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SYNERGISTIC EFFECTS OF BIOCHAR AND VERMICOMPOST ON YIELD AND QUALITY OF POTATO

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Abstract

Poor-quality potatoes are the key constraint on growth and development of Bangladesh's potato processing industry. This study aims to investigate the potential benefits of using vermicompost and biochar in conjunction with recommended dose of fertilizers (RDF) to improve potato yield and quality. The research study was performed at the research field of Sher-e-Bangla Agricultural University (SAU) in Dhaka, Bangladesh, from November 2023 to April 2024. The study utilized a split-plot design with three replications to assess the impacts of four different levels of biochar (B) and vermicompost (Vm): B_1 (0 t ha^{-1}), B_2 (1.5t ha^{-1}), B_3 (3.0 t ha^{-1}), and B_4 (4.5 t ha^{-1}), and Vm_1 (0 t ha^{-1}), Vm_2 (1.5 t ha^{-1}), Vm_3 (3.0 t ha^{-1}), and Vm_4 (4.5 t ha^{-1}) on yield and quality of potato. The results demonstrated significant effects of biochar and vermicompost on a wide range of yield and quality parameters studied in this experiment. All of these trends were generally positive, with an increase in the amount of applied biochar and/or vermicompost, except for a decrease in reducing sugar content, which is harmful constituent of potato. Among the treatment combinations, B_4Vm_4 produced the highest tuber yield at 32.47 t ha^{-1} with its corresponding marketable yield at 32.07 t ha^{-1} and yield of potato suitable for French fry production at 6.37 t ha^{-1}. It is statistically comparable to the B_4Vm_3, B_3Vm_4, and B_3Vm_3. The quality in terms of specific gravity and starch content was higher in B_4Vm_4 with 1.068 g cm^{-3} and 18.45 mg g^{-2} fresh weight, respectively. However, B_4Vm_3, B_3Vm_4, and B_3Vm_3 are statistically comparable. So, potato farmers can use 3 tons per hectare of biochar and vermicompost, in addition to RDF, which includes 325-220-250-120-14 kg ha^{-1} of urea, TSP, MoP, Gypsum, and zinc sulfate for producing good quality potato without sacrificing yield.

Introduction

In Bangladesh, the annual potato demand is approximately 8.0 million tons, while the production reaches 11.0 million tons, resulting in a surplus of around 5.0 million tons (Jannat *et al.*, 2021). However, a significant portion of these potatoes fail to meet the necessary processing criteria, rendering them unsuitable for export or industrial processing, Bangladeshi exporters have successfully exported about 1.03 million tons of fresh potatoes in the fiscal year 2013-14, but exports have since declined to around 80,000 tons per year since fiscal year 2021-22, primarily due to a shortage of export-grade potatoes (BBS, 2022).

The quality of potato tubers is a crucial factor for both consumer and industrial demand. Quality is assessed based on specific gravity (≥1.06%), dry matter content (≥20%), starch content (≥13%), and reducing sugar concentration (<0.30%) (Solaiman *et al.*, 2015). Manufacturers prefer high-specific gravity potatoes for various processing applications, as they are crispier and more suitable for mashing, baking, frying and french fry production (Lal *et al.*, 2023). Roy *et al.* (2017) found that the dry matter, starch, reducing sugar, non-reducing sugar, and total sugar levels of 40 potato varieties in Bangladesh varied from 13.56 to 24.6 %, 6.8 to 18.93 %, 0.02 to 0.61%, 0.09 to 0.53% and 0.27 to 0.78%, respectively. Bangladeshi potato growers often struggle to meet international quality standards due to a lack of sufficient information on the appropriate utilization of organic and chemical fertilizers. To achieve long-term improvement in potato productivity, it is necessary to utilize both organic and inorganic nutrient sources for effective soil fertility management. Biochar is a solid residue produced through pyrolysis, enhances soil properties by increasing its pH, cation exchange capacity (CEC), enzymatic activity, and the accessibility of nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) (Tomczyk *et al.*, 2020). Applying biochar at a rate of 10 t ha^{-1} increases the levels of soil organic carbon and available nitrogen, phosphorus, and potassium by 40.5, 23.1, 15.2 and 30.5 %, respectively, in soils after harvesting (Premalatha *et al.*, 2022). In addition, studies have shown that biochar, utilized with inorganic fertilizers, has significant agronomic advantages in terms of crop growth and productivity, especially in soils with low fertility. This is achieved either by directly providing nutrients or by improving the availability of nutrients in the soil (Alkharabsheh *et al.*, 2021). Vermicompost, an effective organic fertilizer made from agricultural waste, boosts crop yield and improves the quality of agricultural products by enhancing soil NPK levels, water-holding capacity, and overall productivity (Kamar and Yaacob, 2022). It improves soil aeration and provides essential macronutrients and micronutrients for crop growth and development (Oyege and Bhaskar, 2023). The application of vermicompost at a rate of 12.5 t ha^{-1} resulted in higher yield and growth (Mostofa *et al.*, 2021). In order to achieve long-term and environmentally friendly crop production with high yield and quality, it is crucial to prioritize the cultivation of agronomic crops using organic inputs. This approach will effectively improve soil productivity. The present study seeks to examine the impacts of biochar and vermicompost on both the quantity and quality of potatoes.

Materials and Methods

The research field of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, was the location where the investigation was conducted between November 2023 and March 2024. The site of study is located at latitude 23 7'N and longitude 93 E, having an altitude of 8.6 m above sea level, which lies within the "Madhupur Tract" agro-ecological zone (AEZ-28) (Chakma *et al.*, 2020). Two factors were involved in this experiment: Factor A: Biochar levels (4) – B_1: control (0 t ha^{-1}), B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1}, B_4: 4.5 t ha^{-1}. Factor B: Vermicompost levels (4) – Vm_1: control (0 t ha^{-1}), Vm_2: 1.5 t ha^{-1}, Vm_3: 3.0 t ha^{-1}, Vm_4: 4.5 t ha^{-1}. The variety used for testing was BARI Alu-25 "Asterix". A split-plot experimental design with three replications was adopted where biochar levels were assigned to main plots and vermicompost levels to the sub-plots. The soil of this experimental field had sandy loam texture having initial properties as follows: pH 5.67; EC 3.00 dS m^{-1}; organic carbon 0.44%; organic matter 1.09%; total nitrogen content 0.14%; exchangeable K content 0.16 meq 100g $soil^{-1}$; available P amounting to 7.34 mg g^{-1} soil; available S amounting to 28.75 mg g^{-1} soil; B content at 0.57 mg g^{-1} and Zn level at 4.62 mg g^{-1}. Fertilizer application was done according to recommended rates: Urea at 325 kg ha^{-1}, TSP at 220 kg ha^{-1}, MoP at 250 kg ha^{-1}, Gypsum at 220 kg ha^{-1}, Zinc sulfate at 14 kg ha^{-1}, respectively (Rahman *et al.*, 2008). Biochar and vermicompost were applied after final plot preparation. One third urea along with full TSP, MoP and gypsum were applied in furrow apart from 5 cm of planted tuber. The rest amount of urea was applied at 35 and 50 days after planting (DAP) as top dressing.

The properly sprouted, healthy and uniform sized (60-70 g) seed potato tubers were planted. The plot size was 5.0 m × 2.0 m and 60 cm × 20 cm spacing was maintained. Seed potatoes were planted on an average 5 to 6 cm depth in the soil. All the intercultural operations and plant protection standards were taken as per Tuber Crops Research Centre (TCRC) recommendation. Haulm pulling was done at 90 DAP when the majority of plants showed senescence and the top portion started drying. After haulm pulling, the tubers were kept under the soil for 10 days for skin hardening. The potatoes of each plot were separately harvested, bagged, tagged and brought to the laboratory for further analysis. Yield and quality contributing parameters were calculated as per following procedure.

Yield for canned potato production (20-30 mm in size)

The tubers are 20 to 30 mm of their diameter size. Nahid *et al.* (2023) were considered for canned tuber and then the entire tuber weighted by using an electronic balance from total tuber yield against each plot. Then the means were taken in tons per hectare unit.

Yields of potato for flakes production (30-45 mm in size)

The tubers had a diameter of 30 to 45 mm each. Nahid *et al.* (2023) were considered for flakes tuber and then the entire tuber weighted by using an electronic balance from total tuber yield against each plot. Then the means were taken in tons per hectare unit.

Yield of potatoes for chip production (45-75 mm in size)

The tubers are 45 to75 mm in diameter. For chips tuber, Nahid *et al.* (2023) were looked at, and then the whole tuber was weighted by using an electronic balance to compare the total tuber yield to each plot. Then the means were taken in tons per hectare unit.

Yield of the potato for French fry production (>75 mm)

The tubers were then considered for French fries, >75 mm of their length, according to Nahid *et al.* (2023) and the yield against each plot was considered from the total tuber yield. An electronic balance was used to weigh the entire tuber, after which the mean in tons per hectare was taken.

Specific gravity (g cm^{-3})

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

$$\text{Specicifc gravity } \left(\frac{\text{g}}{\text{cubic centimeter}}\right) = \frac{\text{Weight of tuber in air}}{\text{Weight of equal volume of water at } 4°\text{C}}$$

Dry matter content (DMC, %)

The potato tuber samples were kept in separate envelopes for each plot and five potato tubers were taken after harvest to calculate the DMC and were oven dried at 70 °C for 72 h. Dry weight was determined with a digital balance and means were calculated in percent unit.

$$\text{DMC} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

Starch content

The starch content of potato tuber was estimated by the standard procedure (Shigematsu *et al.*, 2017).

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

Immediately after the harvest, within 10 days, the reducing sugar content of tubers was estimated by the method of Somogyi-Nelson. The content was calculated using the glucose standard curve at Abs660nm (Abs1) (Shigematsu *et al.*, 2017).

Statistical analysis

The data collected on different parameters were analyzed statistically by using the technique of analysis of variance with the help of the WASP (Web Agri Stat Package: version 1) computer program, and the means were adjusted by using LSD at 5% level of probability (Gomez and Gomez, 1984).

Results and Discussion

The tables contain data on both the yield and quality parameters of potato. The results have been discussed, and potential explanations are presented under the specified categories.

Tuber numbers hill^{-1}

The number of tubers per hill was not statistically significant because of variations in biochar levels (Table 1).

Table 1. Effect of biochar and/ or vermicompost on the yield and yield contributing traits of potato

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Biochar level	No. of tubers hill^{-1}	Average weight of tuber (g)	Tuber yield (t ha^{-1})	Marketable yield (t ha^{-1})
B_1	11.50	38.01 d	25.30 c	23.47 c
B_2	11.48	41.62 c	27.63 b	24.88 b
B_3	11.83	44.55 b	29.22 a	27.45 a
B_4	12.00	46.97 a	29.63 a	27.94 a
CV (%)	5.63	6.21	5.24	5.14
LSD (0.05)	-	1.217	0.581	0.668
Significance level	NS	*	**	*
		Vermicompost level		
Vm_1	11.17	37.69d	23.85 d	19.21 c
Vm_2	11.75	41.09c	27.54 c	25.94 b
Vm_3	12.00	45.29b	29.77 b	28.95 a
Vm_4	11.83	47.07 a	30.62 a	29.64 a
CV (%)	8.82	3.87	2.77	3.16
LSD (0.05)	-	1.395	0.653	0.695
Significance level	NS	**	**	**
		Biochar × Vermicompost		
$B_1 \times Vm_1$	11.00	32.53	22.13 e	17.47 g
$B_1 \times Vm_2$	11.33	36.47	24.17 d	23.83 d
$B_1 \times Vm_3$	11.67	40.17	26.63 c	25.53 c
$B_1 \times Vm_4$	12.00	42.87	28.27 b	27.03 b
$B_2 \times Vm_1$	10.67	36.17	23.90 d	18.63 fg
$B_2 \times Vm_2$	11.67	39.87	28.27 b	26.47 bc
$B_2 \times Vm_3$	12.00	44.90	28.83 b	26.97 b
$B_2 \times Vm_4$	11.33	45.53	29.53 b	27.47 b
$B_3 \times Vm_1$	11.00	39.53	24.57 d	19.63 f
$B_3 \times Vm_2$	12.33	41.83	28.47 b	26.53 bc
$B_3 \times Vm_3$	12.00	46.93	31.63 a	31.63 a
$B_3 \times Vm_4$	12.00	49.90	32.20 a	32.00 a
$B_4 \times Vm_1$	12.00	42.53	24.80 d	21.10 e
$B_4 \times Vm_2$	11.67	46.20	29.27 b	26.93 b
$B_4 \times Vm_3$	12.33	49.17	31.97 a	31.67 a
$B_4 \times Vm_4$	12.00	49.97	32.47 a	32.07 a
CV (%)	8.82	3.87	2.77	3.16
LSD (0.05)	----	----	1.269	1.374
Significance level	NS	NS	*	*

Values with common letter (s) within a column do not differ significantly at 5% level of probability ** & * indicate significant at 1% and 5% level of probability; NS=non-significant, B_1: 0 t ha^{-1}, B_2: 1.5 t ha^{-1}, B_3: 3.0 t ha^{-1}, and B_4: 4.5 t ha^{-1}. Vm_1: control (0 t ha^{-1}), Vm_2: 1.5 t ha^{-1}, Vm_3:3.0 t ha^{-1}and Vm_4: 4.5 t ha^{-1}

As shown in Table 1, the application of Vm did not have a significant effect on the number of tubers per hill. B_4Vm_3 and B_3Vm_2 yielded the highest numerical value (12.33). According to the available research, an increase in stem numbers corresponds to an increase in tuber production. On the contrary, the yield of potatoes is dependent on the number and average weight of tubers (Koch *et al.*, 2020).

The average weight of tuber

The average weight of tubers was found to be statistically significant ($p \leq 0.01$) when varied quantities of biochar and/or vermicompost were applied (Table 1). In both situations, the average weight of tubers scaled gradually as their levels increased. The beneficial impact of combining inorganic fertilizers with organic manures may have contributed to the rise in average weight of potato tubers. This combination probably encouraged increased vegetative growth, resulting in the synthesis of a larger quantity of food material (Linus and Irungu, 2004). Subsequently, these nutrients were transferred to the growing tubers, which resulted in an increase in their weight. In a study of Dewi *et al.* (2024), it was shown that the application of biochar resulted in a significant increase in the weight of tubers. Overall, the 16 treatment combinations did not significantly differ in the average weight of potato tubers (Table 1). Out of the 16 treatment combinations, the B_4Vm_4 combination had the greatest average weight of tuber, which was 49.97 g. On the other hand, the B_1Vm_1 combination had the lowest average tuber weight, which was 32.53 g (Table 1).

Tuber yield

The tuber yield was significantly influenced ($p \leq 0.01$) by the application of varied amounts of biochar and vermicompost. Table. 1. As the quantities of biochar and vermicompost increased, the tuber yields consistently increased. A statistically significant difference ($p \leq 0.01$) in potato tuber yield was observed among the treatment combinations, as shown in Table 1. The B_4Vm_4 combination had the highest tuber yield, which was statistically comparable to B_4Vm_3, V_3Vm_4, and V_3Vm_3. Conversely, V_1Vm_1 showed the lowest tuber yield. The tuber yield per hectare was highest due to the biggest number of tubers per hill and the maximum average weight of each tuber. The application of biochar and vermicompost solubilizes plant nutrients, increasing NPK uptake and leading to an increase in tuber yield (Chaudhari *et al.*, 2021). Additionally, the incorporation of biochar or vermicompost would have enhanced the nutrient content of soil and ability to retain water. According to research, as the amount of biochar increased, both the total yield and marketable yield of potatoes increased gradually (Roy *et al.*, 2021). In a study, it was found that adding biochar to the soil improved its cation exchange capacity (CEC) and ability to hold water. This led to a 16-35% rise in grain yield compared to the control group (Khan *et al.*, 2024).

Marketable yield

Marketable yield of tuber was found significant ($p \leq 0.01$) against the different biochar and vermicompost levels (Table-1). A study shown that using 10 t ha^{-1} biochar improved both the production and growth of vegetable crops the most (Singh *et al.*, 2019). A statistically significant ($p \leq 0.01$) variance was observed among the treatment combinations in relation to the marketable yield of potato tubers, as shown in Table 1. The V_4Vm_4 treatment combination achieved the highest yield of 32.07 t ha^{-1}, which was statistically equivalent to the yields of the V_4Vm_3, V_3Vm_4, and V_3Vm_3 treatments. The V_1Vm_1 treatment produced the lowest amount, measuring 17.47 metric tons per hectare. The application of fertilizer nutrients could have resulted in an increase in the marketable potatoes. This is due to improved growth, increased foliage and leaf area, and an abundant supply of photosynthates. These factors contribute to the production of larger tubers, ultimately resulting in a higher yield (Boubaker *et al.*, 2023).

Yield for canned potato production

The application of different levels of biochar has a significant effect on canned potato production. The B_1 treatment recorded the highest production at 2.24 t ha^{-1}, followed by B_2, while V4 yielded the lowest at 1.82 t ha^{-1}. The study found that as the amount of biochar increased, the yield of canned potatoes dropped. The levels of vermicompost did not have any impact on the output of canned potatoes, as shown by the data presented in Table 2.

Table 2. Effect of biochar and/ or vermicompost on the yield of potato or different processing purpose

Treatments	Yield for canned potato production (t ha^{-1}) (20-30 mm)	Yield of potato for flakes 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)
		Biochar level		
B1	2.24 a	5.66 a	14.41 d	1.54 d
B2	2.03 b	4.53 b	15.02 c	3.30 c
B3	1.88 c	4.38 c	17.08 b	4.12 b
B4	1.82 c	3.92 d	17.83 a	4.94 a
CV (%)	2.31	3.14	4.52	2.01
LSD (0.05)	0.097	0.130	0.582	0.144
Significance level	**	**	*	**
		Vermicompost level		
Vm1	2.07	4.63	12.41 c	0.944 d
Vm2	2.01	4.64	15.95 b	3.326 c
Vm3	1.97	4.69	17.68 a	4.70 b
Vm4	1.90	4.53	18.29 a	4.92 a
CV (%)	2.36	3.54	5.12	4.58
LSD (0.05)	---	----	0.979	0.137
Significance level	NS	NS	**	**
		Biochar × Vermicompost		
B1 × Vm1	2.33	4.67 cd	11.84	NF
B1 × Vm2	2.30	5.59 b	14.40	1.54 j
B1 × Vm3	2.23	6.10 a	15.10	2.16 i
B1 × Vm4	2.08	6.30 a	16.30	2.44 h
B2 × Vm1	2.00	4.80 c	11.40	0.42 k
B2 × Vm2	2.00	4.60 cd	15.90	3.96 e
B2 × Vm3	2.10	4.60 cd	16.00	4.20 d
B2 × Vm4	2.00	4.10 e-g	16.77	4.56 c
B3 × Vm1	2.00	4.70 cd	12.30	0.63 k
B3 × Vm2	1.90	4.50 c-e	16.60	3.52 f
B3 × Vm3	1.80	4.30 d-f	19.50	6.23 ab
B3 × Vm4	1.80	4.00 fg	19.90	6.30 ab
B4 × Vm1	1.95	4.33 d-f	14.40	2.73 g
B4 × Vm2	1.85	3.90 fg	16.90	4.28 d
B4 × Vm3	1.75	3.75 g	20.10	6.36 a
B4 × Vm4	1.73	3.70 g	20.20	6.37 a
CV (%)	2.36	3.54	5.12	4.58
LSD (0.05)	----	0.437	----	0.277
Significance level	NS	*	NS	**

Values with common letter (s) within a column do not differ significantly at 5% level of probability ** & * indicate significant at 1% and 5% level of probability; NS=non-significant, B1: 0 t ha^{-1}), B2: 1.5 t ha^{-1}, B3: 3.0 t ha^{-1}, and B4: 4.5 t ha^{-1}. Vm1: control (0 t ha^{-1}), Vm2: 1.5 t ha^{-1}, Vm3:3.0 t ha^{-1}and Vm4: 4.5 t ha^{-1}.

The correlation between biochar and vermicompost levels did not have a statistically significant impact on canned potato yield. The highest yield of canned potatoes was documented quantitatively from B1Vm1, equal to 2.33 t ha^{-1}.

Yield of potato for flakes production

The tuber yield for flakes production showed a significant difference ($p \leq 0.01$) when various levels of biochar were applied. However, the application of vermicompost did not yield any significant effect. The B_1 treatment had the maximum output of 5.66 t ha^{-1}, whereas the B_4 treatment had the lowest yield of 3.92 t ha^{-1}. A significant difference ($p \leq 0.01$) was found among the treatment combinations in terms of the yield of potato tubers for the production of flakes. The treatment combination B_1Vm_4 yielded the largest quantity of 6.30 t ha^{-1}, which was statistically equivalent to the yield produced with the B_1Vm_3 combination. However, the B_4Vm_4 treatment resulted in the lowest yield of 3.70 t ha^{-1}.

Yield of potato for chips production

The tuber yield for chip production was found to be significant ($p \leq 0.01$) against the application of different levels of biochar and vermicompost (Table 2). In both cases, there was a regular increase in yield in response to increasing levels of biochar and vermicompost application. This finding was consistent with a study which reported that vermicompost increases the availability of nutrients, including micronutrients, in the soil for improved crop nutrient uptake and tuber production (Chaudhary *et al.*, 2004). Organic fertilizer application increases the availability of both macro- and micronutrients in the soil, providing sufficient nutrients to meet crop requirements and thus encouraging the production processes (Möller, 2018). The combination of biochar and vermicompost showed no significant variation among the treatment combinations compared to potato tuber yield for chip production (Table 2). Mathematically, the highest yield (20.20 t ha^{-1}) from B_4Vm_4 was recorded, followed by B_4Vm_3.

Yield potato for French fry production

The yield of tuber for French fry production was found to be significant ($p \leq 0.01$) against the application of different levels of biochar and vermicompost (Table 2). The results revealed that the yield of potatoes for French fry production gradually increased with increasing biochar and vermicompost levels. The interactive effect of biochar and vermicompost significantly ($p \leq 0.01$) influenced the tuber yield for French fry production under study. The highest yield (6.37 t ha^{-1}) was found from B_4Vm_4, which was statistically similar to B_4Vm_3., B_3Vm_4, and B_3Vm_3 (Table 2). French fry yield was not found in B_1Vm_1.

Specific gravity

The specific gravity of the tuber changed significantly ($p \leq 0.01$) when different amounts of biochar and vermicompost were added (Table 3). The results showed a gradual increase in specific gravity as the rate of biochar and vermicompost increased. A similar trend was also observed a study which reported that increased biochar application significantly ($p < 0.05$) increased tuber specific gravity (Melo *et al.*, 2022). Application of 50% recommended nitrogen, 25% recommended N through FYM @ 7.5 t ha^{-1}, and 25% recommended nitrogen through vermicompost @ 2.25 t ha^{-1} resulted in the maximum specific gravity of potatoes (Taha *et al.*, 2017). In terms of interaction effects, a significant ($p \leq 0.01$) difference was also found among the treatment combinations against the specific gravity of potato tubers (Table 3). The B_4Vm_4 treatment combination yielded the highest specific gravity (1.068 g cm^{-3}), statistically comparable to B_4Vm_3. The B_3Vm_4 and B_3Vm_3 treatment combinations yielded the highest specific gravity, while V_1Vm_1 produced the lowest (0.974 g cm^{-3}). Tuber specific gravity increased with increasing organic manure, which is more important to the tuber specific gravity under warmer conditions (Shayanowako *et al.*, 2015).

Dry matter content

Significant ($p \leq 0.01$) variation was noted among the application of different levels of biochar and vermicompost against the dry matter content of tubers (Table 3). The (DMC) of potatoes gradually increased as the levels of biochar and vermicompost increased, reaching levels B_3 and Vm_3, and then showing statistically similar results. The result aligned with the findings of a report that observed a significant increase in tuber dry matter content upon the application of biochar (Mostofa *et al.*, 2019). The T4 treatment (Crop residue incorporation + biofertilizers (Azotobacter and Rhizobacteria) + Vermicompost @ 5 t ha^{-1} + microbial culture) yielded a higher dry matter content (19.66%), possibly because the application of vermicompost positively influenced the dry matter of tubers (Mostofa *et al.*, 2019). Though the combination effects of biochar and vermicompost had no significant effect on dry matter content of tubers, B4Vm4, B4Vm3, B3Vm4 and B3Vm3 produced more than 20% dry matter content, which is suitable for processing industries (Luthra and Gupta, 2019). According to the findings, the model calculations of the fraction of total dry matter produced. However, those allocated to the tuber were on the assumption that the tubers had been the dominant sink in the potato crop (Kooman and Rabbinge, 1996).

Table 3. Response of biochar and/ or vermicompost on the quality parameter of potato

Treatments	Specific gravity (g cm^{-3})	Dry matter content (%)	Reducing sugar (mg g^{-1} FW)	Starch content (mg g^{-1} FW)
		Biochar level		
B1	1.026 d	18.32 c	0.541 a	14.033 c
B2	1.045 c	19.29 b	0.412 b	15.537 b
B3	1.052 b	20.56 a	0.330 c	17.603 a
B4	1.056 a	20.93 a	0.325 d	17.713 a
CV (%)	0.27	3.18	0.24	2.57
LSD (0.05)	0.027	0.780	0.030	0.204
Significance level	**	**	**	**
		Vermicompost level		
Vm1	1.018 d	17.61 c	0.492 a	14.333 c
Vm2	1.046 c	19.58 b	0.411 b	16.355 b
Vm3	1.055 b	20.70 a	0.364 c	16.929 a
Vm4	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	**	**	**	**
		Biochar × Vermicompost		
B1Vm1	0.974 k	16.05	0.595 a	12.160 g
B1Vm2	1.035 i	18.65	0.546 b	13.610 f
B1Vm3	1.045 gh	19.17	0.522 c	14.650 e
B1Vm4	1.051 ef	19.41	0.502 d	15.712 d
B2Vm1	1.025 j	17.45	0.497 e	13.670 f
B2Vm2	1.047 fg	19.57	0.422 g	15.817 d
B2Vm3	1.051 ef	19.97	0.380 i	16.120 cd
B2Vm4	1.057 cd	20.16	0.347 k	16.540 c
B3Vm1	1.031 i	18.16	0.464 f	15.834 d
B3Vm2	1.053 de	19.92	0.312 l	17.634 b
B3Vm3	1.064 ab	21.65	0.282 m	18.573 a
B3Vm4	1.064 ab	22.52	0.262 o	18.370 a
B4Vm1	1.041 h	18.79	0.412 h	15.670 d
B4Vm2	1.050 e-g	20.16	0.365 j	18.360 a
B4Vm3	1.064 ab	21.99	0.271 n	18.373 a
B4Vm4	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	**	*

Values with common letter (s) within a column do not differ significantly at 5% level of probability ** & * indicate significant at 1% and 5% level of probability; NS=non-significant, B1: (0 t ha^{-1}), B2: 1.5 t ha^{-1}, B3: 3.0 t ha^{-1}, and B4: 4.5 t ha^{-1}. Vm1: control (0 t ha^{-1}), Vm2: 1.5 t ha^{-1}, Vm3:3.0 t $ha^{-1}$and Vm4: 4.5 t ha^{-1}

Reducing sugar

Reducing sugar is one of the most harmful constituents of potato, and more than 0.5% reducing sugar may cause toxicity to human health (Bethke and Bussan, 2013). A significant variation at $p \leq 0.01$ was found among the different levels of biochar and vermicompost application against reducing sugar content of tubers; the values are given in Table 3. The results showed that reducing sugar contents decreased with increasing levels of biochar and vermicompost. According to research, sugar content of tuber decreased with increasing levels of biochar and vermicompost application compared to the control treatment (Ferdous *et al.*, 2019). This study also reported that increasing vermicompost levels significantly decreased tuber-reducing sugar content. The treatment combination of biochar and vermicompost showed a significant ($p \leq 0.01$) variation that was found among the treatment combinations against reducing sugar content of potato tubers (Table 3). The lowest reducing sugar (0.251 mg g^{-1} FW) was found from B_4Vm_4 treatment combination. The combination of B_4Vm_3, B_3Vm_4, and B_3Vm_3 also contained less than 0.3 mg g $^{-1}$ FW reducing sugar content, which is suitable for processing products, while the highest (0.595 mg g^{-1} FW) reducing sugar was in V_1Vm_1. Due to the higher application of organic manures, it may decrease the internal respiration of potato stored matter like starch. Due to that, the reducing sugar was lower by a slower rate of breaking the starch into less reducing sugars than that of no application of organic manure (Shayanowako *et al.*, 2015).

Starch content

Significant ($p \leq 0.01$) variation was noted among the application of different levels of biochar and vermicompost application against starch content of tuber (Table 3). Data showed that starch content progressively increased with increasing biochar and vermicompost levels upto B_3 and Vm_3 and after that exhibited statistical similar result. 17.713 mg g^{-1} FW was found from B_4 treatment which was similar to B_3 treatment and the less significant ($p \leq 0.05$) variation was also found among the treatment combinations against starch content of potato tubers (Table 3). The maximum starch (18.450 mg g^{-1} FW) was found from B_4Vm_4 treatment combination which was statistically at par with B_4Vm_3, B_4 Vm_2, B_3Vm_4 and B_3Vm_3, where the lowest (12.160 mg g^{-1} FW) was recorded in B_1Vm_1 (Table 3). Starch content also varied significantly with organic manures application, they also indicated a judicious Trend of starch accumulation in case of application of different levels of organic manures is presented in, which showed similar result of the research (Jaipaul *et al.*, 2011).

Conclusion

These results clearly show that the yield and quality parameters of potatoes responded significantly to biochar, vermicompost, or their combination. Although different mixes were tried, the best one for potato yield and quality was 3 t ha^{-1} of both biochar and vermicompost mixed together. This was better than using higher rates of each ingredient separately. It was suggested that 325 kg ha^{-1} of Urea, 220 kg ha^{-1} of TSP, 250 kg ha^{-1} of MoP, 120 kg ha^{-1} of Gypsum, and 14 kg ha^{-1} of Zinc Sulfate be used with 3 t ha^{-1} of biochar and 3 t ha^{-1} of vermicompost. This led to the best potato yield and quality.

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