tubers hill^{-1} showed non-significant difference as a result of different doses of biochar application (Figure 11). According to the experimental findings, the B_4 treatment had the highest number of tubers hill^{-1} (12.00) while the B_2 treatment had the lowest (11.48) number of tubers hill^{-1}. Youseef *et al.* (2017) revealed that the number of tubers increased with increasing biochar application rates up to 12 m^3 ha^{-1}.

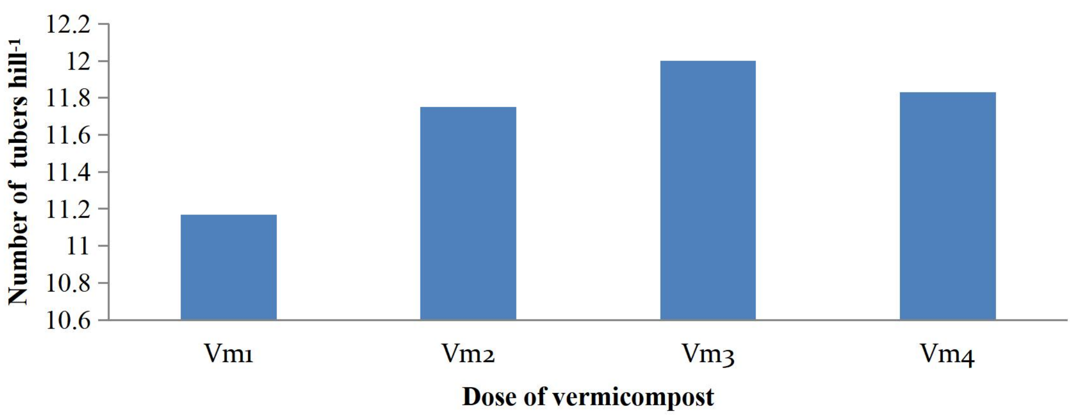


Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 11. Effect of doses of biochar on number of tubers hill^{-1} of potato ($LSD_{0.05}$ = NS)

Effect of vermicompost

Statistically non-significant variation was observed in the number of potato tubers hill^{-1} due to different doses of vermicompost application (Figure 12). According to the results of the experiments, the highest number of tubers hill^{-1} (12.00) was observed in Vm_3 treatment while Vm_1 treatment had the lowest (11.17) number of tubers hill^{-1}. Barman *et al*. (2018) reported that maximum number of tuber hill^{-1} was recorded under treatment (Vermicompost @ 2.5 t ha^{-1} + half NPK through inorganic fertilizer).



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 12. Effect of different doses of vermicompost on number of tubers hill^{-1} of potato ($LSD_{0.05}$ = NS)

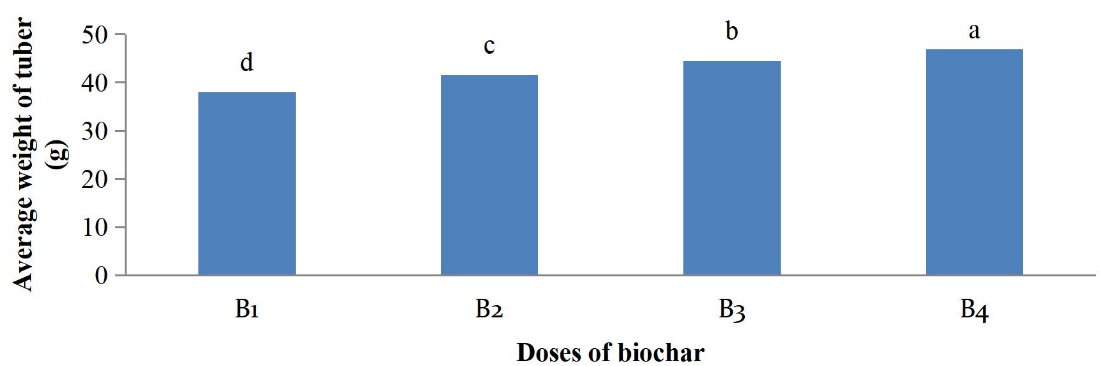
Interaction effect of biochar and vermicompost

The interaction effect of different doses of biochar and vermicompost application resulted in a non-significant variation in respect of the number of tubers hill^{-1} of potato (Table 5). Experimental result revealed that the highest number of tubers hill^{-1} (12.33) was observed in B_4Vm_3 interaction treatment while B_2Vm_1 interaction treatment had the lowest (10.67) number of tubers hill^{-1}.

4.7 Average weight of tuber (g)

Effect of biochar

The average weight of potato tuber differed significantly as a result of different biochar application doses. (Figure 13). According to the experimental findings, the B_4 treatment had the highest average weight of potato tuber (46.97 g) while the B_1 treatment had the lowest average weight of potato tuber (38.01 g). Increased average weight of potato tuber might be due to positive effects of inorganic fertilizers with organic manures (biochar) which could have induced higher vegetative growth and ultimately helped in the synthesis of greater amount of food material. These were later translocated into the developing tubers, resulting in an increased number of fruits. Similar result was also observed by Mollick *et al*. (2020) reported that biochar application significantly increased weight of tubers.

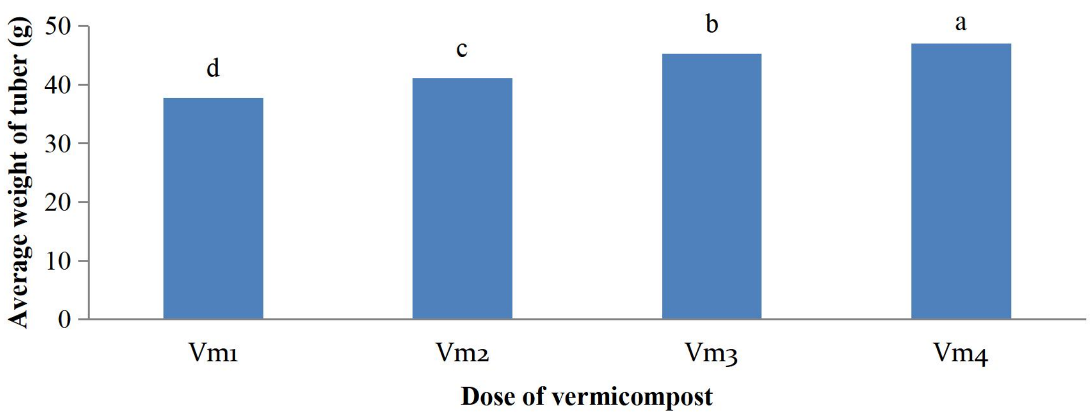


Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 13. Effect of doses of biochar on average weight of tuber of potato ($LSD_{0.05}$ = 1.21; the same letters indicate that there is no significant difference between the meanings from LSD test)

Effect of vermicompost

The levels of vermicompost application significantly influenced average weight of potato tuber (Figure 14). Experimental result revealed that the lowest average weight of potato tuber (37.69 g) was observed in Vm_1 treatment. While application of vermicompost influenced tuber weight and the highest average weight of potato tuber (47.07 g) was observed in Vm_4 treatment. Badrunnesa *et al*. (2021) also reported that the average tuber weight was increased with the increasing of vermicompost level. This could be attributed to increased availability of nutrients including micro nutrients in the soil which led to enhanced absorption of nutrients by the crop resulting in increased tuber weight.



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 14. Effect of doses of vermicompost on average weight of tuber of potato ($LSD_{0.05}$ = 1.39; the same letters indicate that there is no significant difference between the meanings from LSD test**)**

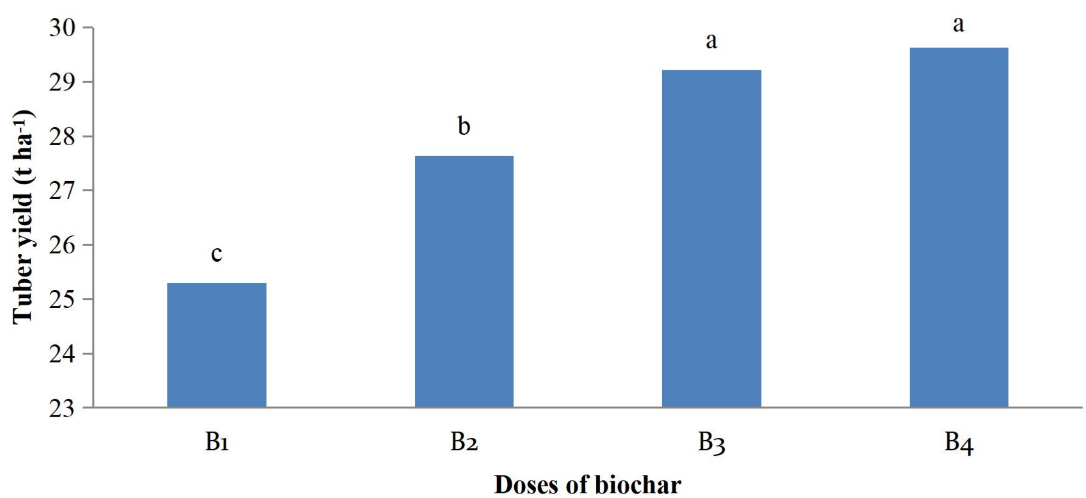
Interaction effect of biochar and vermicompost

The average weight of potato tubers significantly varied as a result of the interaction effect of different doses of biochar and vermicompost application (Table 5). Experimental result revealed that the highest average weight of potato tuber (49.97 g) was observed in B_4Vm_4 interaction treatment which was statistically similar to B_4Vm_3 (49.17 g), B_3Vm_4 (49.90 g) and B_2Vm_4 (45.53 g) interaction treatment. While B_1Vm_1 interaction treatment had the lowest (32.53 g) average weight of potato tuber.

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

Effect of biochar

Yield was found to be highly significant among the different levels of biochar application (Figure 15). Experimental result revealed that the B_1 treatment had the lowest tuber yield (25.30 t ha^{-1}). While the B_4 treatment had the highest tuber yield (29.63 t ha^{-1}) which was statistically similar to B_3 (29.22 t ha^{-1}) treatment. The reason for increased tuber yield could be attributed to solubilization effect of plant nutrients by the addition of biochar leading to increased uptake of NPK. Further biochar would have helped the soil to improve the nutrients status and water holding capacity. Roy *et al*. (2021) reported that the total yield and marketable yield of potato gradually increased with increasing biochar level. Haefele *et al.* (2011) reported that biochar application improved the CEC and soil water holding capacity and thereby 16-35% improvements in grain yield over control.

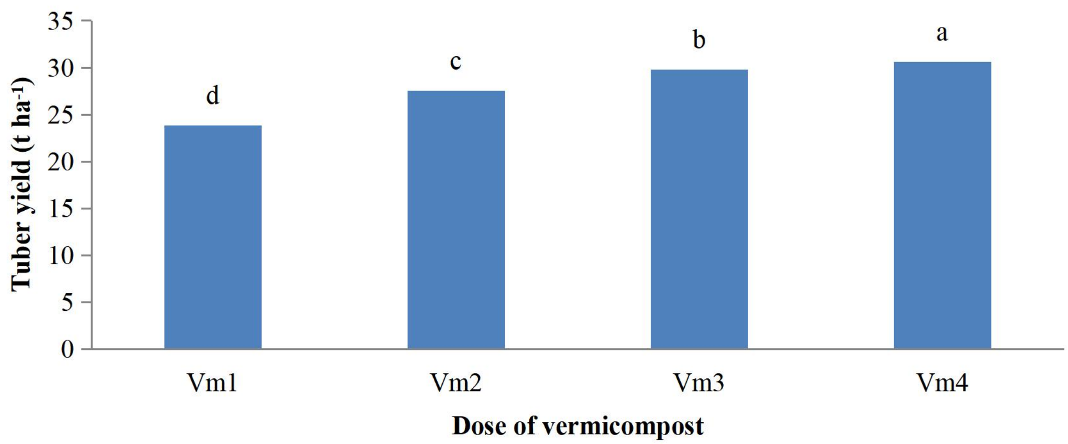


Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 15. Effect of different doses of biochar on tuber yield of potato ($LSD_{0.05}$ = 0.58; the same letters indicate that there is no significant difference between the meanings from LSD test**)**

Effect of vermicompost

The levels of vermicompost were found to have a significant impact on tuber yield (Figure 16). Experimental result revealed that the Vm_1 treatment had the lowest tuber yield (23.85 t ha^{-1}). While the application of vermicompost fertilizer influenced tuber yield and the highest tuber yield (30.62 t ha^{-1}) was observed in Vm_4 treatment. Badrunnesa *et al*. (2021) reported that the tuber yield and different categories of potato tuber were increased with the increasing of vermicompost level. Najar and Khan (2013) reported that the macronutrients provided by vermicompost improve crop yield via activation of enzymes involved in chlorophyll synthesis, growth, yield and enzyme system maintenance.



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 16. Effect of doses of vermicompost on tuber yield of potato ($LSD_{0.05}$ = 0.65; the same letters indicate that there is no significant difference between the meanings from LSD test**)**

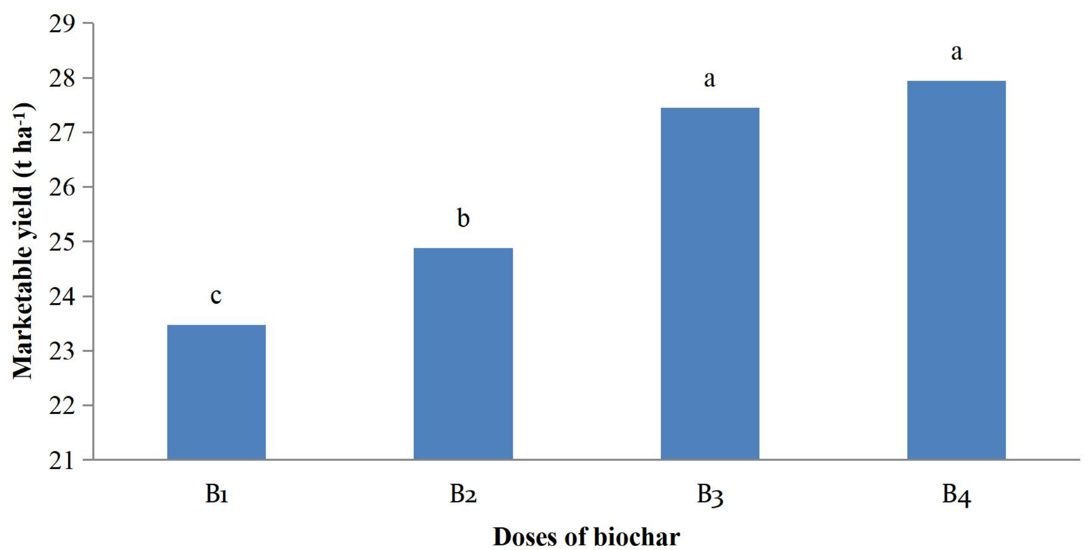
Interaction effect of biochar and vermicompost

The interaction effect of biochar and vermicompost fertilizer doses had a significant impact on tuber yield (Table 5). According to the experimental findings, the B_4Vm_4 interaction treatment recorded the highest tuber yield (32.47 t ha^{-1}) which was statistically similar to B_4Vm_3 (31.97 t ha^{-1}), B_3Vm_4 ((32.20 t ha^{-1}) and B_3Vm_3 (31.63 t ha^{-1}) interaction treatment. However, the B_1Vm_1 interaction treatment showed the lowest tuber yield (22.13 t ha^{-1}).

4.9 Marketable yield

Effect of biochar

The levels of biochar application were found to have highly significant differences in marketable tuber yield (Figure 17). According to experimental findings, the B_1 treatment had the lowest marketable tuber yield (23.47 t ha^{-1}). While the highest marketable tuber yield (27.94 t ha^{-1}) was observed by the B_4 treatment which was statistically comparable to the B_3 treatment (27.45 t ha^{-1}). Roy *et al*. (2021) reported that the total yield and marketable yield of potato gradually increased with increasing biochar level.

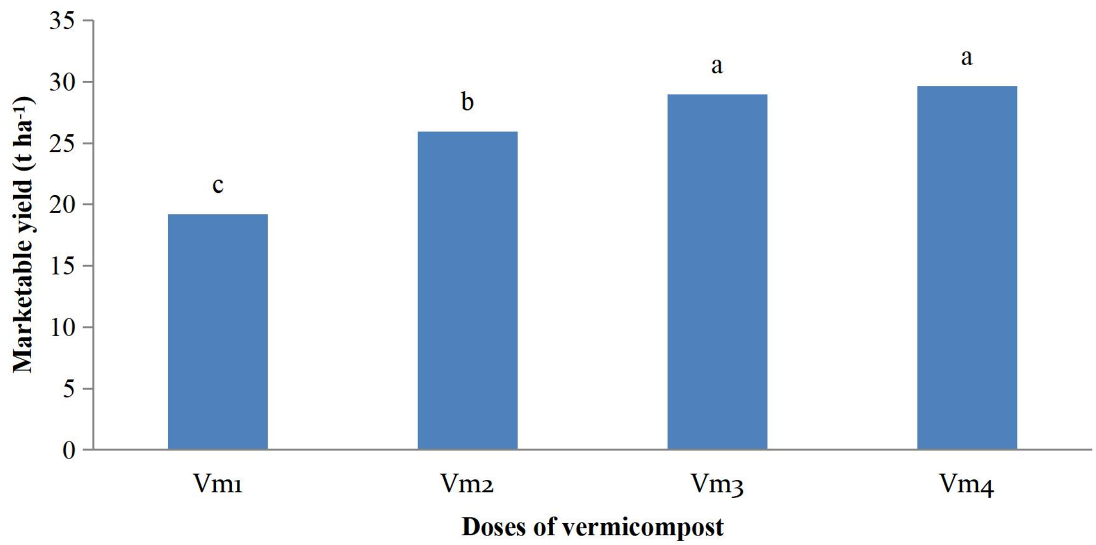


Note: B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

Figure 17. Effect of doses of biochar on marketable yield of potato ($LSD_{0.05}$ = 0.66; the same letters indicate that there is no significant difference between the meanings from LSD test)

Effect of vermicompost

Different doses of vermicompost levels were found to have a significant impact on marketable tuber yield (Figure 18). According to experimental findings, the highest marketable tuber yield (29.64 t ha^{-1}) was observed by the Vm_4 treatment which was statistically comparable to the Vm_3 treatment (28.95 t ha^{-1}). While the Vm_1 treatment had the lowest marketable tuber yield in the experiments (19.21 t ha^{-1}).



Note: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

Figure 18. Effect of different doses of vermicompost on marketable yield of potato (LSD value = 0.65; the same letters indicate that there is no significant difference between the meanings from LSD test)

Interaction effect of biochar and vermicompost

The interaction effect of biochar and vermicompost fertilizer doses had a significant impact on marketable tuber yield (Table 5). According to the experimental results, the B_4Vm_4 interaction treatment had the highest marketable tuber yield (32.07 t ha^{-1}) and was statistically similar to the B_4Vm_3 (31.67 t ha^{-1}), B_3Vm_4 (32.00 t ha^{-1}) and B_3Vm_3 (31.63 t ha^{-1}) interaction treatments. However, the B_1Vm_1 interaction treatment had the lowest marketable tuber yield (17.47 t ha^{-1}) which was statistically similar to the B_2Vm_1 (18.63 t ha^{-1}) interaction treatment.

Table 5. Interaction effect of biochar and vermicompost on the yield and yield contributing traits of potato

Interaction treatment	Number of tubers $hill^{-1}$	Average weight of tuber (g)	Tuber yield ($t\ ha^{-1}$)	Marketable yield ($t\ ha^{-1}$)
B_1Vm_1	11.00	32.53 h	22.13 e	17.47 g
B_1Vm_2	11.33	36.47 g	24.17 d	23.83 d
B_1Vm_3	11.67	40.17 ef	26.63 c	25.53 c
B_1Vm_4	12.00	42.87 de	28.27 b	27.03 b
B_2Vm_1	10.67	36.17 g	23.90 d	18.63fg
B_2Vm_2	11.67	39.87 f	28.27 b	26.47 bc
B_2Vm_3	12.00	44.90 cd	28.83 b	26.97 b
B_2Vm_4	11.33	45.53 abc	29.53 b	27.47 b
B_3Vm_1	11.00	39.53 f	24.57 d	19.63 f
B_3Vm_2	12.33	41.83 ef	28.47 b	26.53 bc
B_3Vm_3	12.00	46.93 bc	31.63 a	31.63 a
B_3Vm_4	12.00	49.90 a	32.20 a	32.00 a
B_4Vm_1	12.00	42.53 de	24.80 d	21.10 e
B_4Vm_2	11.67	46.20 c	29.27 b	26.93 b
B_4Vm_3	12.33	49.17 ab	31.97 a	31.67 a
B_4Vm_4	12.00	49.97 a	32.47 a	32.07 a
CV(%)	8.82	3.87	2.77	3.16
$LSD_{(0.05)}$	----	2.623	1.269	1.374
Significance level	NS	**	*	*

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: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}, Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

* and ** indicate 5% and 1% level of probability, respectively.
NS means non-significance

4.10 Yield for canned potato production

Effect of biochar

The different levels of biochar application were found to have highly significant differences in respect of yield for canned potato production (Table 6). According to experimental findings, the B_1 treatment had the highest yield for canned potato production (2.24 t ha^{-1}). While the lowest yield for canned potato production (1.82 t ha^{-1}) was observed by the B_4 treatment, which was statistically comparable to the B_3 treatment (1.88 t ha^{-1}).

Table 6. Effect of different doses of biochar on the yield of potato for different processing purpose

Biochar doses	Yield for canned potato production ($t\ ha^{-1}$) (20-30 mm)	Yield of potato for flakes potato production ($t\ ha^{-1}$) (30-45 mm)	Yield of potato for chips production ($t\ ha^{-1}$) (45-75 mm)	Yield of potato or French fry production ($t\ ha^{-1}$) (>75 mm)
B_1	2.24 a	5.66 a	14.41 d	1.54 d
B_2	2.03 b	4.53 b	15.02 c	3.30 c
B_3	1.88 c	4.38 c	17.08 b	4.12 b
B_4	1.82 c	3.92 d	17.83 a	4.94 a
CV (%)	4.89	2.82	3.63	4.16
$LSD_{(0.05)}$	0.097	0.130	0.582	0.144
Significance level	**	**	**	**

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: 0 (Control), B_2: 1.5 $t\ ha^{-1}$, B_3: 3.0 $t\ ha^{-1}$ and B_4: 4.5 $t\ ha^{-1}$.

** indicates 1% level of probability

Effect of vermicompost

Different levels of vermicompost application were found to have no significant effect on canned potato yield (Table 7). According to experimental findings, the highest canned potato production (2.07 $t\ ha^{-1}$) was observed by the Vm_1 treatment. While the Vm_4 treatment had the lowest canned potato production (1.90 $t\ ha^{-1}$).

Interaction effect of biochar and vermicompost

The interaction effect of biochar and vermicompost fertilizer doses had shown non-significant impact on canned potato production (Table 8). According to the experimental results, the B_1Vm_1 interaction treatment had the highest canned potato production (2.33 $t\ ha^{-1}$). However, the B_4Vm_4 interaction treatment had the lowest canned potato production (1.73 $t\ ha^{-1}$).

4.11 Yield of potato for flakes potato production

Effect of biochar

Yield of tuber for flakes potato production was found significant against the application of different levels of biochar (Table 6). According to the results of the experiments, the B_1 treatment had the highest yield for flakes potato production (5.66 t ha^{-1}). While the B_4 treatment had the lowest yield for flakes potato production (3.92 t ha^{-1}).

Effect of vermicompost

The application of different levels of vermicompost had no significant effect on flakes potato yield (Table 7). According to the results of the experiment, the Vm_3 treatment produced the highest flakes potato yield (4.69 t ha^{-1}). While the Vm_4 treatment produced the lowest flakes potato yield (4.53 t ha^{-1}).

Interaction effect of biochar and vermicompost

A significant variation was found among the interaction treatments against the yield of potato tubers for flakes production (Table 8). Experimental result revealed that the highest yield for flakes potato (6.30 t ha^{-1}) was found from B_1Vm_4 interaction treatment which was statistically similar to B_1Vm_3 (6.10 t ha^{-1}) interactiont. While the lowest yield for flakes potato (3.70 t ha^{-1}) was found in B_4Vm_4 interaction treatment which was statistically similar to B_4Vm_3 (3.75 t ha^{-1}), B_4Vm_2 (3.90 t ha^{-1}), B_3Vm_4 (4.00 t ha^{-1}) and B_2Vm_4 (4.10 t ha^{-1}) interaction.

4.12 Yield of potato for chips production

Effect of biochar

The different biochar levels had a significant impact on potato yields for chips production (Table 6). The B_4 treatment produced the highest potato yield for chips production (17.83 t ha^{-1}) while the B_1 treatment produced the lowest potato yield for chips production (14.41 t ha^{-1}). This result had agreements with the findings of Vista *et al.* (2017) who reported that the application of 30 t ha^{-1} of biochar was most satisfactory for overall improvement of yield and growth parameters of vegetable crops. Youseef *et al.* (2017) revealed that the number of tubers for chips potato production was significantly increased with increasing biochar application rates up to 12 m^3 ha^{-1}.

Effect of vermicompost

The use of various levels of vermicompost had a significant impact on chips potato yield (Table 7). According to the experiment results, the Vm_4 treatment produced the highest chips potato yield (18.29 t ha^{-1}) which was statistically similar to Vm_3 (17.68 t ha^{-1}) treatment. However, the Vm_1 treatment resulted in the lowest chips potato yield (12.41 t ha^{-1}). This result agrees with the findings of Hensh *et al*. (2020) who reported that vermicompost increased the availability of nutrients including micro nutrients in the soil, resulting in improved nutrient absorption by the crop, thereby increased tuber production. Mirdad (2010) also reported that organic fertilizer application increased the availability of soil macro-nutrients and micro-nutrients and provides nutrients to meet crop requirements supporting crop production.

Table 7. Effect of doses of vermicompost on the yield of potato for different processing purpose

Vermicompost doses	Yield for canned potato production (t ha^{-1}) (20-30 mm)	Yield of potato for flakes potato production (t ha^{-1}) (30-45 mm)	Yield of potato for chips production (t ha^{-1}) (45-75 mm)	Yield of potato for French product (t ha^{-1}) (>75 m)
Vm_1	2.07	4.63	12.41 c	0.94 d
Vm_2	2.01	4.64	15.95 b	3.32 c
Vm_3	1.97	4.69	17.68 a	4.70 b
Vm_4	1.90	4.53	18.29 a	4.92 a
CV(%)	8.25	6.20	7.22	4.68
$LSD_{(0.05)}$	---	----	0.979	0.137
Significance level	NS	NS	**	**

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: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

** indicates 1% level of probability
NS means non-significance

Interaction effect of biochar and vermicompost

Potato yield for chips production was found to be statistically not-significant when different levels of biochar and vermicompost were applied (Table 8). Experimental result revealed that the B_4Vm_4 interaction treatment produced the highest chips potato yield (20.20 t ha^{-1}). While the B_2Vm_1 interaction treatment produced the lowest chips potato yield (11.40 t ha^{-1}).

4.13 Yield of potato for french fry production

Effect of biochar

The yield of potato tuber for french fry production was found to be significant when compared to different levels of biochar application (Table 6). The B_4 treatment produced the highest potato yield for french fry production (4.94 t ha^{-1}). While the B_1 treatment produced the lowest potato yield for french fry production (1.54 t ha^{-1}).

Effect of vermicompost

The yield of french fry potatoes was significantly influenced by the use of different vermicompost levels (Table 7). According to the experiment results, the Vm_4 treatment produced the highest french fry potato yield (4.92 t ha^{-1}). However, the Vm_1 treatment resulted in the lowest french fry potato yield (0.94 t ha^{-1}).

Interaction effect of biochar and vermicompost

Potato yield for french fry production was found to be statistically significant when different levels of biochar and vermicompost were applied (Table 8). Experimental results revealed that the B_4Vm_4 interaction treatment produced the highest french fry potato yield (6.37 t ha^{-1}) which was statistically similar to B_4Vm_3 (6.36 t ha^{-1}), B_3Vm_4 (6.30 t ha^{-1}) and B_3Vm_3 (6.23 t ha^{-1}) interaction treatment. While the B_1Vm_1 interaction treatment did not produce french fry potato.

Table 8. Interaction effect of biochar and vermicompost on the yield of potato for different processing purpose

Interaction treatment	Yield for canned potato production (t ha^{-1}) (20-30 mm)	Yield of potato for flakes potato production (t ha^{-1}) (30-45 mm)	Yield of potato for chips production (t ha^{-1}) (45-75 mm)	Yield of potato for French fry production (t ha^{-1}) (>75 mm)
B_1Vm_1	2.33	4.67 cd	11.84	0.00 l
B_1Vm_2	2.30	5.59 b	14.40	1.54 j
B_1Vm_3	2.23	6.10 a	15.10	2.16 i
B_1Vm_4	2.08	6.30 a	16.30	2.44 h
B_2Vm_1	2.00	4.80 c	11.40	0.42 k
B_2Vm_2	2.00	4.60 cd	15.90	3.96 e
B_2Vm_3	2.10	4.60 cd	16.00	4.20 d
B_2Vm_4	2.00	4.10 efg	16.77	4.56 c
B_3Vm_1	2.00	4.70 cd	12.30	0.63 k
B_3Vm_2	1.90	4.50 cde	16.60	3.52 f
B_3Vm_3	1.80	4.30 def	19.50	6.23ab
B_3Vm_4	1.80	4.00 fg	19.90	6.30ab
B_4Vm_1	1.95	4.33 def	14.40	2.73 g
B_4Vm_2	1.85	3.90 fg	16.90	4.28 d
B_4Vm_3	1.75	3.75 g	20.10	6.36 a
B_4Vm_4	1.73	3.70 g	20.20	6.37 a
CV(%)	8.25	6.20	7.22	4.68
$LSD_{(0.05)}$	----	0.437	----	0.277
Significance level	NS	**	NS	**

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: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}, Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

** indicates 1% level of probability
NS means non-significance

4.14 Specific gravity

Effect of biochar

The specific gravity of potato was significantly influenced by different levels of biochar application (Table 9). The results of the experiment indicated that the B_4 treatment had the highest specific gravity of potato (1.056 g cm^{-3}) whereas the lowest specific gravity of potato was found in the B_1 treatment (1.026 g cm^{-3}). Similar result was also observed by

Mollick *et al*. (2020) who reported that increased biochar application significantly ($p<0.05$) increased tuber specific gravity.

Table 9. Effect of different doses of biochar on the processing quality of potato

Biochar levels	Specific gravity (g cm^{-3})	Dry matter content (%)	Reducing sugar (mg g^{-1} FW)	Starch content (mg g^{-1} FW)
B_1	1.026 d	18.32 c	0.541 a	14.033 c
B_2	1.045 c	19.29 b	0.412 b	15.537 b
B_3	1.052 b	20.56 a	0.330 c	17.603 a
B_4	1.056 a	20.93 a	0.325 d	17.713 a
CV(%)	0.29	3.95	0.22	1.26
$LSD_{(0.05)}$	0.027	0.780	0.030	0.204
Significance level	**	**	**	**

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: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}.

** indicates 1% level of probability

Effect of vermicompost

The experimental findings demonstrated that the different levels of vermicompost application had shown significant effect on the specific gravity of potato (Table 10). According to the experimental findings, the Vm_4 treatment had the highest specific gravity of potato (1.060 g cm^{-3}). While the Vm_1 treatment, however, had the lowest potato specific gravity (1.018 g cm^{-3}). This result was in support with the findings of Taha *et al.* (2017) who reported that the maximum specific gravity of potato (1.093 g cm^{-3}) was observed with the application of 50% recommended nitrogen + 25% recommended nitrogen through FYM @ 7.5 t ha^{-1} + 25% recommended nitrogen through VC @ 2.25 t ha^{-1}.

Interaction effect of biochar and vermicompost

The specific gravity of potato was shown significant effect due to application of different levels of biochar in conjunction with the application of different levels of vermicompost fertilizer (Table 11). The experimental findings showed that the B_4Vm_4 interaction treatment produced the highest specific gravity of potato (1.068 g cm^{-3}) which was statistically similar to B_4Vm_3 (1.064 t ha^{-1}), B_3Vm_4 (1.064 t ha^{-1}) and B_3Vm_3 (1.064 t ha^{-1}) interaction treatment. However, the lowest specific gravity of potato was found in the B_1Vm_1 interaction treatment (0.974 g cm^{-3}).

4.15 Dry matter content

Effect of biochar

Different doses of biochar application significantly influenced dry matter content of potato (Table 9). Experimental result showed that the highest dry matter content of potato (20.93%) was found in B_4 treatment which was statistically similar to B_3 (20.56%) treatment. While the B_1 treatment had the lowest dry matter content of potato (18.32%). The result was similar to the findings of Mollick *et al*. (2020) who reported that biochar application significantly increased tuber dry matter content.

Effect of vermicompost

The dry matter content of potatoes was significantly influenced by different doses of vermicompost application (Table 10). The experimental results revealed that the Vm_4 treatment had the highest dry matter content of potato (21.22%) which was statistically similar to the Vm_3 (20.70%) treatment. While the Vm_1 treatment had the lowest potato dry matter content (17.61%). Ram *et al.* (2017) reported that the higher dry matter content (19.66%) was achieved in T_4 treatment (Crop residue incorporation + biofertilizers (*Azotobacter* and *Phosphobacteria*) + Vermicompost @ 5 t ha^{-1} + microbial culture) which might be due to application of vermicompost that played a positive role in affecting dry matter of tubers.

Interaction effect of biochar and vermicompost

The application of different levels of biochar in conjunction with the application of different levels of vermicompost fertilizer had no significant effect on potato dry matter content (Table 11). The experimental findings showed that the B_4Vm_4 interaction treatment produced the highest dry matter content of potato (22.79 g cm^{-3}). However, the lowest dry matter content of potato was found in the B_1Vm_1 interaction treatment (16.05 g cm^{-3}).

4.16 Reducing sugar

Effect of biochar

Reducing sugar content in potato tubers varied significantly due to different levels of biochar application (Table 9). The B_1 treatment had the highest reducing sugar content in potato tubers (0.541 mg g^{-1} FW). However, the B_4 treatment had the lowest (0.325 mg g^{-1} FW).

Effect of vermicompost

Potato tubers reducing sugar content varied significantly due to different levels of vermicompost application (Table 10). According to the experimental result, the Vm_1 had the highest reducing sugar content in potato tubers (0.49 mg g^{-1} FW). However, the Vm_3 treatment had the lowest reducing sugar content in potato tubers (0.34 mg g^{-1} FW).

Table 10. Effect of different doses of vermicompost on the processing quality of potato

Biochar levels	Specific gravity (g cm^{-3})	Dry matter content (%)	Reducing sugar (mg g^{-1} FW)	Starch content (mg g^{-1} FW)
Vm_1	1.018 d	17.61 c	0.492 a	14.333 c
Vm_2	1.046 c	19.58 b	0.411 b	16.355 b
Vm_3	1.055 b	20.70 a	0.364 c	16.929 a
Vm_4	1.060 a	21.22 a	0.341 d	17.268 a
CV(%)	0.28	3.26	0.25	2.61
$LSD_{(0.05)}$	0.028	0.544	0.032	0.357
Significance level	**	**	**	**

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: Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

** indicates 1% level of probability

Interaction effect of biochar and vermicompost

The reducing sugar content of potatoes was significantly affected by the interaction effect of biochar and vermicompost (Table 11). Experimental result revealed that the highest reducing sugar content of potato (0.59 mg g^{-1} FW) was found from B_1Vm_1 interaction treatment whereas the lowest (0.251 mg g^{-1} FW) was recorded from B_4Vm_4 interaction treatment.

4.17 Starch content

Effect of biochar

The starch content of potato was significantly influenced by different levels of biochar application (Table 9). The results of the experiment indicated that the B_4 treatment had potatoes with the highest starch content (17.713%) which was statistically comparable to the B_3 treatment (17.60 mg g^{-1} FW). However, the lowest starch content of potato was found in the B_1 treatment (14.03 mg g^{-1} FW). Ferdous *et al.* (2019) also reported that starch content of tuber was increased with the increasing levels biochar application as compared to that of control treatment. It might be due to the better vegetative growth and role of Biochar in reducing soil density and soil hardening, increasing soil aeration and cation-exchange capacity and changing the soil structure and consistency through the changes in physical and chemical properties, increased nutrient uptake, starch formation, and translocation, resulting in more reserve food accumulation in tubers.

Effect of vermicompost

The results of the experiment revealed that the application of different doses of vermicompost had a significant effect on the starch content of potato (Table 10). The results of the experiment indicated that the Vm_4 treatment had the highest starch content of potato (17.27 mg g^{-1} FW) which was statistically comparable to the Vm_3 treatment (16.93 mg g^{-1} FW). However, the lowest starch content of potato was found in the Vm_1 treatment (14.33 mg g^{-1} FW). The results were consistent with the findings of Ferdous *et al.* (2019) who reported that increasing Vermicompost levels significantly increased tuber starch content.

Interaction effect of biochar and vermicompost

The starch content of potatoes was significantly affected by the use of different levels of biochar in conjunction with the application of different levels of vermicompost fertilizer (Table 11). Experimental result revealed that the highest starch (18.45 mg g^{-1} FW) was found from B_4Vm_4 interaction treatment combination which was statistically similar to B_4Vm_3 (18.37 mg g^{-1} FW), B_4Vm_2 (18.36 mg g^{-1} FW), B_3Vm_4 (18.37 mg g^{-1} FW) and B_3Vm_3 (18.57 mg g^{-1} FW) whereas the lowest (12.160 mg g^{-1} FW) was recorded from B_1Vm_1 interaction treatment (Table 11).

Table 11. Interaction effect of biochar and vermicompost on the processing quality of potato

Interaction treatment	Specific gravity (g cm^{-3})	Dry matter content (%)	Reducing sugar (mg g^{-1} FW)	Starch content (mg g^{-1} FW)
B_1Vm_1	0.974 k	16.05	0.595 a	12.160 g
B_1Vm_2	1.035 i	18.65	0.546 b	13.610 f
B_1Vm_3	1.045 gh	19.17	0.522 c	14.650 e
B_1Vm_4	1.051ef	19.41	0.502 d	15.712 d
B_2Vm_1	1.025 j	17.45	0.497 e	13.670 f
B_2Vm_2	1.047 fg	19.57	0.422 g	15.817 d
B_2Vm_3	1.051 ef	19.97	0.380 i	16.120 cd
B_2Vm_4	1.057 cd	20.16	0.347 k	16.540 c
B_3Vm_1	1.031 i	18.16	0.464 f	15.834 d
B_3Vm_2	1.053 de	19.92	0.312 l	17.634 b
B_3Vm_3	1.064 ab	21.65	0.282 m	18.573 a
B_3Vm_4	1.064 ab	22.52	0.262 o	18.370 a
B_4Vm_1	1.041 h	18.79	0.412 h	15.670 d
B_4Vm_2	1.050 efg	20.16	0.365 j	18.360 a
B_4Vm_3	1.064 ab	21.99	0.271 n	18.373 a
B_4Vm_4	1.068 a	22.79	0.251 p	18.450 a
CV(%)	0.28	3.26	0.25	2.61
$LSD_{(0.05)}$	0.025	----	0.028	0.650
Significance level	**	NS	**	*

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: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1}, Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}.

* and ** indicate 5% and 1% level of probability, respectively
NS means non-significance

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted at the Agronomic Research Field of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from November 2021 to February 2022 in the Rabi season to study the growth, yield and quality of potato through biochar and vermicompost management. The experiment consisted of two factors and followed split plot design with three replications. Factor A, different doses of biochar application *viz*., (4) B_1: 0 (Control), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1} and B_4: 4.5 t ha^{-1} and Factor B, different doses of vermicompost application *viz.,* (4) Vm_1: 0 (Control), Vm_2: 1.5 t ha^{-1} Vm_3: 3.0 t ha^{-1} and Vm_4: 4.5 t ha^{-1}. For the purpose of evaluating the experimental outcomes, data on various parameters were evaluated. The analysis of various parameters' data revealed significant and non-significant differences in potato growth, yield, and quality characteristics as a result of biochar and vermicompost application doses and their interaction treatment.

In case of levels of biochar application, the growth parameters i.e., days required for 1st emergence, days required for 80% emergence, plant height, number of leaves plant^{-1} and number of stems plant^{-1} varied due to different levels of biochar application. However, in terms of yield and quality characteristics, the B_4 treatment had the highest number of tubers hill^{-1} (12.00) while the B_2 treatment had the lowest (11.48) number. The B_4 treatment had the highest average weight of potato tuber (46.97) while the B_1 treatment had the lowest average weight of potato tuber (38.01 g). The B_4 treatment had the highest tuber yield (29.63 t ha^{-1}) while the B_1 treatment had the lowest one (25.30 t ha^{-1}). The highest marketable tuber yield (27.94 t ha^{-1}) was observed from the B_4 treatment while the B_1 treatment had the lowest figure (23.47 t ha^{-1}). The B_1 treatment had the highest yield for canned potato production (2.24 t ha^{-1}) while the lowest yield for canned potato (1.82 t ha^{-1}) was observed from B_4 treatment. The B_1 treatment had the highest yield for flakes potato (5.66 t ha^{-1}) while the B_4 treatment had the lowest yield for flakes potato (3.92 t ha^{-1}). The B_4 treatment produced the highest potato yields for chips (17.83 t ha^{-1}) while the B_1 treatment produced the lowest potato yields for chips production (14.41 t ha^{-1}). The B_4 treatment produced the highest potato yield for french fry production (4.94 t ha^{-1}) while the B_1 treatment produced the lowest value for french fry production (1.54 t ha^{-1}). The B_4 treatment had the highest specific gravity of potato (1.056 g cm^{-3}) whereas the lowest specific gravity of potato was found in the B_1 treatment (1.026 g cm^{-3}). The highest dry matter content of potato (20.93%) was found in B_4 treatment while the B_1 treatment had the lowest dry matter content of potato (18.32%). The B_1 treatment had the highest reducing sugar content in potato tubers (0.541 mg g^{-1} FW). However, the B_4 treatment had the lowest (0.325 mg g^{-1} FW). The B_4 treatment had potatoes with the highest starch content (17.713%). However, the lowest starch content of potato was found in the B_1 treatment (14.03 mg g^{-1} FW).

The growth parameters, such as days required for 1st emergence, days required for 80% emergence, plant height, number of leaves plant^{-1} and number of stems plant^{-1} varied for different levels of vermicompost. However, in terms of yield and quality characteristics of potato, the highest number of tubers hill^{-1} (12.00) was observed in Vm_3 treatment while Vm_1 treatment had the lowest (11.17) number of tubers hill^{-1}. The highest average weight of potato tuber (47.07 g) was observed in Vm_4 treatment. However, the lowest average weight of potato tuber (37.69 g) was observed in Vm_1 treatment. The highest tuber yield (30.62 t ha^{-1}) was observed in Vm_4 treatment while the Vm_1 treatment had the lowest tuber yield (23.85 t ha^{-1}). The highest marketable tuber yield (29.64 t ha^{-1}) was observed by the Vm_4 treatment while the Vm_1 treatment had the lowest marketable tuber yield in the experiments (19.21 t ha^{-1}). The highest canned potato production (2.07 t ha^{-1}) was observed by the Vm_1 treatment while the Vm_4 treatment had the lowest canned potato production (1.90 t ha^{-1}). The Vm_3 treatment produced the highest flakes potato yield (4.69 t ha^{-1}) while the Vm_4 treatment produced the lowest flakes potato yield (4.53 t ha^{-1}). The Vm_4 treatment produced the highest chips potato yield (18.29 t ha^{-1}) which was statistically similar to Vm_3 (17.68 t ha^{-1}) treatment. However, the Vm_1 treatment resulted in the lowest chips potato yield (12.41 t ha^{-1}). The Vm_4 treatment produced the highest french fry potato yield (4.92 t ha^{-1}). However, the Vm_1 treatment resulted in the lowest french fry potato yield (0.94 t ha^{-1}). The Vm_4 treatment had the highest specific gravity of potato (1.060 g cm^{-3}) while the Vm_1 treatment, however, had the lowest potato specific gravity (1.018 g cm^{-3}). The Vm_4 treatment had the highest dry matter content of potato

(21.22%) while the Vm_1 treatment had the lowest potato dry matter content (17.61%). The Vm_1 had the highest reducing sugar content in potato tubers (0.49 mg g^{-1} FW). However, the Vm_3 treatment had the lowest reducing sugar content in potato tubers (0.34 mg g^{-1} FW). The results of the experiment indicated that the Vm_4 treatment had the highest starch content of potato (17.27 mg g^{-1} FW). However, the lowest starch content of potato was found in the Vm_1 treatment (14.33 mg g^{-1} FW).

In case of interaction treatment, the growth parameters such as days required for 1st emergence, days required for 80% emergence, plant height, number of leaves $plant^{-1}$ and number of stems $plant^{-1}$ varied as a result of the interaction effect of various biochar and vermicompost application doses. However, in terms of yield and quality characteristics of potato, the highest number of tubers $hill^{-1}$ (12.33) was observed in B_4Vm_3 interaction treatment while B_2Vm_1 interaction treatment had the lowest (10.67) number of tubers $hill^{-1}$. The highest average weight of potato tuber (49.97 g) was observed in B_4Vm_4 interaction treatment while B_1Vm_1interaction treatment had the lowest (32.53 g) average weight of potato tuber. The B_4Vm_4 interaction treatment recorded the highest tuber yield (32.47 t ha^{-1}). However, the B_1Vm_1 interaction treatment showed the lowest tuber yield (22.13 t ha^{-1}). The B_4Vm_4 interaction treatment had the highest marketable tuber yield (32.07 t ha^{-1}). However, the B_1Vm_1 interaction treatment had the lowest marketable tuber yield (17.47 t ha^{-1}). The B_1Vm_1 interaction treatment had the highest canned potato production (2.33 t ha^{-1}). However, the B_4Vm_4 interaction treatment had the lowest canned potato production (1.73 t ha^{-1}). The highest yield for flakes potato production(6.30 t ha^{-1}) was found from B_1Vm_4 interaction treatment while the lowest yield for flakes potato production (3.70 t ha^{-1}) was found in B_4Vm_4 interaction treatment. The B_4Vm_4 interaction treatment produced the highest chips potato yield (20.20 t ha^{-1}) while the B_2Vm_1 interaction treatment produced the lowest chips potato yield (11.40 t ha^{-1}). The B_4Vm_4 interaction treatment produced the highest french fry potato yield (6.37 t ha^{-1}) while the B_1Vm_1 interaction treatment produced the lowest french fry potato yield (10.00 t ha^{-1}). The B_4Vm_4 interaction treatment produced the highest specific gravity of potato (1.068 g cm^{-3}). However, the lowest specific gravity of potato was found in the B_1Vm_1 interaction treatment (0.974 g cm^{-3}). The B_4Vm_4 interaction treatment produced the highest dry matter content of potato (22.79g cm^{-3}). However, the lowest dry matter content of potato was found in the B_1Vm_1 interaction treatment (16.05 g cm^{-3}). The highest reducing sugar content of potato (0.59 mg g^{-1} FW) was found from B_1 Vm_1 interaction treatment whereas the lowest (0.251 mg g^{-1} FW) was recorded from B_4Vm_4 interaction treatment. The highest starch (18.45 mg g^{-1} FW) was found from B_4Vm_4 interaction treatment combination whereas the lowest (12.160 mg g^{-1} FW) was recorded from B_1Vm_1 interaction treatment.

Conclusion

The application doses of biochar and vermicompost as well as their interaction treatment resulted in significant and non-significant differences in potato growth, yield and quality characteristics.

- The experimental findings for different doses of biochar application revealed non-significantly for different growth parameters but significantly varied for different yield and quality attributes of potato. Among the various biochar application doses, B_4 (4.5 t ha^{-1} biochar) and B_3 (3.0 t ha^{-1} biochar) treatments outperformed other treatments in terms of yield and quality of potato.
- Among the different levels of vermicompost application, the Vm_4 (4.5 t ha^{-1} vermicompost) treatment performed better, but it was statistically similar to the Vm_3 (3.0 t ha^{-1} vermicompost) treatment.
- B_4 and B_3 treatments, combined with Vm_4 and Vm_3 treatments, resulted in good potato yield and processing qualities. However, in terms of availability and economics in Bangladesh, B_3 treatment interaction with Vm_3 treatment would be used to produce processing quality potato without sacrificing yield.

Therefore, it may be concluded that both biochar and vermicompost had beneficial effects on yield and quality of potato. Application of biochar along with vermicompost (B_3Vm_3) at the rate of each 3 t ha^{-1} exhibited the best performance on yield and quality of potato compared to that of their individual application at higher rate.

Recommendation

Further research in the following areas may be suggested based on the results of the current experiment:

i. Other organic and inorganic fertilizer sources and doses could be used for further research to narrow down the specific combination.

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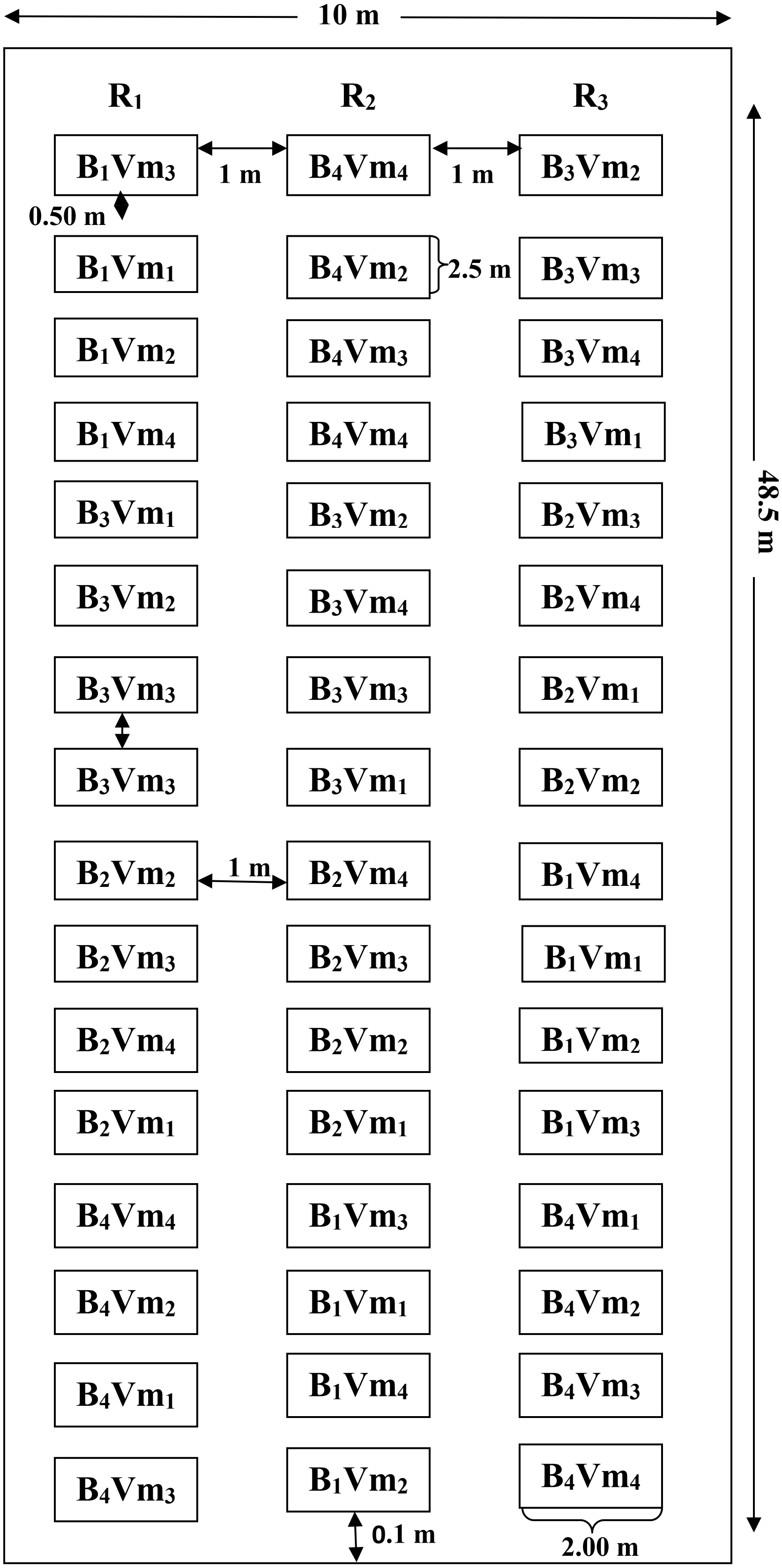
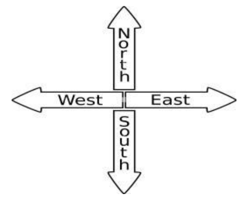
APPENDICES

Appendix I. Map showing the experimental location under study

Appendix II. Layout of the experimental plot





Total plot: 48
Plot size: 5 m^2
(2.5 m × 2 m).
Plot distance: 0.50 m
Block distance: 1 m

Factor A. 4 doses of biochar
B_1: 0 (Control)
B_2: 1.5 t ha^{-1}
B_3: 3.0 t ha^{-1} and
B_4: 4.5 t ha^{-1}

Factor B. 4 doses of vermicompost
Vm_1: 0 (Control)
Vm_2: 1.5 t ha^{-1}
Vm_3: 3.0 t ha^{-1} and
Vm_4: 4.5 t ha^{-1}

Appendix III. Soil characteristics of the experimental field

A. Morphological features of the experimental field

Morphological features	**Characteristics**
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka-1207
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0- 15 cm depth)

Physical characteristics	
Constituents	**Percent**
Clay	29 %
Sand	26 %
Silt	45 %
Textural class	Silty clay
Chemical characteristics	
Soil characteristics	**Value**
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10
Organic carbon (%)	0.45
Organic matter (%)	0.78
pH	5.6
Total nitrogen (%)	0.03

Sourse: Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka.

Appendix IV. Monthly meteorological information during the period from November 2021 to February 2022

Year	Month	Air temperature (^0C)		Relative humidity (%)	Average rainfall (mm)
		Maximum	Minimum		
2021	November	29.6	19.8	53	00 mm
	December	28.8	19.1	47	00 mm
2022	January	25.5	13.1	41	00 mm
	February	25.9	14	34	7.7 m

Source: Metrological Centre, Agargaon, Dhaka (Climate Division)

Appendix V. Analysis of variance of the data of the days required for 1st and 80% emergence of potato seedlings

Source	DF	Mean square of	
		Days required for 1st emergence	Days required for 80% emergence
Replication (R)	2	0.64583	0.6458
Biochar (B)	3	4.97222**	3.1875NS
Error	6	0.36806	0.8125
Vermicompost (Vm)	3	3.36111*	14.0208***
B×Vm	9	1.73148NS	1.0208*
Error	24	1.07639	1.0208

NS means non-significance
* means significant at 5% level of significance
** means significant at 1% level of significance
*** means highly significant

Appendix VI. Analysis of variance of the data of on plant height of potato at different days after planting (DAP)

Source	DF	Mean square of plant height at			
		30 DAP	45 DAP	60 DAP	75 DAP
Replication (R)	2	0.5833	7.3125	11.4375	23.5208
Biochar (B)	3	6.8889^{NS}	3.3611^{NS}	8.1319^{NS}	11.6875^{NS}
Error	6	3.1389	5.5903	11.1319	10.1875
Vermicompost (Vm)	3	26.5000**	39.5833***	28.4653**	32.9097**
B×Vm	9	8.4630^{NS}	7.3796**	5.1505^{NS}	3.1690^{NS}
Error	24	4.0556	2.9097	4.7083	5.7708

NS means non-significance
** means significant at 1% level of significance
*** means highly significant

Appendix VII. Analysis of variance of the data of on number of leaves plant^{-1} of potato at different days after planting (DAP)

Source	DF	Mean square of number of leaves plant^{-1} at			
		30 DAP	45 DAP	60 DAP	75 DAP
Replication (R)	2	5.0106	5.3508	3.3081	1.0863
Biochar (B)	3	13.6747*	22.0052**	9.0414**	8.5042**
Error	6	0.8937	1.8750	1.3595	0.6021
Vermicompost (Vm)	3	65.5392***	59.0424***	49.6936***	42.7448***
B×Vm	9	7.5182*	5.5298^{NS}	6.0764^{NS}	17.1662^{NS}
Error	24	2.3551	3.6417	3.0969	2.9079

NS means non-significance
* means significant at 5% level of significance
** means significant at 1% level of significance
*** means highly significant

Appendix VIII. Analysis of variance of the data of number of stems plant^{-1} of potato at different days after planting (DAP)

Source	DF	Mean square of number of stems plant^{-1} at			
		30 DAP	45 DAP	60 DAP	75 DAP
Replication (R)	2	1.40083	2.20583	1.89396	1.65813
Biochar (B)	3	1.14576^{NS}	1.00854^{NS}	0.37187^{NS}	0.34799^{NS}
Error	6	0.73639	1.16333	0.54479	0.84007
Vermicompost (Vm)	3	0.72243*	0.52354^{NS}	0.18188^{NS}	0.18132^{NS}
B×Vm	9	0.50984*	0.43780^{NS}	0.30206^{NS}	0.15873^{NS}
Error	24	0.17361	0.57507	0.47931	0.34542

NS means non-significance
* means significant at 5% level of significance

Appendix IX. Analysis of variance of the data of yield and yield contributing traits of potato

Source	DF	Number of tubers hill^{-1}	Average weight of tuber	Tuber yield	Marketable yield
Replication (R)	2	0.06	0.554	0.923	2.403
Biochar (B)	3	0.91^{NS}	179.132**	46.131**	54.082**
Error	6	0.62	1.485	0.338	0.447
Vermicompost (Vm)	3	1.57^{NS}	213.702**	109.552**	272.311**
B×Vm	9	0.39^{NS}	2.243**	1.874*	4.086*
Error	24	1.06	2.741	0.601	0.681

NS means non-significance
* means significant at 5% level of significance
** means significant at 1% level of significance

Appendix X. Analysis of variance of the data of yield of potato for different processing purpose

Source	DF	Yield for canned potato production	Yield of potato for flakes potato production	Yield of potato for chips production	Yield of potato or French fry production
Replication (R)	2	0.00270	0.04818	1.3762	0.0063
Biochar (B)	3	0.41422**	6.59960**	31.8185**	25.3599**
Error	6	0.00945	0.01693	0.3402	0.0209
Vermicompost (Vm)	3	0.06147^{NS}	0.05745^{NS}	83.6851**	40.0693**
B×Vm	9	0.01374^{NS}	0.77140**	2.4310^{NS}	1.6929**
Error	24	0.02696	0.08203	1.3492	0.0264

NS means non-significance
** means significant at 1% level of significance

Appendix XI. Analysis of variance of the data of processing quality of potato

Source	DF	Specific gravity	Dry matter content	Reducing sugar	Starch content
Replication (R)	2	3.938e-06	0.1576	6.250e-08	0.0001
Biochar (B)	3	2.056e-03**	17.2618**	0.12253**	37.5664**
Error	6	8.937e-06	0.6104	8.125e-07	0.0415
Vermicompost (Vm)	3	4.276e-03**	30.5937**	0.05378**	20.7147**
B×Vm	9	3.997e-04**	0.7370^{NS}	2.163e-03**	0.4383*
Error	24	8.437e-06	0.4163	1.014e-06	0.1794

NS means non-significance
* means significant at 5% level of significance
** means significant at 1% level of significance

PLATES

Plate 1. Experimental field after setting up signboard

Plate 2. Layout of the experimental field

Plate 3. Data collection

Plate 4. Field visited by supervisor and teachers

Plate 5. Harvesting of potato

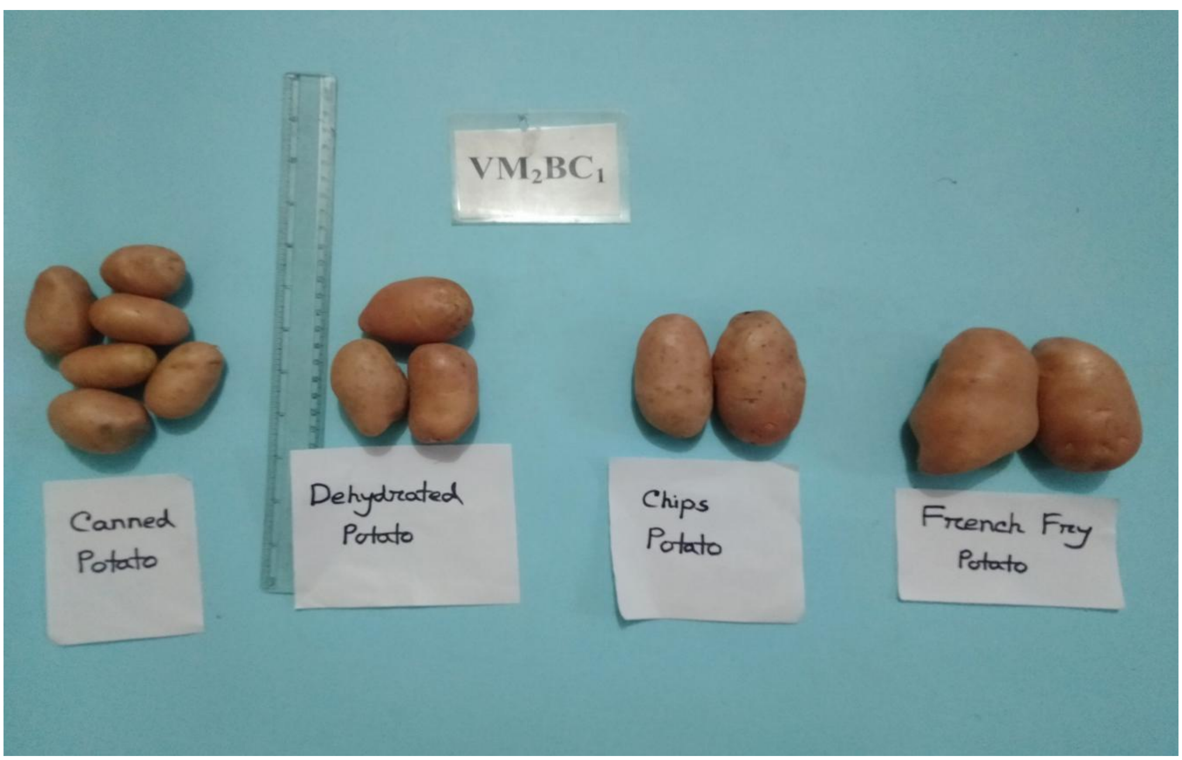


Plate 6. Grading of potato

Plate 7. Tubers from different treatment combinations