Original Research Article

Co-application of biochar and organic fertiliser for improved productivity of sesame (*Sesamum indicum* L.) in the humid tropics

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Abstract

Sesame (*Sesamum indicum* L.) grain yield has recently declined partly because of the limited use of organic nutrient sources on degraded tropical soils. The study assessed the agronomic performance of three sesame varieties (V) as affected by organic nutrient sources (T) application. The two factors were arranged in a split-plot with V (White Benue, Cameroun White, and E-8) as the main plot and T (T1: Control, T2: biochar at 2.5 t/ha, T3: biochar at 5.0 t/ha, T4: organic fertiliser at 5.0 t/ha, T5: organic fertiliser + biochar at 2.5 t/ha and T6: organic fertiliser + biochar 5.0 t/ha) as the subplot in a Randomised Complete Block Design and replicated three times. Data were collected on agronomic traits of sesame. The varieties were significantly ($p < 0.05$) different in number of days to flowering, capsule formation, and physiological maturity in 2020. Varietal and organic nutrient source effects were significant ($p < 0.05$) for height at flowering and harvest in both years. Factor T (T4–T6) significantly ($p < 0.05$) increased capsule and seed weight per plant, and grain yield in both years relative to T1. The V × T interaction was significant for height to the first capsule and seed weight per plant in 2020. Sesame grain yields recorded under T3–T6 were significantly higher ($p < 0.05$) than the control (T1) in 2020 (1.2–1.5 t/ha) and 2021 (1.3–1.6 t/ha). Prospective organic sesame producers can apply organic fertiliser at 5 t/ha (T4) alone in the humid tropics.

Keywords: bamboo biochar; grain yield; humid tropics; nutrient source; organic sesame

INTRODUCTION

Sesame (*Sesamum indicum* L.) is an oilseed crop widely grown for its high-quality nutritional seeds in tropical and subtropical regions of Asia and Africa. It is grown mainly for its seed which contains 50% oil and 25% protein (Burden, 2005). It is presently cultivated on approximately 12.8 million hectares in 59 countries, including countries in tropical Africa such as Sudan, Tanzania, and Nigeria occupying the first, fourth, and fifth positions in its world production (FAOSTAT, 2024). At present, Africa accounts for 59.3% (4,000,119 t) of the world's 6,741,479.41 tons of sesame production (FAOSTAT, 2024). However, as of 2022, the total land area under organic oilseeds was

1.82 million ha with sesame (4.3%) occupying the fifth position after soybean (58.6%), sunflower (16.8%), other oilseeds (9.6%), rape and turnip rape (5.0%) as reported by Willer et al. (2024). This is against the backdrop that the world's sesame seed market was projected to reach US$7.94 billion in 2030 at a growth rate of 2.1% (Market Research Future, 2023).

Sesame grain yield declined over the last ten years due to the cultivation of low-yielding dehiscent varieties, lack of appropriate agricultural inputs, vagaries of climate, degrading soil fertility status of tropical soils, lack of use of appropriate management practices such as crop residue management, nutrient imbalance in soil among others (Ndor et al., 2015; Olowe, 2018; Hirapara et al., 2020; Somefun et al., 2020).

Most soils in sub-Saharan Africa (SSA) where more than half of the world's sesame is produced, are severely depleted of their soil organic carbon (SOC) and nutrient reserves and strongly degraded (Lal, 2011). The poor status of the soils could be attributed to climate change and excessive agricultural activities by resource-constrained farmers on their limited and less productive farmlands (Harvey and Pilgrim, 2011). Soil degradation was recently described as the most critical problem in agricultural production in the world (Brusseau et al., 2019). Soils depleted of SOC not only yield less but also have low use efficiency of added inputs and can sequester less atmospheric CO_2, especially when continuous arable cropping under intensive tillage is being practiced (Lal, 2006; 2011). Since most of these soils cannot supply the needed nutrients, most practitioners now try to provide additional nutrients, especially synthetic fertilisers to boost food production. Globally in 2021, a total of 190 million tons of chemical fertilisers (56% N, 24% P, and 21% K) were used in agriculture (FAO, 2023). The breakdown revealed that overall fertilizer use in 2021 was 60 million tons (44%) higher than in 2020 by 34, 43, and 85% higher for N, P, and K, respectively (FAO, 2023). Unfortunately, these chemical fertilisers come with their attendant challenges for humans and the environment such as loss of biodiversity, contamination of underground water, nutrient imbalance, and accumulation of heavy metals among others (Chali Abate, 2023).

Among several solutions being proffered to mitigate climate change and food insecurity (Jacobson, 2009), an important option is the sequestration of carbon (C) in agroecosystems, especially in agricultural soils through the use of organic soil amendments such as biochar (de la Rosa, 2020). Biochar research has focused on enhancing soil fertility, carbon (C) sequestration, activities of microorganisms, agricultural production, mitigating climate change, soil contamination, and many other aspects (Hussain et al., 2017). Biochar is a biomaterial that is capable of improving soil characteristics such as water content, soil pH, cation exchange capacity (CEC), soil organic carbon (SOC) (Bass et al., 2016; Bera et al., 2016), field capacity (Chan et al., 2008; Abel et al., 2013), organic matter, nutrients availability (Laird et al., 2010), and microorganisms biomass (Shah et al., 2021). Biochar is now considered a sustainable technology to improve highly weathered or degraded soils and soil fertility (Filiberto and Gaunt, 2013).

Earlier studies have confirmed the potential use of biochar and organic fertiliser in sesame production using rice husk and sawdust to improve soil properties in Nigeria (Ndor et al., 2015), a combination of biochar and NPK in Australia (Furtado et al. 2016), biochar application on upland fields in Japan (Wacal et al., 2019), biochar alone in Bangladesh (Roy et al. 2019), biochar enriched with vermicompost in India (Hirapara et al., 2020) and biochar enriched with poultry manure in Ghana (Issahaku et al., 2023). However, how biochar and fertiliser application result in improved productivity relative to conventional fertilisers and their interaction mechanisms are still poorly understood (Solaiman, 2023). Furthermore, there is still a paucity of information on sesame agronomic performance following the co-application of biochar with other organic amendments such as organic fertiliser in the tropics of Africa. The study hypothesised that there is no difference in the productivity of sesame irrespective of the nutrient source adopted in the tropics. Consequently, this study evaluated the effects of the integrated use of biochar and organic fertiliser on sesame productivity in a forest-savannah transition zone of tropical Africa.

MATERIALS AND METHODS

Experimental site

The field experiment was carried out during the late cropping seasons (July–November) of 2020 and 2021 on the organic research plot of the Institute of Food Security, Environmental Resources and Agricultural Research, (IFSERAR), the Federal University of Agriculture Abeokuta (FUNAAB) as shown in Figure 1. The research farm is located at Latitude 7°13′53.16″N and 7°13′51.17″N, Longitude 3°23′49.12″E, and 3°23′51.86″E, 139 m above sea level.

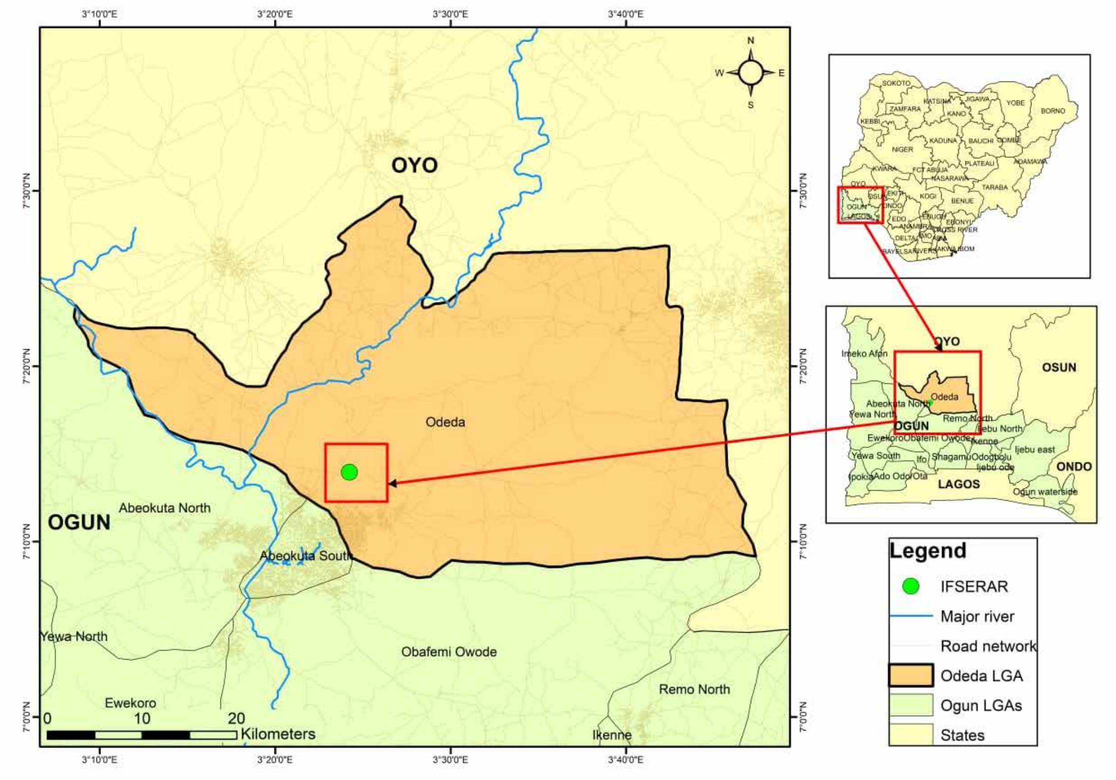

Figure 1. Map of the experiment location

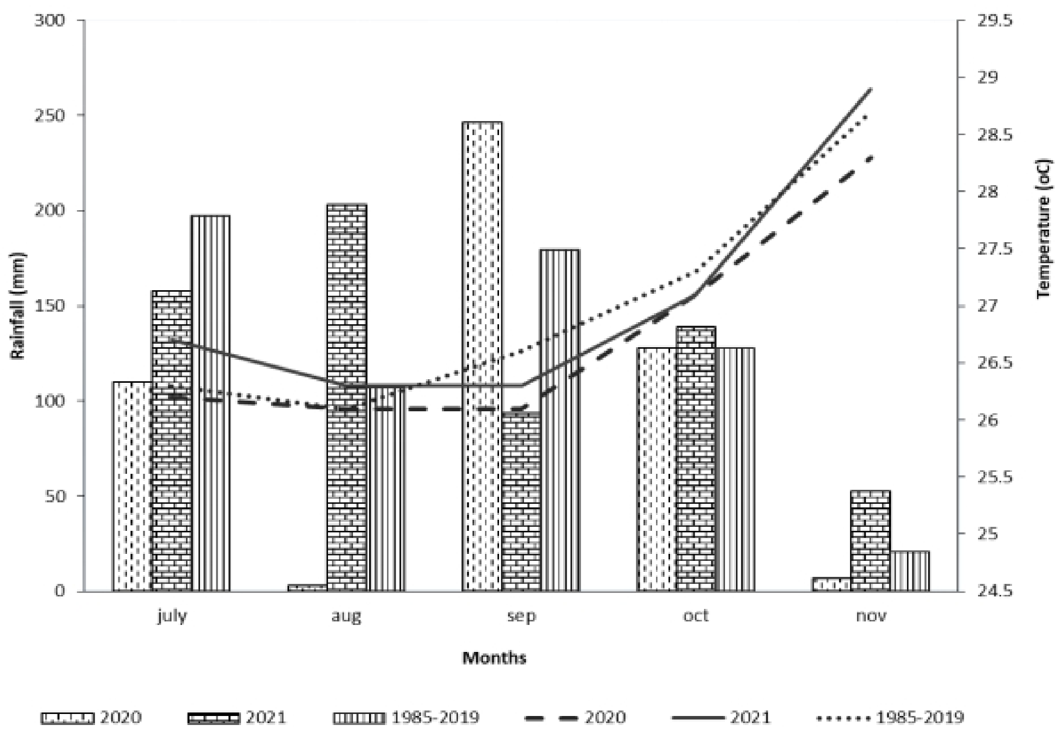

Figure 2. Monthly rainfall and mean monthly temperature during the late cropping season (July–November) of 2020, 2021 and Long-term period (1985–2019)
Source: Department of Water Resources Management and Agrometeorology, FUNAAB

Traditionally, the rainfall pattern of this area is bimodal having two peaks in July and September, with a dry spell in August termed 'August break' However, this trend did not play out in both years. The two peaks were recorded in June and September in 2020, and July and August in 2021. During the period of experimentation, total rainfall of 493.8 mm and 645.9 mm was recorded in 2020 and 2021, respectively compared with 632.8 mm for the thirty-five years long-term period (1985–2019). Temperature was not limiting during the period of experimentation in both years and it ranged between 26.0 and 28.3 °C in both years. Some weather data are presented in Figure 2.

Soil, biochar, and organic fertiliser characteristics

Soil samples were taken from a depth of 0–20 cm using soil auger and analysed to determine their nutrient status before and after experimentation on a treatment basis. The experimental soil belonged to the textural class of loamy sand with a pH that was slightly alkaline in 2020 and 2021. The soil was very low in nitrogen – 0.62 and 0.71 g/kg, high in phosphorus – 34.82 and 46.83 mg/kg, moderate in potassium – 0.42 and 0.51 cmol/kg, low in calcium – 1.11 and 1.13 cmol/kg, and high in magnesium – 0.72–0.82 cmol/kg in 2020 and 2021, respectively (Table 1). The feedstock for biochar production was bamboo (*Bambusa vulgaris* L.) stems. It was subjected to pyrolysis under high temperatures between 200 °C and 400 °C (Weber and Quicker, 2018). The pH of the bamboo biochar was alkaline in both years and was also very low in nitrogen – 2.6 and 2.3 g/kg N in 2020 and 2021, respectively, and richer in phosphorus and potassium in 2020 than in 2021. Biochar was incorporated into the soil on the sowing date using the broadcast and incorporated method as described by Yeboah et al. (2020). The organic fertiliser applied in both years was Aleshinloye Grade B, an abattoir-based fertiliser. It contained 12.30 (g/kg) and 10.30 (g/kg) total nitrogen in 2020 and 2021, respectively, and was also slightly richer in phosphorus in 2020 than in 2021.

Sesame test varieties

The three test varieties used in the experiment were White Benue (V1): an extra-early maturing variety with pearly white seeds, Cameroon White (V2): an early maturing variety with whitish brown color seeds and E-8 (V3): an early maturing and high yielding variety, the colour of the seed is pearly white as described by Olowe et al., (2003). Camroon White and E-8 varieties have been released, while White Benue is a commonly grown variety by sesame farmers.

Table 1. Pre-cropping physical and chemical properties of experimental soil in 2020 and 2021

Properties	2020	2021
Physical properties		
Sand (g/kg)	718.0	852.0
Silt (g/kg)	250.0	120.0
Clay (g/kg)	32.0	28.0
Textural class	LS	LS
Chemical properties		
pH	7.31	7.50
Total N (g/kg)	0.62	0.71
Organic carbon (%)	0.25	1.21
Available P (mg/kg)	34.82	46.83
Exchangeable		
K (cmol/kg)	0.41	0.51
Ca (cmol/kg)	1.13	1.13
Mg (cmol/kg)	0.72	0.82
Na (cmol/kg)	0.24	0.24
Extractable		
Mn (mg/kg)	4.24	4.74
Fe (mg/kg)	13.62	18.82
Zn (mg/kg)	6.82	9.72

LS – Loamy sand

Study design and management

The two-year field experiment evaluated two factors, namely Variety (White Benue, Cameroun White and E8) and organic nutrient sources (T1: Control, T2: Biochar at 2.5 t/ha, T3: Biochar at 5.0 t/ha, T4: Organic fertiliser at 5 t/ha, T5: Biochar at 2.5 t/ha + Organic fertiliser 5.0 t/ha and T6: Biochar at 5.0 t/ha + Organic fertiliser 5.0 t/ha). The two factors were arranged in split-plot and replicated three times in a Randomised Complete Block Design. The main plot factor was variety and the sub-plot factor was the organic nutrient source. The experimental field was ploughed twice at two-week intervals and later harrowed a week after. The plot was marked out, pegged, and divided into three replications (blocks) each 1.0 m apart. The land area used for this experiment was 26.5 m × 32.6 m (863.9 m^2) and each experimental plot measured 3.0 m × 4.0 m (12.0 m^2) and separated by 0.50 cm. After the marking out of plots in the three replicates, sowing was done on July 29 and August 12 in 2020 and 2021, respectively. Plant spacing adopted was 60 cm × 5 cm with a corresponding plant population of 333,000 plants per ha. Manual weeding was done at three Weeks After Sowing (WAS), and 6 WAS in both years to simulate the practice of resource-constrained farmers in the tropics. Five plants were randomly selected and tagged at 4 WAS from the net plot for plant height and yield attribute measurements on a plot basis. The experiment was carried out under rain-fed conditions and harvesting was done manually at physiological maturity as described by Lagham et al. (2008) in both years.

Data collection

The agronomic characteristics measured on sesame were the number of days to 50 % flowering, capsule formation, and physiological maturity, plant height (cm) at flowering and physiological maturity, height (cm) to the first capsule, number and weight (g) of capsules and seeds per plant, number of branches per plant, and grain yield (kg/ha).

Statistical analysis

All data collected on the agronomic characteristics were subjected to analysis of variance (ANOVA) to test the effects of the variety and organic nutrient sources and their interaction during the two field trials by using MSTATC package version 1.42 (Freed et al., 1989). The significant ($p < 0.05$, F-test) treatment means of the main effects and interactions were separated using the least significant difference method at $p = 0.05$. The ANOVA was carried out every year because the two years were markedly different.

RESULTS

Post-cropping chemical properties of the soil at the experimental site in 2020 and 2021

Organic nutrient sources significantly ($p < 0.05$) affected the pH, macro-nutrient, and organic carbon level of the soil of the experimental sites after cropping in both years, except the total nitrogen in 2021 (Table 2). The pH across the six treatments was slightly alkaline after cropping in both years due to a slight increase in pH values. The total nitrogen remained low across the treatments in both years. However, available phosphorus was high across the treatments, except under T2 (16.9 mg/kg), T3 (19.6 mg/kg), and T6 (19.5 mg/kg) in 2021. Phosphorus was generally higher after the first season relative to that of natives. However, despite P application during the second season in addition to the high native P before planting, the post-cropping P was generally and severely depleted. A similar trend was recorded for exchangeable potassium across the treatments in both years (Table 2). Exchangeable K appeared to be slightly improved compared to native K but indifferent in both seasons. Organic carbon was low in 2020 but high in 2021.

Effects of variety and organic nutrient source on the number of days to 50 % flowering, capsule formation, and physiological maturity of sesame in 2020 and 2021

The varietal effect was significant ($p < 0.05$) for the number of days to flowering, capsule formation, and physiological maturity in 2020 with Cameroon White (V2) and E8 (V3) attaining those dates significantly ($p < 0.05$) later than White Benue (V1) (Table 3). Whereas, in 2021, the varietal effect was not significant for the number of days to flowering and capsule formation. White Benue, however, attained physiological maturity eight days earlier than Cameroon White and E8 (significant at a 5 % probability level). Organic nutrient source only significantly ($p < 0.05$) affected the number of days to flowering in 2020.

Effects of variety and organic nutrient source on the number of branches per plant height at flowering and maturity, height to the first capsule of sesame in 2020 and 2021

The varietal effect was significant ($p < 0.05$) for height at flowering and harvest, and height to the first capsule of sesame in 2020 and 2021 (Table 4). In both years, no

Table 2. Post-cropping chemical properties of the soil in 2020 and 2021

Organic nutrient source	pH		Total N (g/kg)		Available P (mg/kg)		Exchangeable K (cmol/kg)		OC (%)	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
T_1	7.60	7.80	0.40	0.90	50.10	21.60	0.56	0.59	0.31	1.22
T_2	7.62	7.83	0.62	1.01	39.52	16.91	0.52	0.56	0.32	1.24
T_3	7.63	7.83	0.63	0.92	49.23	19.63	0.58	0.54	0.33	1.25
T_4	7.73	7.82	0.63	1.03	48.53	21.22	0.52	0.54	0.33	1.26
T_5	7.72	7.71	0.52	0.93	41.52	20.63	0.52	0.53	0.33	1.27
T_6	7.70	7.60	0.51	0.91	47.41	19.51	0.53	0.53	0.33	1.26
LSD (5 %)	0.04	0.07	ns	0.04	4.00	1.50	0.02	0.02	ns	0.02

Key: T_1 = Control, T_2 = Biochar at 2.5 t/ha, T_3 = Biochar at 5.0 t/ha, T_4 = Organic fertiliser at 5.0 t/ha, T_5 = Biochar at 2.5 t/ha + Organic fertiliser at 5.0 t/ha, T_6 = Biochar at 5.0 t/ha + Organic fertiliser at 5.0 t/ha; ns = Not Significant, LSD = Least Significant Difference, OC = Organic Carbon

Table 3. Effect of variety and organic nutrient source on the number of days to 50% flowering, full capsule, and physiological maturity of sesame in 2020 and 2021

Treatment	Number of days to 50% flowering	Number of days to capsule	Number of days to physiological maturity
		2020	
Variety (V)			
White Benue (V1)	43.8	52.7	92.6
Cameroon White (v2)	47.1	62.1	108.6
E-8 (V3)	47.6	64.6	105.8
LSD (5%)	2.38	2.66	6.16
Organic nutrient source (T)			
T_1	47.6	61.1	102.1
T_2	46.7	60.2	102.9
T_3	47.3	60.9	101.6
T_4	45.8	59.3	103.0
T_5	43.6	58.8	102.0
T_6	46.2	58.3	102.6
LSD (5%)	1.54	ns	ns
V × T	ns	ns	ns
		2021	
Variety (V)			
White Benue (V1)	45.2	51.0	87.0
Cameroon White (v2)	46.8	55.9	95.8
E-8 (V3)	47.1	54.7	95.4
LSD (5%)	ns	ns	3.21
Organic nutrient source (T)			
T1	46.6	54.4	92.3
T2	45.8	53.8	92.8
T3	46.9	54.2	92.4
T4	46.7	53.7	93.2
T5	46.0	53.2	92.8
T6	46.1	53.9	92.9
LSD (5%)	ns	ns	ns
V × T	ns	ns	*

Key: T_1 = Control, T_2 = Biochar at 2.5 tonnes/ha, T_3 = Biochar at 5.0 tonnes/ha, T_4 = Organic fertiliser at 5.0 tonnes/ha, T_5 = Biochar at 2.5 tonnes/ha + Organic fertilizer at 5.0 tonnes/ha, T_6= Biochar at 5.0 tonnes/ha + Organic fertiliser at 5.0 tonnes/ha; ns = Not Significant, LSD = Least Significant Difference, V × T = Variety and Organic nutrient source interaction, * = significantly different at $p < 0.05$.

significant varietal effect was recorded for the number of branches per plant. Height at flowering and harvest of White Benue were significantly ($p < 0.05$) lower than the values recorded for Cameroon White and E8 in both years.

Organic nutrient sources significantly ($p < 0.05$) affected the number of branches per plant, height at flowering, and maturity of sesame in both years, except the number of branches per plant in 2021. On average, sesame plants that received biochar alone at 5.0 t/ha (T3) recorded the highest number of branches per plant and were significantly ($p < 0.05$) higher than the number of branches of sesame plants that received other treatments. Sesame plants on plots treated with biochar at 5.0 t/ha and organic fertiliser (T6) were significantly ($p < 0.05$) shorter than sesame plants under other treatments at flowering, except sesame under T5 in 2020. However, at harvest, sesame plants under the control (T1) were ($p < 0.05$) shorter than sesame plants under other treatments, except biochar at 2.5 t/ha (T2) in 2020 and biochar at 5.0 t/ha and organic fertiliser (T6) in 2020. In 2021, the organic nutrient source effect was also significant ($p < 0.05$) for the height at flowering and harvest. Sesame plants under control (T1) recorded significantly ($p < 0.05$) lower height values for these traits relative to sesame plants under the other organic nutrient sources (T2–T6). Variety × Organic nutrient source interaction was significant ($p < 0.05$) on the height to the first capsule in 2020 (Figure 3). A combination of V1 × T4 recorded the highest to the first capsule (53.5 cm) and V1 × T6 the lowest (33.2 cm). Whereas, V2 × T4 (76.9 cm) and V2 × T2 (62.7 cm); V3 × T3 (78.7 cm) and V3 × T1 (62.7 cm) recorded the highest and lowest height to the first capsule in 2020, respectively.

Effects of variety and organic nutrient source on 1000-seed weight, number, and weight of capsules per plant, number of seeds per plant, seed weight per plant, and grain yield of sesame in 2020 and 2021

The three test varieties produced grain yield above one ton per hectare in both years however, no significant difference was recorded among the varieties (Table 5). Organic nutrient sources ($p < 0.05$) affected all the traits in both years, except 1000-seed weight and the number of capsules per plant in 2021. Sesame plants on plots treated with biochar at 5.0 t/ha (T3), organic fertiliser at 5.0 t/ha (T4), biochar at 2.5 and 5.0 t/ha, and organic fertiliser at 5.0 t/ha (T5 and T6) recorded a higher ($p < 0.05$) number of capsules per plant than the plants under control (T1) and T2 in 2020. Sesame plants under T3–T6 produced capsules that were significantly ($p < 0.05$) heavier than capsules of sesame under T1 in 2020. In 2021, sesame plants treated with biochar at 5.0 t/ha (T3) were on par with plants under control (T1) and other treatments for capsule weight per plant. Sesame plants that were grown with the application of organic fertiliser (T4), produced the highest number of seeds per plant and were significantly ($p < 0.05$) higher than the number of seeds recorded under control (T1) in 2020. A similar trend was recorded for grain yield in 2020 where sesame under organic amendment treatments (T2–T6) were on par. Sesame treated with biochar at 5.0 t/ha and organic fertiliser (T6) produced seeds that were significantly ($p < 0.05$) larger than what was produced under control (T1), biochar at 2.5 and 5.0 t/ha (T2 and T3) but on par to values recorded for sesame under organic fertiliser (T4) and biochar at 2.5 t/ha and organic fertiliser (T5) in 2021. Sesame plants under biochar at 2.5 t/ha and organic fertiliser (T5) and biochar at 5.0 t/ha and organic fertiliser (T6) recorded a grain yield of 1.6 t/ha which was significantly ($p < 0.05$) greater than grain yield values recorded under control (T1: 0.7 t/ha), biochar at 2.5 (T2: 0.9 t/ha) in 2021 as shown in Table 5. Variety × Organic nutrient source interaction was significant ($p < 0.05$) on the weight of seeds per plant in 2020 (Figure 4). The combination of V1 × T5 and V1 × T1 recorded the highest seed weight (11.2 g) and lowest seed weight (3.9 g). Whereas, V2 × T5 and V2 × T1 recorded the highest (9.6 g) and lowest (4.6 g), respectively, and V3 × T4 and V3 × T1 the highest (12.0 g) and lowest (2.7 g), respectively.

DISCUSSION

In this study disparities in climatic conditions were recorded during the late cropping seasons of 2020 and 2021. The 2020 growing season was 139 mm dryer than the average (35-year average) and 2021 was 12.8 mm wetter than the average. Overall, the two years of experimentation experienced relatively

Table 4. Effects of variety and organic nutrient source on number of branches per plant, height (cm) at flowering and harvest, and height to the first capsule of sesame in 2020 and 2021

Treatment	No of branches per plant	Height at flowering (cm)	Height at harvest (cm)	Height to the first capsule (cm)
		2020		
Variety (V)				
White Benue (V1)	2	71.0	94.9	45.2
Cameroon White (V2)	3	90.6	119.3	66.5
E-8 (V3)	3	98.3	126.9	67.1
LSD (5%)	ns	7.89	18.04	14.52
Organic nutrient source (T)				
T_1	2	91.5	101.9	60.7
T_2	2	91.0	106.4	55.2
T_3	4	90.4	121.9	62.3
T_4	2	85.7	124.1	65.8
T_5	3	84.5	115.6	58.5
T_6	2	76.7	112.3	55.0
LSD 5%	0.8	8.90	13.30	7.73
V × T	ns	**	**	*
		2021		
Variety (V)				
White Benue (V1)	1	102.0	119.8	64.5
Cameroon White (V2)	2	129.7	156.7	89.4
E-8 (V3)	1	121.3	147.3	85.9
LSD (5%)	ns	18.30	11.03	7.07
Organic nutrient source (T)				
T_1	1	89.7	114.8	59.2
T_2	1	122.5	147.7	80.6
T_3	2	124.3	148.9	87.0
T_4	2	122.0	145.2	84.1
T_5	1	126.5	146.2	88.1
T_6	1	120.9	144.9	80.8
LSD 5%	ns	10.44	20.44	8.87
V × T	ns	ns	ns	ns

Key: T_1 = Control, T_2 = Biochar at 2.5 t/ha, T_3 = Biochar at 5.0 t/ha, T_4 = Organic fertiliser at 5.0 t/ha, T_5 = Biochar at 2.5 t/ha + Organic fertiliser at 5.0 t/ha, T_6 = Biochar at 5.0 t/ha + Organic fertiliser at 5.0 t/ha; ns = Not Significant, LSD = Least Significant Difference, * and ** = significant at 5 and 1% probability levels, respectively

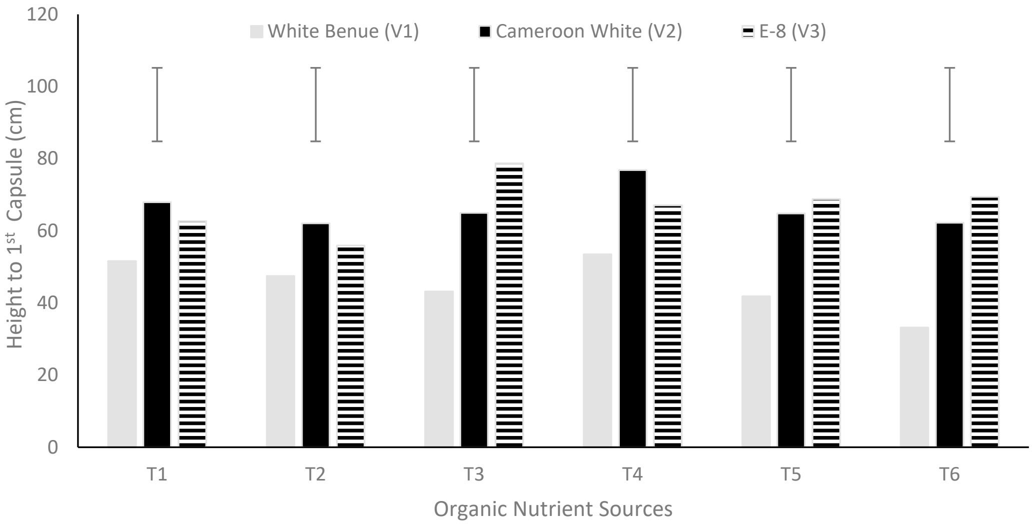

Figure 3. Effect of Variety × Organic nutrient sources on height to first capsule (cm) of sesame in 2020
T_1 = Control, T_2 = Biochar at 2.5 t/ha, T_3 = Biochar at 5.0 t/ha, T_4 = Organic fertiliser at 5.0 t/ha, T_5 = Biochar at 2.5 t/ha + Organic fertiliser at 5.0 t/ha, T_6 = Biochar at 5.0 t/ha + Organic fertiliser at 5.0 t/ha. Capped vertical lines represent Least Significant Difference (L.S.D.) (p = 0.05)

favourable rainfall distribution during the critical growth periods of mid-bloom to early ripening as described by Lagham et al. (2008). This critical reproductive period occurred in September and October that were relatively moist and the overall agronomic performance of sesame was not adversely impacted by the weather conditions during these two months in both years.

Biochar has the potential to reduce soil acidity because of its high alkalinity, high buffering capacity, and presence of functional groups (El-Naggar et al., 2019; Liu et al., 2022). In this study, pH slightly increased from 7.3 to 7.6–7.7 in 2020 and 7.5 to 7.6–7.8 in 2021. It has been reported in the literature that the long-term effect of biochar is more beneficial than the short-term (Major et al., 2010). Consequently, Vijay et al. (2021) have advocated for an in-depth understanding of the mechanisms for longevity effects of biochar. Biochar application alone and in combination with organic fertiliser enhanced soil N, P, and K in both years, except for P in 2021 when its level was reduced. This reduction in phosphorus level could partly be attributed to the fixation of P with metals such as Fe, Al and Ca, and uptake by sesame plants. Similarly, biochar application has been reported to have increased soil macronutrient availability in tropical soils of Zambia (Martinsen et al., 2014) and India (Mankasingh et al., 2011) using maize cob and rice husk-derived biochar, respectively. The enhanced availability of nutrients to plants has been attributed to reduced leaching of nutrients from the soil (Luo et al., 2020).

Organic carbon (OC) increased as biochar and organic fertiliser were applied singly or in combination in this study, especially during the wetter year 2021. The synergistic relationship between the two organic nutrient sources resulted in a significantly higher grain yield of sesame in both years. An increase in OC after the application of biochar to degraded soil of the southern Guinea savannah zone of Africa had been reported by Ndor et al. (2014). Similarly, an increase in OC following the application of rice husk and sawdust biochar in soil planted to sesame with a resultant yield increase has also been reported (Ndor et al., 2015). Improved soil environment that contributed to better yield had been attributed to organic amendments applied to the soil and subsequently increased OC that enhanced the formation of soil aggregates, improved water holding capacity, carbon sequestration, and microbial communities (Guo et al., 2016; Omondi et al., 2016).

White Benue, an extra early variety, flowered and matured earlier than Cameroon White and E8, especially during the dryer year 2020. The number of days to flowering of sesame is a function of the cultivar's genetic makeup of the varieties and/or the genetic × environment interaction (Olowe, 2007; El-Nakhlawy and Shakeen 2009). In this study, days to flowering were slightly induced by the organic fertiliser and 2.5 tons of biochar (T5) in 2020 relative to the control. Whereas, in the more favourable year 2021, the application of organic nutrients did not affect the days to flowering. The inducement of flowering in sesame following organic nutrient application has been reported in the literature by Amare et al. (2019). Similarly, Yagoub et al. (2012) reported that nitrogen fertiliser tends to induce flowering in plants. Also Craft et al. (2019) reported that the difference in the flowering of sesame is influenced by the type of fertiliser applied, rate of application, available forms of nitrogen utilised by crops, and the timing of application. The delay in the flowering of sesame following nitrogen fertiliser application has been reported in the literature (Fathy and Mohammed 2009; El-Nakhlawy and Shahee, 2009; Haruna et al. 2011). They attributed the delay in flowering to the availability of excessive nitrogen from the fertilisers and poultry manure applied which could have delayed the onset of the reproductive period. The significant delay in maturity of the Cameroon White variety in 2021 when organic fertiliser and biochar at 5 tons/ha (V3 × T6) could be due to improved soil agronomic and biochemical environment and slow release of nutrients by the organic fertiliser as earlier opined by Liu et al. (2014) and Amare et al. (2019).

The three test varieties exhibited some significant differences in height characteristics in both years. Cameroon White and E8 were significantly taller than White Benue in height at maturity in both years. Plant height has been reported to be associated with the varietal characteristics of sesame (Weiss, 2000). On average, sesame plants were more vigorous during the wetter 2021 than in 2020. The height of the first capsule has implications for the mechanical harvest of sesame since it determines the height at which

Table 5. Effects of variety and organic nutrient source on some sesame yield attributes and grain yield in 2020 and 2021

Treatment	1000-seed weight (g)	No of capsules per plant	Capsule weight per plant (g)	No. of seeds per plant (g)	Seed weight per plant (g)	Grain yield (t/ha)
			2020			
Variety (V)						
White Benue (V1)	3.10	24.5	15.8	2244	6.8	1376.7
Cameroon White (V2)	3.23	20.0	14.1	1875	6.1	1237.8
E-8 (V3)	3.32	26.8	18.0	1902	5.8	1218.9
LSD (5%)	ns	ns	ns	ns	ns	ns
Organic nutrient source (T)						
T_1	3.20	16	9.0	1182	3.7	0.7
T_2	3.32	17	12.7	1938	6.4	1.2
T_3	3.10	30	16.9	1979	5.4	1.2
T_4	3.22	30	19.2	2413	7.8	1.5
T_5	3.11	26	19.3	2233	6.9	1.3
T_6	3.20	25	18.4	2296	7.4	1.4
LSD (5%)	ns	6.5	6.31	624.9	1.64	0.37
V × T	ns	*	ns	ns	*	ns
			2021			
Variety (V)						
White Benue (V1)	2.80	11.0	10.0	2817	7.8	1359.2
Cameroon White (V2)	3.10	15.0	10.8	2417	7.4	1254.2
E-8 (V3)	3.01	11.6	9.2	2601	8.0	1402.4
LSD (5%)	0.19	ns	ns	ns	ns	ns
Organic nutrient source (T)						
T_1	3.00	10	7.4	1686	4.4	0.7
T_2	2.94	12	10.4	1997	6.3	0.9
T_3	3.03	12	9.6	2643	7.8	1.3
T_4	3.02	15	11.6	2964	9.0	1.5
T_5	3.14	14	10.4	3060	9.5	1.6
T_6	3.02	12	10.7	3327	9.7	1.6
LSD (5%)	ns	ns	2.33	558.2	1.46	0.26
V × T	ns	ns	ns	ns	ns	ns

Key: T_1 = Control, T_2 = Biochar at 2.5 t/ha, T_3 = Biochar at 5.0 t/ha, T_4 = Organic fertiliser at 5.0 t/ha, T_5 = Biochar at 2.5 t/ha + Organic fertiliser at 5.0 t/ha, T_6 = Biochar at 5.0 t/ha + Organic fertiliser at 5.0 t/ha; ns = Not Significant, LSD = Least Significant Difference.

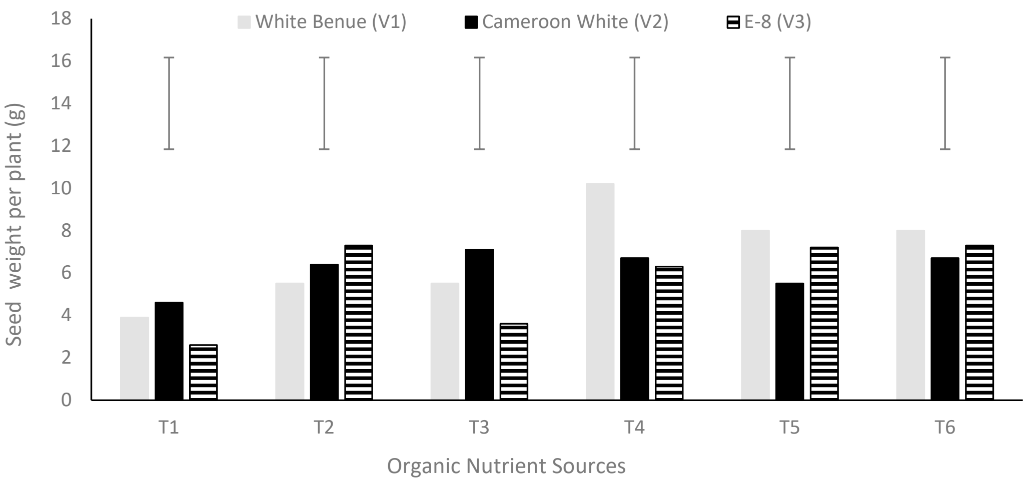

Figure 4. Effects of Variety × Organic nutrient source on seed weight per plant in 2020
T_1 = Control, T_2 = Biochar at 2.5 t/ha, T_3 = Biochar at 5.0 t/ha, T_4 = Organic fertiliser at 5.0 t/ha, T_5 = Biochar at 2.5 t/ha + Organic fertiliser at 5.0 t/ha, T_6 = Biochar at 5.0 t/ha + Organic fertiliser at 5.0 t/ha. Capped vertical lines represent Least Significant Difference (L.S.S.) (p = 0.05)

the cutter bar of the combine harvester must be set to reduce field loss during mechanical harvesting (Olowe, 2004). The average height at harvest recorded in 2020 (101.9–124.1 cm) and in 2021 (114.8–146.2 cm) compared favourably with the average values (115.2–147.1 cm) earlier reported for 14 sesame entries in the same forest-savanna transition zone of the tropics (Olowe, 2004). Application of biochar at two rates (T2 and T3), enriched with organic fertiliser at 5.0 t/ha (T5 and T6) and organic fertiliser alone (T4) significantly increased sesame plant height in the wetter year 2021compapred to the control (T1). This result conforms with the findings of Ndor et al. (2015), Furtado et al. (2016), Choudhary et al. (2017), and Hirapara et al. (2020) following the application of biochar enriched with poultry manure, farm yard manure, and vermicompost. They attributed the response to nutrient availability to improved physical and chemical properties of the soil and its improved microbial activities. As the biochar rate increased from 2.5 to 5.0 t/ha, sesame plant height at harvest increased in both years though not significantly in 2021. A similar tendency of plant height increasing with biochar addition was reported on sesame that received rice husk biochar in Japan (Wacal et al., 2019)

The three major yield attributes directly related to sesame grain yield have been reported to be the number and weight of capsules per plant, and seed weight per plant (Olowe, 2004). These three traits were significantly increased in this study following the application of organic fertiliser alone or in combination with biochar at the two levels compared with the control. This finding is consistent with the results of El-Nakhlawy and Shaheen (2009) and Roy et al. (2019) who applied 6 t/ha of biochar to record the highest number of capsules per plant. This could be attributed to the availability of nutrients required for the development of structural and functional components of sesame plants during the vegetative and reproductive stages of development, activation of various digestive supporting enzymes related to chemical processes, and chlorophyll-synthesis enzymes (Abdel-Aziz and El-Shafie, 2005; Yasin et al. 2013; Haseeb and Maqbool, 2015; Adam and Iwona 2018). The average values recorded in this study across the treatments in 2020 (3.1–3.3 g) and 2021 (2.9–3.1 g) compared well with the premium standard of > 3.0 g for sesame in the international market (Day, 2000; Burden, 2005). This result confirmed the suitability of the three test varieties for large-scale export production. Recently, Iqbal et al. (2018), reported a strong relation of 1000 seed weight with seed yield of sesame.

The seed yield values recorded among the varieties ranged between 1.2 to 1.3 t/ha in 2020 and 1.2 to 1.4 t/ha in 2021. Application of organic nutrient sources significantly affected sesame grain yield in both years of experimentation with sesame that received only organic fertiliser (T4), organic fertiliser and 2.5 t of biochar (T5), and organic fertiliser and 5.0 t of biochar (T6) recording comparably high yield values. The grain yield values recorded in both years were superior to the African (0. 4 t/ha) and the world yield (4.8 t/ha) reported in FAOSTAT (2024). This confirmed the earlier demonstrated suitability of sesame for large-scale production in the forest-savanna transition zone which is outside its traditional growing region (Olowe and Adeoniregun, 2009; Olowe and Adeyemo, 2009; Somefun et al., 2020). The increase in grain yield following the application of organic fertiliser and biochar (T4, T5, and T6) could be attributed to the higher number and weight of capsules per plant and seed weight per plant recorded by sesame subjected to these treatments. The positive response of sesame to biochar enriched with organic amendments in terms of yield attributes and grain yield has been recently reported by Wacal et al. (2019), Hirapara et al. (2020), and Issahaku et al. (2023).

CONCLUSION

Results of this study revealed that the White Benue variety attained physiological maturity earlier than the Cameroon White and E8 in both years. However, Cameroon White and E8 had a more vigorous growth than White Benue. Applying biochar at 5 t/ha alone (T3) significantly enhanced the number of branches per plant and height at harvest in 2020 (dry year) relative to the control. All the applied combinations of both organic nutrient sources enhanced the seed weight of sesame relative to the control treatment. Moreover, biochar application at the rate of 2.5 and 5.0 t/ha (T2 and T3) and enriched with organic fertiliser at 5.0 t/ha (T5 and T6) and organic fertiliser alone (T4) significantly increased sesame grain yield in both years, except T2 in 2021. Based on the results of this research work, it is concluded that for enhanced organic sesame production in the forest-savannah transition zone, its cultivation can be done economically using organic fertiliser applied at 5.0 t/ha (T4).

CONFLICT OF INTEREST

The authors declared no conflicts of interest concerning the research, authorship, and publication of this article.

ETHICAL COMPLIANCE

The authors have followed ethical standards in conducting the research and preparing the manuscript.

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