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Efficacy of biochar in the management of *Fusarium verticillioides* Sacc. causing ear rot in *Zea mays* L.

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ABSTRACT

Maize ear rot caused by *Fusarium verticillioides* (Fv) is a major disease associated with reduced grain yield and ear quality. The use of biochar in management of ear rot has not been established. Efficacy of biochar aganst the disease was therefore investigated. Efficacy of biochars produced from poultry faecal waste (Bpw) and sawdust (Bsd) against pathogenic *Fusarium verticillioides* (Fv) causing ear rot in maize was determined using biochar treatment combinations (Bpw, Bsd, Bpw + Bsd, Bpw + Fv, Bsd + Fv, Bpw + Bsd + Fv, Fv and control) as soil amendments. Additional treatments consisted of fungicide (Cibaplus), poultry feacal waste (Pw), sawdust (Sd), Bpw + Fungicide, Bsd + Fungicide, Bpw + Bsd + Fungicide, Fungicide + Fv, and Pw + Sd. The Bpw and Pw at 1, 2 and 3 kg/m^2 each, Bsd and Sd (0.50, 1.00 and 1.50 kg/m^2) and fungicide (0.25, 0.50 and 1.00 g/L) were applied. Inoculation of pathogenic *F. verticillioides* strain was conducted at 7th week after planting and ear rot severity assessed at harvest. Residual effects of treatments were examined in the second season. Data gathered were subjected to ANOVA at $\alpha_{0.05}$. Maize treated with Sd, Bpw and Bpw + Fungicide scored 1–3% severity; Bpw + Bsd, Bsd, Fungicide, Pw + Sd, Bsd + Fv, Bsd + Fungicide, Bpw + Bsd + Fungicide, Bpw + Fv, Bpw + Bsd + Fv and Fungicide + Fv scored 4–10 %. Severity rating for control and Pw was 11–25 % while Fv was 26–50 %. Poultry faecal waste and Bpw based treatments recorded significant impact on growth characters across varying concentrations compared to other treatments. Poultry faecal waste biochar and sawdust biochar were effective in the management of Fusarium ear rot of maize and could be used as soil amendments.

1. Introduction

Maize is the most important cereal crop and staple food for about 1.2 billion people [1,2] and occupies a third of the cultivated area in sub-Saharan Africa [3]. The cereal which accounts for over 30 % lower-house income, contributes 60 % of dietary calories and 50 % of protein intake is currently under a continuous threat of food security, largely due to the ear rot caused by *Fusarium verticillioides* [1,4].

Fusarium verticillioides is the most common cause of ear and kernel rot of maize considered as field fungi invading more than 50 % of maize grains before harvest [5]. The pathogen has been found associated with reduced grain yield quality and with adverse implication on food security across the world. More so, tolerable limits of fumonisin intake are often exceeded in *Fusarium verticillioides* contaminated maize [6,7]. Hence, leading to serious health impairments in animals and human [8], several measures ranging from cultural to the use of chemical had been employed in the control of ear rot caused by *F. verticillioides* [9], but excessive and inappropriate use of chemical pesticides in maize cultivation had raised serious concern about health and environmental hazards which further results in setback such as; increased cost, handling hazards and pesticide residues in food [10]. Thus, effective management of Fusarium ear rot has been a serious challenge across the world. As many disease control methods could not mitigate effect of the pathogenic *F. verticillioides* in the subsequent seasons.

The quest for improved grain yield, disease and toxin-free had become imperative for profitable maize production [11,12]. More so, with the increasing population and rise in demand for safe and quality maize, agriculture is under intense pressure to produce more food with less environmental impact and increased resource efficiency [13]. The need to proffer an environmental friendly alternative to the use of fungicide in managing the menace of *F. verticillioides* in maize production therefore necessitated the investigation of biochar.

Biochar has been explored in mitigating greenhouse gas emission, enhancement of soil health and plant yield [14,15]. It

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had also been reported as effective in suppressing diseases caused by some air and soil borne plant pathogens [16]. However, its prospect in plant disease management has not being fully explored, and to the best of our knowledge, this is the first study of the efficacy of biochar in managing *F. verticillioides* causing ear rot in maize. This study therefore, investigated the potential of biochar as soil amendment in the sustainable management of *Fusarium verticillioides* causing ear rot in maize.

2. Materials and methods

2.1. Study location and sources of materials used

The field experiment was carried out at the experimental plots of Teaching and Research Farm, University of Ibadan, between August and November, 2015 and repeated on the residual effect of biochar from April to July, 2016. Maize variety DMR LSR Y used was obtained from the Institute of Agricultural Research and Training (IAR & T), Apata, Ibadan while the pathogenic *Fusarium verticillioides* strain AKR 05 documented by Olowe et al. [17] was obtained from the culture collections of Plant Pathology Laboratory, Department of Botany, University of Ibadan, Ibadan, Nigeria.

Poultry faecal wastes (Pw) were collected from the dumping site of layers' wastes at the poultry section of Teaching and Research Farm, University of Ibadan, Ibadan and sawdust (Sd) was obtained from commercial saw millers at Bodija, Ibadan, Oyo State, Nigeria. The two biochar materials were sun dried to reach the moisture level of about 15 %. They were separated from other materials (i.e. small stones, plastics, grass, branch etc) while the clustered ones were broken by hand to meet size of 4–5 cm in order to achieve uniform heating during combustion.

2.2. Preparation of poultry faecal waste biochar

A modified biochar kiln was developed according to the model of 55 gallon drum reported by Major [18]. The kiln was sealed after loading and combustion with fire wood was maintained at average temperature of 485 °C, monitored at 30 min interval by the use of infra-red pyrometer designed to measure temperature from; −50 °C to 1500 °C. Yield was harvested when dense smoky black colour chars was observed after 9 h of continous heating. The yield was cooled by spraying water thoroughly over surface of the kiln and left till the second day before opening.

2.3. Production of sawdust biochar

Sawdust biochar was prepared according to the modified method of biochar stove described by Major [18].

2.3.1. Elemental analysis of biochar and feedstocks

Laboratory analysis of the feedstocks (poultry faecal waste and sawdust) and biochars produced were conducted. The elemental C and N, were determined using C, N, S elemental analyser (Vario El III) and P, K, Ca, Mg and Na using acid digestion [19], followed by the use of Inductively Coupled Plasmas-Atomic Emission Spectrometer (ICP-AES, Perkin Elmer). Cation exchange capacity (CEC) was analysed using Barium acetate method [20]. The pH was measured using pH electrodes and conductivity (EC) with the use of a conductivity meter at ratio sample: water at 1:10. Ash content [21] was determined by ignition of known weight of samples at 600 °C until all carbon was removed. The final calculation was based on the percentage of ash from the original compound.

2.4. Field layout and experimental design

The field used for the experiment was situated on plane topography. It was harrowed, ploughed and re-ploughed two weeks later. Field size 25m × 30m mapped out was sub divided into 144 min. plots of 1.2m × 1.2m each. Thus, a total of 16 min. plots were arranged along the length and 9 along the width of the main plot, while the space of 100 cm was observed in between the columns and across the rows. A total of 16 treatments were set up at three concentration levels and three replications as;

T1=Bpw+Fv

T2=Bsd+Fv

T3=Bpw + Bsd+Fv

T4=Fungicide+Fv

T5 =Fv alone

T6 =Bpw alone

T7 =Bsd alone

T8 =Bpw + Bsd

T9 =Fungicide alone

T10 =Bpw + Fungicide

T11=Bsd + Fungicide

T12=Bpw + Bsd + Fungicide

T13 =Control (Untreated maize)

T14 =Pw alone

T15 =Sd alone

T16 =Pw + Sd

Where; **Bpw=** Poultry feacal waste biochar, **Bsd**= Sawduust biochar, ***Fv***= *Fusarium verticillioides,* Pw = Poultry feacal waste, Sd = Sawdust.

The experiment was laid out in a randomized complete block design (RCBD). On each respective mini plots, Bpw was applied at the rate of; 1, 2 and 3 kg/m^2 according to the ratio used by Mukherjee and Lal [22], while Bsd was applied at 0.5, 1 and 1.5 kg/m^2. In cases of combined treatments, 1/2 or 1/3 strength of each

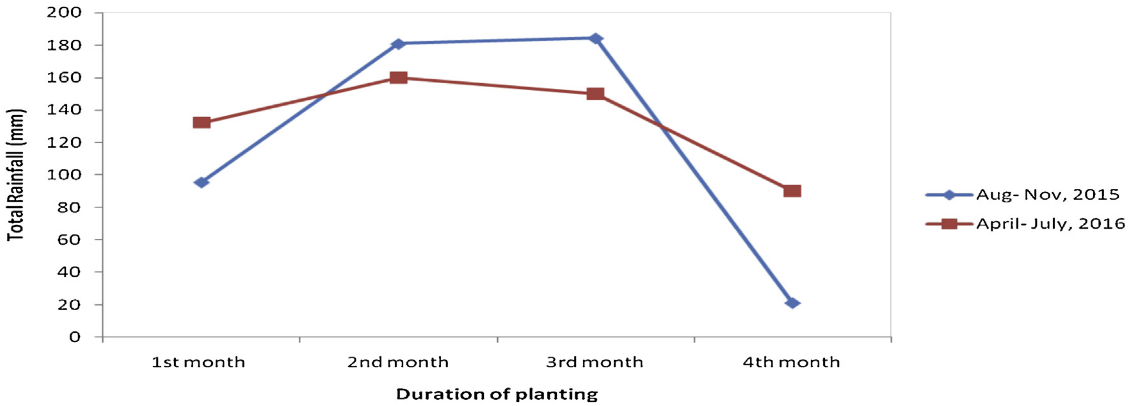

Fig. 1. Total rainfall recorded during the period of planting.

component was applied with respect to the number of components involved. Similar application rate was employed for treatments involving the feedstocks, poultry feacal waste (Pw) and sawdust (Sd).

2.5. Seed sterilization and planting

Maize seeds were soaked in 5 % Sodium hypochlorite solution (NaOCl) for 3 min and rinsed in two times with sterile distilled water, then air dried in the laminar flow for 2 h according to the method described by Anderegg and Guthrie [23]. Three viable seeds were planted 2–3 cm deep into the soil but thinned to one plant per pot at 2 weeks after planting (WAP).

2.6. Inoculum quantification and inoculation

The mycelial growths of seven day old cultures of *F. verticillioides* strain AKR 05 were flooded with 2 mL sterile distilled water and gently brushed with glass rod into sterile conical flask. The solution was sieved with double folded sterile cheese cloth to allow the passage of fungal spores only. The spore suspension were then counted using haematocytometer and adjusted with sterile distilled water to 1×10^6 spores/ ml for each strain of *F. verticillioides*. The pathogen suspension (2 mL) was inoculated in the respective treatments through the silk channel at full silk stage of the maize development (7th week after planting) using sterile syringe and needle according to the procedure described by Cardwell et al. [24]. The growing cobs were covered with sterile polythene bag immediately after inoculation to avoid multiple infections and as well to allow the build-up of humidity that would enhance the disease initiation process.

2.7. Application of fungicide

Fungicide (Cibaplus) containing active ingredients; Imidacloprid 10 % + Metalaxyl 10 % + Carbendazin 10 % was applied to the respective treatment a week and third week after pathogen inoculation (8th and 10th WAP) by spraying all plants in each block from the foliar part to the root zone. The fungicide was mixed and applied on the respective treatments at three concentration levels; 0.25, 0.50 and 1.00 g/mL.

2.8. Establishment of second season evaluation

The field experiment was repeated with the same maize variety. This was conducted without fresh application of biochar and feedstock treatments. However, the pathogen inoculations and fungicide spraying were duly observed on the respective treatment at the appriopriate time as was carried out in the first evaluation.

3. Disease assessment

3.1. Disease incidence rating

The experiment set up was observed for ear rot disease development having symptoms such as; powdery or cottony-pink mould growth on the infected kernel. The percentage incidence of infected ear was estimated as described by Michel et al. [25]:

$$\% \text{ incidence} = n / N \times 100$$

Where n = number of harvested ear showing disease symptoms.
N = Total Number of ear.

3.2. Disease severity

The ear rot severity was determined by estimating the percentage proportion of the length of each infected ear to their total length. These were further scored on a scale of 1–7, according to the method described by Reid et al. [26]. Where 1 = 0 % infection, 2 = 1–3 %, 3 = 4–10 %, 4 = 11–25 %, 5 = 26–50 %, 6 = 51–75 % and 7 = >75 % of the kernels exhibiting visible symptoms of infection such as rot and mycelial or visually mouldy growths.

3.3. Meteorological data

Weather reports of rainfall (Fig. 1), relative humidity (Fig. 2) and temperature (Fig. 3) covering the period of field planting were obtained from Nigeria Meteorological Services, Ibadan, Oyo State, Nigeria.

3.4. Measurement of growth and disease characters, and field management

Data on the growth parameters were recorded at 4th, 8th and 12th weeks after planting (WAP). Disease incidence and severity were recorded on the harvested cobs at the 12th week after planting (WAP). Agronomic practices such as field monitoring,

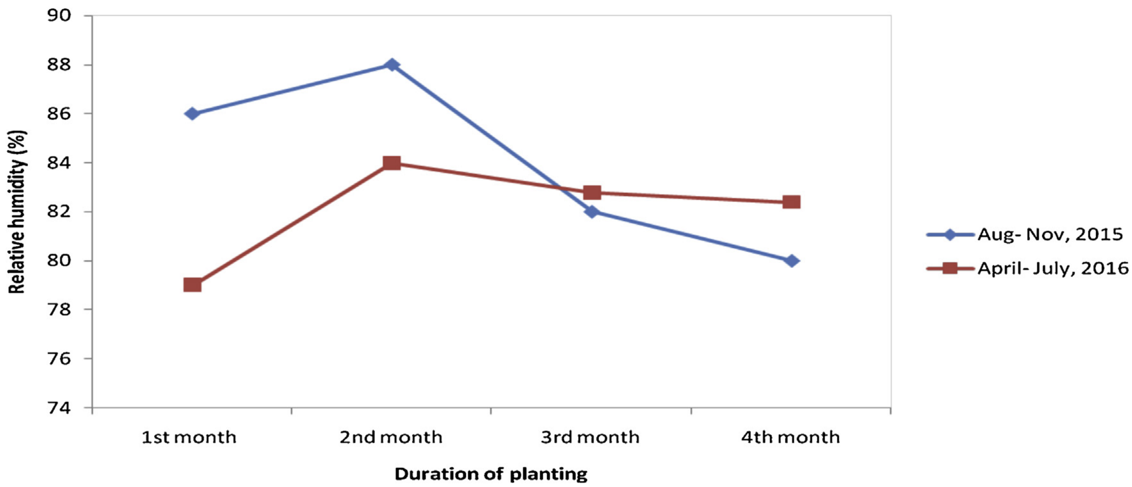

Fig. 2. Relative humidity recorded during the period of planting.

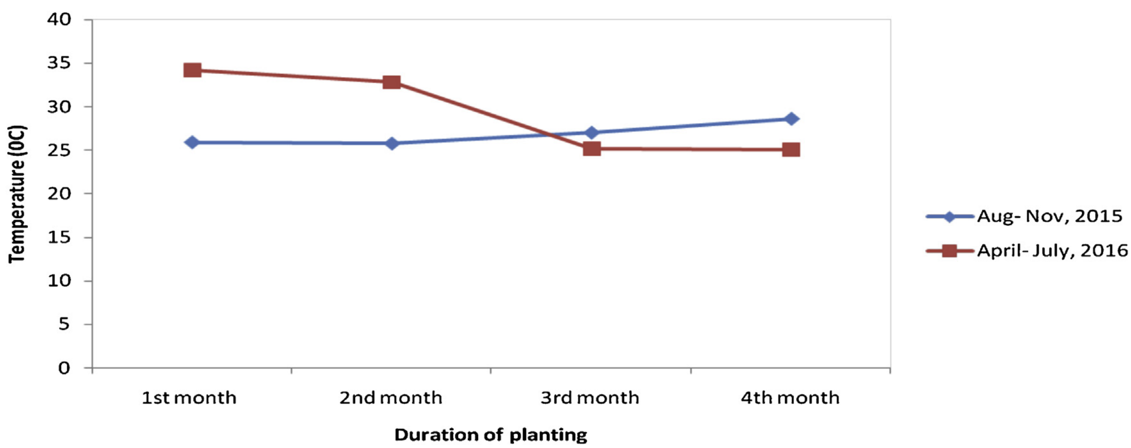

Fig. 3. Atmospheric temperature recorded in the period of planting.

Table 1
Physicochemical properties of biochars and their feedstocks.

Treatments	Poultry waste source		Sawdust source		Soil sample
	Biochar (Bpw)	Poultry faecal waste (Pw)	Biochar (Bsd)	Sawdust (Sd)	
Carbon	64.92a	49.28b	46.20c	41.65d	5.14
Total Nitrogen	1.646a	0.96b	0.659c	0.38d	0.14
Total Phosphorus	2.59a	2.55b	0.20c	0.08d	4.90
Potassium	1.45a	0.08b	0.55c	0.40d	0.11
Calcium	3.44a	3.15b	0.72c	0.24d	2.95
Magnesium	0.51a	0.39b	0.09c	0.05d	0.31
Sodium	0.88a	0.57b	0.38c	0.26d	0.25
Ash	4.00a	3.00b	3.00b	2.00c	1.98
Moisture content	10.00a	5.00b	5.00b	4.00c	2.00
Electrical conductivity	1220d	1930a	1900b	1300c	1656
pH	8.80a	8.42b	7.87c	7.68d	5.80
CEC	–	–	–	–	10.12
Exchangeable acidity	–	–	–	–	0.40
Clay %	–	–	–	–	5.40
Silt %	–	–	–	–	7.40
Sand %	–	–	–	–	87.2

Means with different letters are significantly ($p < 0.05$) different across each row.

boundary clearing and manual weeding at 3rd, 6th and 9th week after planting were observed.

3.5. Data analysis

All **t**he data obtained in this study were analyzed using Statistical Analysis System, SAS version 9.1 [27] software and

Table 2
Effect varying treatment concentrations on maize growth at 4th week after planting.

Treatments	Concentration 1 kg/m²					Concentration 2 kg/m²					Concentration 3 kg/m²				
	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length (cm)	Leaf width (cm)	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length (cm)	Leaf width (cm)	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length (cm)	Leaf width (cm)
Bpw + Fv	21.47abc	1.23ab	7.16a	61.24a	4.42abc	22.78b	1.29abc	8.11abc	56.90a-e	4.58cde	19.93ab	1.25abc	7.50bc	55.53abc	4.83abc
Bsd + Fv	21.17abc	1.21ab	7.22a	51.93a-d	3.92bc	19.44c-g	1.09bcd	7.67bcd	47.72c-h	0.46de	20.95a	1.32a	8.33a	57.00ab	4.77a-d
Bpw + Bsd + Fv	23.38a	1.40ab	7.33a	56.32abc	4.76abc	20.77b-e	1.19cd	7.11cd	54.37b-h	5.37abc	17.48bc	1.03c-f	7.00c	50.45b-e	3.8b-e
Fungicide + Fv	20.96abc	1.47a	7.44a	55.86a-d	4.69abc	17.67efg	1.12cd	7.44cd	45.42fgh	4.24de	16.22cd	1.07b-f	7.00c	48.08cde	4.04cde
Bpw alone	21.56abc	1.20ab	7.44a	62.24a	4.72abc	22.18bc	1.54ab	8.56ab	57.54a-d	5.67ab	19.35ab	1.21a-e	7.33c	53.35a-d	4.51a-d
Bsd alone	18.50c	1.35ab	6.78a	49.34cd	4.37abc	17.07fg	0.99d	7.00d	4.41gh	4.42de	18.43abc	0.99def	7.17c	55.32a-d	4.77a-d
Bpw + Bsd	21.76abc	1.44a	7.56a	59.08abc	4.70abc	18.74d-g	1.06d	7.00d	46.64e-h	4.54cde	19.97ab	1.05b-f	7.00c	49.88b-e	4.33c-d
Fungicide alone	21.51abc	1.25ab	7.56a	56.63abc	5.12a	16.89fg	0.96cd	7.22cd	47.30d-h	4.48de	13.67de	1.19a-e	7.00c	42.95e	3.70e
Bpw + Fungicide	23.01ab	1.32ab	7.33a	61.33ab	4.94ab	20.16b-f	1.25cd	7.33cd	57.88abc	4.89bcd	19.32ab	1.05b-f	7.00c	47.82cde	4.17cde
Bsd + Fungicide	19.31abc	1.11b	6.55a	51.30bcd	4.57abc	17.76efg	1.19d	6.78d	51.26b-h	4.58cde	12.26e	0.69g	6.83c	42.95e	3.97e
Bpw + Bsd + Fungicide	19.85abc	1.31ab	6.56a	55.83a-d	4.57abc	20.06c-f	1.08bcd	7.78bcd	52.46c-h	4.14de	17.12bc	0.98ef	6.67c	46.95de	3.75de
Control(Untreated)	18.64c	1.19ab	6.78a	45.59d	4.81abc	19.41c-g	1.10cd	7.44cd	55.43a-f	4.82bcd	18.72abc	1.04c-f	7.17c	52.22a-d	4.07a-d
Poultry fecal waste (Pw)	20.64abc	1.32ab	7.00a	54.10a-d	4.50abc	29.17a	1.54a	8.78a	64.74a	6.12a	21.03a	1.27ab	8.17ab	59.50a	4.98a
Sawdust	19.80abc	1.23ab	7.22a	53.12a-d	4.2abc	17.43efg	1.00cd	7.44cd	54.66a-f	4.91bcd	19.55ab	1.19a-e	6.83c	60.53a	4.75a
Pw + Sawdust	18.32c	1.19ab	6.89a	56.53abc	4.27abc	22.04bcd	1.30cd	7.44cd	58.27ab	4.86bcd	17.97abc	0.97ef	7.17c	53.17a-d	4.95a-d
Fv only	19.18bc	1.22ab	7.33a	51.87a-d	3.82c	16.16g	0.97d	7.00d	3.78h	14.32e	14.32de	0.85fg	6.83c	42.28e	4.00e

Bpw = Poultry waste biochar, **Bsd** = Sawduust biochar, ***Fv*** = *Fusarium verticillioides*, Pw = Poultry feacal waste.
Means with the different letters across the column are significantly ($p < 0.05$) different from one another.

subjected to the analysis of variance, while means were separated at 5% confidence interval, using Duncan multiple range test (DMRT).

4. Results

The physicochemical analysis of the two types of biochar and their feedstocks showed results of the elemental compositions of carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sodium, ash and pH in ther order of significant ($p < 0.05$) as; poultry faecal waste biochar (Bpw) > poultry faecal waste (Pw) > Sawdust biochar (Bsd) > Sawdust. Physicochemical properties of soil samples from the experimental plots showed the soil as slightly acidic and sandy loamy (Table 1).

At 4th week after planting, prior to pathogen and fungicide applications, treatments that received biochar and feedstock application at 1 kg/m^2 showed the highest plant height in (Bpw + Bsd (+Fv) = 23.38 cm), other treatments were not significantly different from one another except in Bsd alone, Pw + Sawdust and *F. verticillioides* only which were not statistically different from the control (18.64 cm) experiment. The most significant stem girth was observed in Bpw + Bsd (1.44 cm), while no significant difference occurred in number of leaves among the treatments. Bpw (+ Fv) (61.24 cm) and Fungicide alone (not yet applied) (5.12 cm) produced the most signigicant ($p < 0.05$) results in the leaf length and width respectively. At 2 kg/m^2 biochar concentration, treatments with Poultry waste (Pw) only recorded the most significant growth across the parameters measured. Also, at 3 kg/m^2 concentration, treatment Bsd (+Fv) showed the most significant growth in plant height, stem, girth and number of leaves. Leaf length and width were most predominant in Sawdust treated soils (Table 2).

At 8th week after planting (WAP), having incoculated the pathogen and fungicide application at the 7th WAP, results at 1 kg/m2 concentrations showed Bpw + Fungicide with the most significant plant height (141.82 cm), stem girth (1.80 cm) and leaf width (15.57 cm). Sawdust treatment produced the most significant value for leaf length while no significant difference occurred in number of leaves among the treatments. At 2 kg/m2, poultry waste significantly increased the plant height (146.49 cm) and leaf width (8.66 cm), with number of leaves significantly enhanced by Bpw + Fv (11.00 cm) while stem girth showed no significant difference across all the treatments. Concentration 3 kg/m2 of biochar application produced treatments Bsd + Fv as the best support of the growth characters (Table 3).

The results of growth parameters obtained at 12th week after planting on 1 kg/m2 biochar concentration showed no significant differences in the stem girth and number of leaves among all the treatments. The treatments; Bsd + Fv (152.66 cm), Sawdust only (150.54 cm), Bp + Bs + Fungicide (149.50 cm), Pw + Sawdust (148.28 cm) and Bpw + Bsd (147.18 cm) produced a more significantly higher plant height results that other treatments. Bpw + Fv (72.00 cm) and Bsd + Fungicide (72.02 cm) recorded highest leaf length while the most significant growth of leaf width was shown in Bpw + Fv (8.40 cm), Bsd + Fungicide (8.14 cm), Bp + Bs + Fungicide (7.90 cm), Pw (7.93 cm) and Sawdust only (8.21 cm) (Table 4).

Maize treated with poultry faecal waste (Pw), followed by those with biochar alone, then biochar and *F. verticillioides* were the order of significance ($p < 0.05$) recorded in the plant height, number of leaves and leaf area. The combined poultry faecal waste and sawdust (Pw + Sd) showed higher significance ($p < 0.05$) in the stem girth, while results of other treatments were not significantly different from the control (Table 5).

The most significant plant heights was recorded at 1 kg/m^2 (89.30 cm), the leaf area increased with increasing concentrations while no significant difference was recorded across the levels in

Table 3
Effect varying treatment concentrations on maize growth at 8th week after planting.

Treatments	Concentration 1 kg/m^2					Concentration 2 kg/m^2					Concentration 3 kg/m^2				
	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length	Leaf width (cm)	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length (cm)	Leaf width (cm)	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length (cm)	Leaf width (cm)
Bpw + Fv	114.82bc	1.51ab	10.44a	78.07ab	7.42b	124.80abc	1.76a	11.00a	73.62ab	8.24abc	110.75a-e	1.63c-f	10.33abc	67.13cde	7.72cd
Bsd + Fv	114.92bc	1.66ab	10.22a	72.77ab	7.27b	99.52ab	1.58a	10.11abc	71.22ab	7.21c	122.07abc	1.98a	10.50ab	80.38a	9.08a
Bpw + Bsd + Fv	127.62abc	1.53ab	11.00a	70.92ab	7.70b	130.53bcd	1.58a	9.67abc	74.01ab	7.62abc	122.82ab	1.71a-e	10.83a	73.45a-d	7.97bcd
Fungicide + Fv	136.53ab	1.63ab	10.33a	73.2ab	7.68b	116.33bcd	1.83a	9.67abc	76.71ab	8.16abc	121.82abc	1.86a-d	9.67b-e	81.57a	8.13bcd
Bpw alone	128.14abc	1.75a	9.89a	69.7b	7.51b	121.78bcd	1.61a	10.00abc	72.13ab	8.18abc	102.15b-f	1.59def	10.00a-d	76.3abc	7.27
Bsd alone	124.89abc	1.72ab	10.78a	74.02ab	8.03b	101.21c-f	1.54a	9.22c	82.30a	7.28bc	119.72a-d	1.62c-f	10.33abc	73.67a-d	7.92bcd
Bpw + Bsd	130.23abc	1.68ab	10.33a	70.24b	8.16b	114.27bcd	1.82a	10.44abc	75.21ab	8.47ab	105.83a-f	1.65c-f	10.67ab	73.51a-d	7.85bcd
Fungicide alone	129.73abc	1.67ab	10.67a	73.52ab	8.18b	89.70ef	1.51a	10.00abc	68.2ab	7.28abc	99.27def	1.53ef	9.00ef	69.88b-e	7.43cd
Bpw + Fungicide	141.82a	1.80a	10.56a	75.84ab	15.57a	109.88 b-e	1.49a	10.44abc	71.56ab	7.47abc	118.10a-d	1.65c-f	10.33abc	67.05cde	7.63cd
Bsd + Fungicide	124.62abc	1.62ab	10.00a	75.11ab	8.30b	120.07bcd	1.56a	9.56bc	70.19ab	7.34bc	128.41a	1.89abc	10.17a-d	72.9a-d	7.97bcd
Bpw + Bsd + Fungicide	129.41abc	1.76a	10.22a	78.4ab	8.07b	110.98b-e	1.57a	9.89abc	68.72ab	7.41bc	99.92c-f	1.89abc	10.52a-d	80.52a	7.70cd
Control(Untreated)	108.22c	1.57ab	10.44a	68.66b	7.33b	119.1bcd	1.64a	9.67abc	73.69ab	7.79abc	122.22abc	1.68b-f	10.17a-d	77.60ab	8.40abc
Poultry feacal waste (Pw)	126.87abc	1.63ab	10.89a	67.97b	7.51b	146.49a	1.79a	10.67ab	76.80ab	8.66a	123.20a	1.95ab	9.50cde	80.08ab	8.75ab
Sawdust	122.01abc	1.76a	10.33a	85.68a	7.99b	107.24b-e	1.56a	9.78abc	63.88b	7.34bc	86.30f	1.39f	8.33f	64.90de	7.17d
Pw + Sawdust	136.49ab	1.52ab	9.89a	66.98b	7.19b	131.22ab	1.72a	9.67abc	78.47ab	8.03abc	92.83ef	1.44ef	9.83a-e	73.03a-d	7.48cd
Fv only	109.77c	1.43b	10.5a	64.35b	6.68b	81.49f	1.69a	10.33abc	68.03ab	7.49abc	103.74b-f	1.49ef	9.17def	61.85e	7.20d

Bpw = Poultry waste biochar, **Bsd** = Sawduust biochar, ***Fv*** = *Fusarium verticillioides,* Pw = Poultry feacal waste.
Means with the different letters across the column are significantly ($p < 0.05$) different from one another.

Table 4
Effect varying treatment concentrations on maize growth at 12th week after planting.

Treatments	Concentration 1					Concentration 2					Concentration 3				
	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length (cm)	Leaf width (cm)	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length (cm)	Leaf width (cm)	Plant height (cm)	Stem girth (cm)	No of leaves	Leaf length (cm)	Leaf width (cm)
Bpw + Fv	128.20ab	1.35a	8.00a	72.00a	8.40a	139.38abc	1.58abc	9.56a	73.03a	7.65b	123.42def	1.48d	8.33d	68.58b-d	7.43def
Bsd + Fv	152.66a	1.60a	9.00a	68.98ab	7.69ab	118.41cd	1.52bc	9.33abc	62.12ab	7.07b	143.82abc	1.87a-d	9.17a-d	77.14ab	9.02ab
Bpw + Bsd + Fv	126.86ab	1.59a	9.19a	64.21abc	7.39ab	138.56abc	1.57abc	8.22c	59.92ab	7.27b	140.13bcd	1.87bcd	9.00bcd	80.80a	8.97ab
Fungicide + Fv	139.78ab	1.50a	9.44a	62.6abc	8.02a	131.66bcd	1.79ab	8.33bc	65.78ab	7.50b	128.97c-f	1.55a-d	9.25a-d	66.38c-f	7.72cde
Bpw alone	139.53ab	1.47a	9.44a	64.36abc	7.50ab	132.64bcd	1.8ab	9.29abc	68.44a	8.40b	150.30ab	1.65abc	9.83abc	70.03bcd	8.65ab
Bsd alone	137.23ab	15.91a	9.50a	65.39abc	7.70ab	127.41bcd	1.66abc	9.29abc	68.36a	7.66b	123.85cde	1.51a-d	9.17a-d	58.15ef	6.65f
Bpw + Bsd	147.18a	1.55a	9.50a	55.33abc	7.60ab	131.34bcd	1.65abc	9.44abc	69.46a	7.93b	133.62cde	1.79ab	10.00ab	64.87c-f	7.58c-f
Fungicide alone	145.33ab	1.47a	9.33a	66.67ab	7.57ab	124.24bcd	1.45c	9.25abc	58.41ab	7.05b	129.93c-f	1.64cd	8.50cd	77.87ab	7.72cde
Bpw + Fungicide	139.7ab	1.69a	9.29a	54.37abc	7.19ab	113.45d	1.49bc	8.38abc	63.60ab	7.44b	133.80cde	1.53a-d	9.33a-d	72.47abc	8.40bc
Bsd + Fungicide	139.54ab	1.65a	9.00a	72.02a	8.14a	121.17bcd	1.57abc	9.11abc	59.78ab	7.19b	117.07ef	1.62d	8.17d	57.52f	7.20ef
Bpw + Bsd + Fungicide	149.50a	1.50a	9.86a	64.27ab	7.90a	136.81abc	1.67abc	9.78a	67.67a	7.20b	129.27c-f	1.59a-d	9.33a-d	59.00ef	7.50c-f
Control(Untreated)	117.88b	1.41a	8.33a	50.74bc	6.26b	131.87bcd	1.52bc	9.33abc	64.26ab	7.47b	126.43def	1.55d	8.00d	61.98c-f	6.95ef
Poultry feacal waste (Pw)	146.75a	1.70a	15.13a	66.01abc	7.93a	153.91a	1.81a	9.22abc	63.58ab	8.10b	157.43a	1.88a	10.17ab	81.78a	9.45a
Sawdust only	150.54a	1.63a	9.25a	69.34ab	8.21a	123.53bcd	1.53abc	9.22abc	62.71ab	14.23a	121.14ef	1.48d	8.38d	61.08def	7.06ef
Pw + Sawdust	148.28a	1.46a	9.00a	65.57abc	7.43ab	140.97ab	1.65abc	8.89abc	72.26a	7.97b	131.5cde	21.82a	10.50a	61.05def	7.05ef
Fv only	125.2ab	1.44a	9.33a	47.22c	7.23ab	123.38bcd	1.48c	9.25abc	51.50b	7.59b	113.83f	1.87bcd	9.00bcd	66.00c-f	8.20bcd

Bpw = Poultry waste biochar, **Bsd** = Sawduust biochar, ***Fv*** = *Fusarium verticillioides,* Pw = Poultry feacal waste.
Means with the different letters across the column are significantly ($p < 0.05$) different from one another.

Table 5
Pooled growth performance of maize after receiving different treatments of biochar, biochar feedstocks, fungicide and *F. verticillioides* (Mean of two years).

Treatments	Variables	Plant heights (cm)	Number of leaves	Stem girth (cm)	Leaf area (cm^2)
Fv treatments	Bpw + *Fv*	91.01bcd	9.20bc	5.14b	344.37abc
	Bsd + *Fv*	89.32bcde	9.34bc	5.18b	343.96abc
	Bpw + Bsd + *Fv*	89.51bcde	9.01bcd	4.77b	314.46abc
	Fungicide + *Fv*	91.76bc	8.86bcde	5.35a	335.94abc
Biochar alone	Bpw alone	92.02b	9.31bc	5.10b	349.96ab
	Bsd alone	85.16cdef	8.96bcde	9.20a	314.55abc
	Bpw + Bsd	91.59bc	9.38b	5.14b	330.43abc
Biochar + Fungicide	Bpw + Fungicide	85.21cdef	8.87bcde	4.69b	359.30a
	Bsd + Fungicide	84.95def	8.56de	4.66b	300.11bc
	Bpw + Bsd + Fungicide	87.24bcdef	9.12bcd	4.96b	317.87abc
Controls	Fungicide alone	85.41cdef	9.00bcd	4.79b	330.43abc
	Maize only (Control)	82.48f	8.81bcde	4.23b	298.46c
	Fv only	78.56g	8.42e	4.15b	228.44d
Feedstock	Poultry feacal waste (Pw)	98.65a	9.88a	5.26b	344.44abc
	Sawdust (Sd)	83.80ef	8.76cde	4.76b	350.44ab
	Pw + Sd	90.31bcde	8.97bcde	11.79a	318.48abc

Bpw = Poultry feacal waste biochar, **Bsd** = Sawduust biochar, ***Fv***= *Fusarium verticillioides*, **WAP** = Week After Planting.
Means with different letter are significantly ($p < 0.05$) different across the column.

Table 6
Pooled effect of varying biochar and feedstock concentrations on maize growth (mean of two seasons).

Concentration	Plant heights (cm)	Number of leaves	Stem girth (cm)	Leaf area (cm^2)
1 kg/m^2	89.30a	8.99a	5.54a	310.04b
2 kg/m^2	87.65ab	9.14a	4.96a	331.59a
3 kg/m^2	85.52b	8.97a	6.23a	327.95ab
Error Means Square	641.36	4.89	237.8	37328.3

Means with different letter are significantly ($p < 0.05$) different across the column.

Table 7
Pooled effect of planting seasons on the growth of maize plants (mean of two seasons).

Planting season	Plant heights (cm)	Number of leaves	Stem girth (cm)	Leaf area (cm^2)
Aug. –Nov., 2015	88.51a	8.88b	5.16a	321.53a
April - July, 2016	86.49b	9.18a	5.99a	324.86a
Error Means Square	641.36	4.89	237.8	37328.3

Means with different letter are significantly ($p < 0.05$) different across the column.

Table 8
Pooled effect of time (WAP) on the growth of maize plants (mean of two seasons).

Period (WAP)	Plant heights (cm)	Number of leaves	Stem girth (cm)	Leaf area (cm^2)
4	20.19c	7.59c	4.07c	184.05c
8	117.35b	10.41a	5.59b	439.56a
12	126.94a	9.10b	7.07a	345.97b
Error Means Square	641.36	4.89	237.8	37328.3

Means with different letter are significantly ($p < 0.05$) different across the column.
WAP = Week After Planting.

number of leaves and stem girths (Table 6). The first planting season favoured increasing plant heights as the number of leaves was significantly increased in the second evaluation, although stem girth and leaf area showed no significant difference in the two seasons of planting (Table 7). Also, plant height and stem girth recorded increasing significance with respect to time (WAP) while the most significant growths was recorded in the number of leaves and leaf area at 8th WAP (Table 8).

At 1 kg/m^2 biochar and feedstock concentration, the treatments of Bpw alone, Bpw + Fungicide, and Pw + Sawdust zero ear rot incidence, while other treatments showed infection rates below the control experiment (50 %), except Bpw + Fv (50 %), Fungicide + Fv (55.56 %), and Fv only (100 %). Treatment of Bpw alone recorded zero infection at 2 kg/m^2 while Bpw + Fv (44.44 %), Bsd + Fv (44.44 %) and Fungicide + Fv (33.33 %) presented infection rate higher than that of control (22.22 %) with Poultry faecal waste (78.78 %) and Fv (88.89 %) treatments shown as the most diseased. At concentration 3 kg/m^2, no disease incidence was recorded in Bpw + Bsd, Bsd + Fungicide, Sawdust and Pw + Sawdust. Treatments; Bsd + Fv (33.33 %), Bpw + Bsd + Fv (44.44 %) and Fv only (66.67 %) recorded incidence rate that is higher than that of control (25 %) (Table 9).

In line with the Reid disease severity scale employed, at 1 kg/m^2 biochar and feedstock concentration, soil treatments with Bpw alone, Bpw + Fungicide and sawdust showed infection rate at 0%. Other treatments produced disease severity rate (4–25 %) that are

Table 9
Yield and ear rot incidence among biochar, feedstocks and fungicide treatment of *F. verticillioides* at varying concentration levels (mean of two seasons).

Treatment	1 kg/m^2 Concentration			2 kg/m^2 Concentration			3 kg/m^2 Concentration		
	Harvested ear / block	Diseased ear / block	Ear rot incidence (%)	Harvested ear / block	Diseased ear / block	Ear rot incidence (%)	Harvested ear / block	Diseased ear / block	Ear rot incidence (%)
Bpw + Fv	6.00d	3.00e	50.00	9.00a	4.00c	44.44	6.00d	1.00b	16.67
Bsd + Fv	6.00d	2.00e	33.33	9.00a	4.00c	44.44	9.00a	3.00b	33.33
Bpw + Bsd + Fv	9.00a	3.00d	33.33	9.00a	2.00e	22.22	9.00a	4.00a	44.44
Fungicide + Fv	9.00a	5.00b	55.56	9.00a	3.00d	33.33	6.00d	1.00b	16.67
Bpw alone	9.00a	2.00e	22.22	6.00c	0.00g	0.00	9.00a	0.00e	0.00
Bsd alone	9.00a	3.00d	33.33	9.00a	2.00e	22.22	4.00f	0.00e	0.00
Bpw + Bsd	7.00c	3.00d	42.86	9.00a	2.00e	22.22	8.00b	1.00b	12.50
Fungicide alone	9.00a	2.00e	22.22	9.00a	2.00e	22.22	8.00b	2.00c	25.00
Bpw + Fungicide	7.00c	0.00g	0.00	8.00b	2.00e	25.00	7.00c	1.00b	14.29
Bsd + Fungicide	5.00e	2.00e	40.00	9.00a	3.00d	33.33	9.00a	0.00e	0.00
Bpw + Bsd + Fungicide	9.00a	3.00d	33.33	9.00a	3.00d	33.33	5.00e	1.00b	20.00
Control	8.00b	4.00c	50.00	9.00a	2.00e	22.22	8.00b	2.00c	25.00
Poultry feacal waste (Pw)	9.00a	3.00d	33.33	9.00a	7.00b	78.78	2.00g	0.30e	6.67
Sawdust	9.00a	1.00f	11.11	6.00c	1.00f	16.67	6.00d	0.00e	0.00
Pw + Sawdust	5.00e	0.00g	0.00	9.00a	7.00b	77.78	7.00c	1.00b	14.29
Fv only	9.00a	9.00a	100.00	9.00a	8.00a	88.89	6.00d	4.00a	66.67
EMS	7.51	2.22		9.60	2.93		6.51	0.71	

Means with different letter are significantly ($p < 0.05$) different across the column.

Table 10
Percentage ear rot severity among biochar, feedstocks and fungicide treatment of *F. verticillioides* at varying concentration levels (mean of two seasons).

Treatment	1 kg/m^2 Concentration			2 kg/m^2 Concentration			3 kg/m^2 Concentration		
	Ear length (cm)	Diseased length (cm)	Ear rot severity (%)	Ear length (cm)	Diseased length (cm)	Ear rot severity (%)	Ear length (cm)	Diseased length (cm)	Ear rot severity (%)
Bpw + Fv	13.67cd	2.75b	7.41cd	15.41abc	4.08ab	12.23a	13.11bc	0.88a	2.59b
Bsd + Fv	10.92bcd	3.25ab	5.47cd	14.34a-d	2.33ab	7.32b	13.91bc	0.93a	3.12b
Bpw + Bsd + Fv	14.46ab	1.23b	2.96cd	13.60cd	2.00ab	8.72b	13.79bc	2.40a	10.52b
Fungicide + Fv	15.28ab	4.40ab	16.98bc	15.87abc	1.62ab	6.54b	12.63bc	0.60a	1.95b
Bpw alone	16.49a	3.50ab	4.75cd	15.43abc	0.00b	0.00b	15.36a	0.00a	0.00b
Bsd alone	14.73ab	3.33ab	8.41cd	14.86a-d	1.83ab	4.07b	13.08bc	0.00a	0.00b
Bpw + Bsd	10.80bcd	3.17ab	8.69cd	16.27ab	1.13ab	3.18b	13.35bc	0.13a	0.44b
Fungicide alone	15.03ab	2.75b	3.83cd	14.28a-d	4.00ab	6.25b	13.79bc	1.50a	2.44b
Bpw + Fungicide	12.44a-d	0.00c	0.00d	13.81a-d	4.00ab	5.23b	12.63bc	3.50a	3.11b
Bsd + Fungicide	8.37d	3.75ab	6.78cd	14.97a-d	4.50ab	10.29b	12.99bc	0.00a	0.00b
Bpw + Bsd + Fungicide	12.49a-d	3.33ab	11.40bcd	13.98a-d	2.20ab	5.65b	15.16b	0.75a	2.08b
Control	11.48a-d	8.00a	25.03b	14.73a-d	1.65ab	5.41b	12.83bc	1.25a	4.36b
Poultry feacal waste (Pw)	15.43ab	5.77ab	13.07bcd	15.30a-d	5.91a	22.54a	18.75a	2.29a	12.20b
Sawdust	16.11a	4.00ab	2.47cd	12.82d	0.90ab	1.38b	12.82bc	0.00a	0.00b
Pw + Sawdust	8.74cd	0.00c	0.00d	16.37a	2.40ab	11.60b	13.24bc	0.33a	1.70b
Fv only	12.10a-d	6.09ab	51.77a	16.37a	3.80ab	27.36a	10.57cd	3.76a	38.14a
Error Mean Square	15.80	14.90	180.67	4.78	7.55	168.77	8.30	4.83	164.92

Means with different letter are significantly ($p < 0.05$) different across the column.
Bpw = Poultry feacal waste biochar, **Bsd** = Sawdust biochar, **Pw** = Poultry feacal waste, **Sd** = Sawdust, **Fv** = *Fusarium verticillioides.*

significantly ($p < 0.05$) lesser than the control experiment (25.03 %), except in *F. verticillioides* treatment alone (51.77 %). At 2 kg/m^2 Bpw alone (0.00 %), Sawdust (1.38 %), Bpw + Bsd (3.18 %), Bsd alone (4.07 %) and Bpw + Fungicide (5.23 %) produced lesser ear rot severity rate compared to control experiment (5.41 %). The most significant ($p < 0.05$) severity was recorded in poultry faecal waste (22.54 %) and *F. verticillioides* only (27.36 %). Ear rot evaluation at 3 kg/m^2 showed disease severity produced across the applied treatments including control as between 11–25 %, except *F. verticillioides* (38.14 %) treatments (Table 10).

The pooled ear rot incidence showed *F. verticllioides* (85.2 %) treated plants with highest infection. Bpw + Fv (37 %), Bsd + Fv (37 %) and Bpw + Bsd + Fv (33.3 %) significantly ($p < 0.05$) reduced the rate of infection. Other treatments applied produced results with lowered ear rot occurrences compared to control (32.4 %), except in Fungicide + Fv (37 %) and Poultry feacal waste (42.6 %) (Fig. 4).

The most significant ear rot severity recorded in the pooled analysis showed plants treated with *F. verticillioides* (39.1 %) and poultry feacal waste (15.9 %) with higher severity percentage than the control experiment (11.6 %). Other treatments showed results that are significantly lowered than control (Plates 1 and 2; Fig. 5).

Variations recorded in the growth and disease characters of maize plants caused by biochar, feedstock and fungicide treatments in the management of ear rot disease as shown in principal component analysis (PCA). The first and second PCAs' accounted for 88.54 % and 9.62 % total variation respectively. The first quadrat showed *F. verticillioides* treatment as related to ear rot incidence and severity. The second quadrat showed that plant height and leaf area was mostly enhanced by the treatments; Pw, Bp + Fv, Bs + Fv,

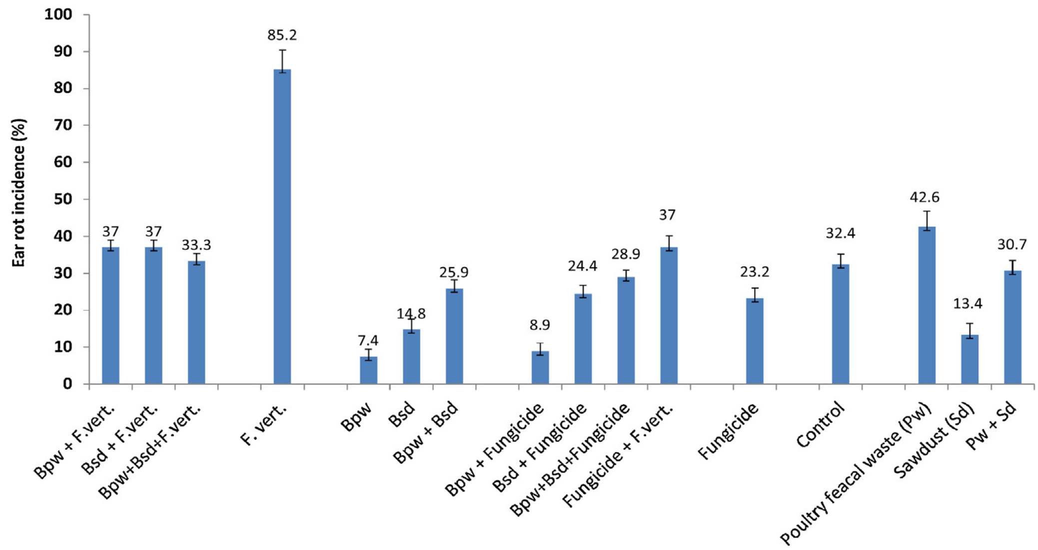

Fig. 4. Pooled ear rot incidence caused by *F. verticillioides* and managed with biochar, fungicide and feedstock treatments.
Bpw = Poultry feacal waste biochar, **Bsd** = Sawdust biochar, **Pw** = Poultry feacal waste, **Sd** = Sawdust, **F. vert**. = *Fusarium verticillioides*.

Plate 1. Maize cobs harvested from field treated with poultry waste biochar **(Bpw)**, sawdust biochar **(Bsd)** and *Fusarium verticillioides* **(*Fv*)**.
a = Control, b = Fv, c = Bpw + Fv, d = Bsd + Fv, e = Bpw + Bsd + Fv, f = Bpw only, g = Bsd only, h = Bpw + Bsd only.

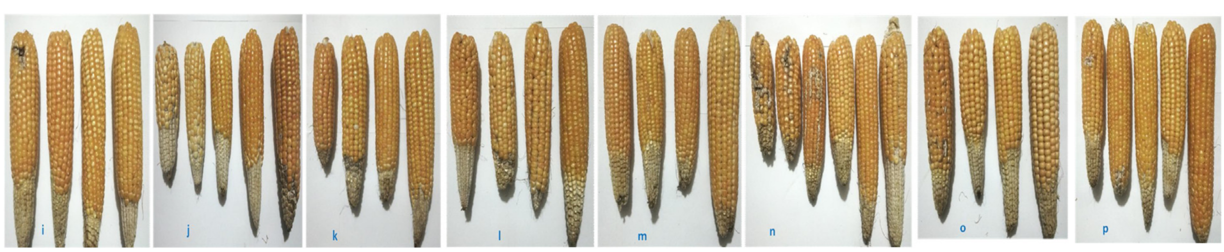

Plate 2. Harvested maize from different treatments of poultry waste biochar **(Bpw)**, sawdust biochar **(Bsd)**, *Fusarium verticillioides* **(*Fv*)**, Fungicide, Poultry feacal waste and sawdust.
i = Fungicide only, j = Fungicide + Fv only, k = Bpw + Fungicide, l = Bsd + Fungicide, m = Bpw + Bsd + Fungicide, n = Poultry feacal waste alone, o = Sawdust alone, p = Poultry feacal waste + Sawdust.

and Fungicide + Fv, while other treatments in the third and fourth quardrat supported the increase in the number of leaves and stem girth (Fig. 6).

5. Discussion

The improved growth performances recorded in the biochar treated plants in relation to control and *Fusarium verticillioides* treatments affirmed the report on the ability of biochar to enhance plant growth and productivity [28–31]. Plants' response to varying biochar levels was rarely significant but consistent growths were recorded with respect to time [32]. More so, the ability of biochar treated soil to maintain its integrity till the second season when it even lead to increased number of leaves can be related to the aromatic structure which made biochar chemically and biologically more stable compared with the organic matter from which it was made [33,34].

The high incidence of ear rot recorded in *F. verticillioides* inoculated maize plants substantiated the claim of ear rot of maize being a continuous threat to food safety and security [35,36]. At all concentration levels evaluated, biochar, feedstock and fungicide showed good management of *F. verticillioides* infection when compared to the results obtained in untreated (control) and *F. verticillioides* treated plants. Thus, effectiveness of individual and combined biochar treatments in suppressing the virulence of ear rot incidence and severity is found in support of the role of biochar

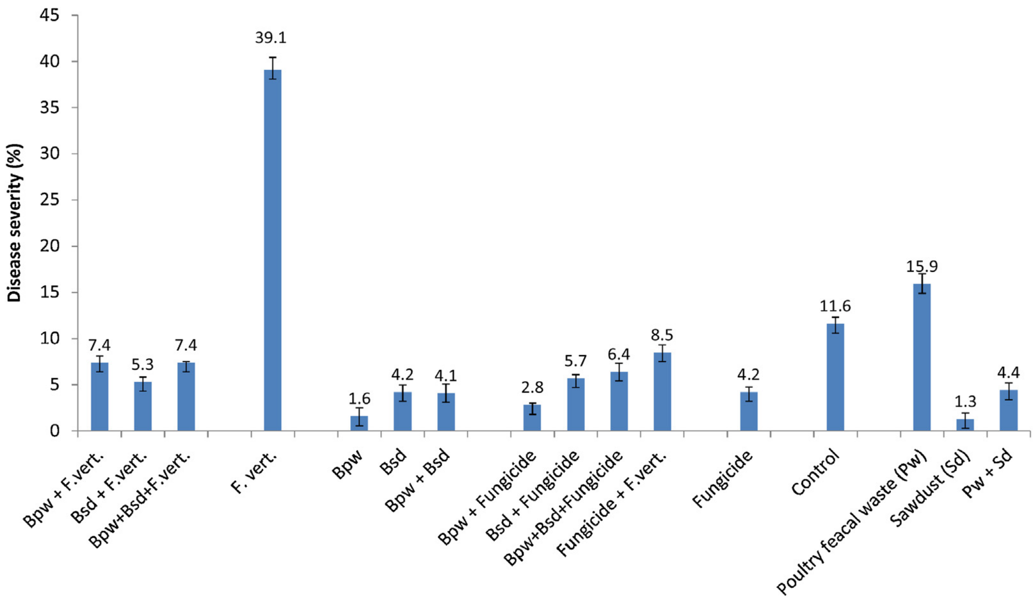

Fig. 5. Pooled ear rot severity caused by *F. verticillioides* and managed with biochar, fungicide and feedstock treatments.
Bpw = Poultry feacal waste biochar, **Bsd** = Sawdust biochar, **Pw** = Poultry feacal waste, **Sd** = Sawdust, **F. vert**. = *Fusarium verticillioides*.

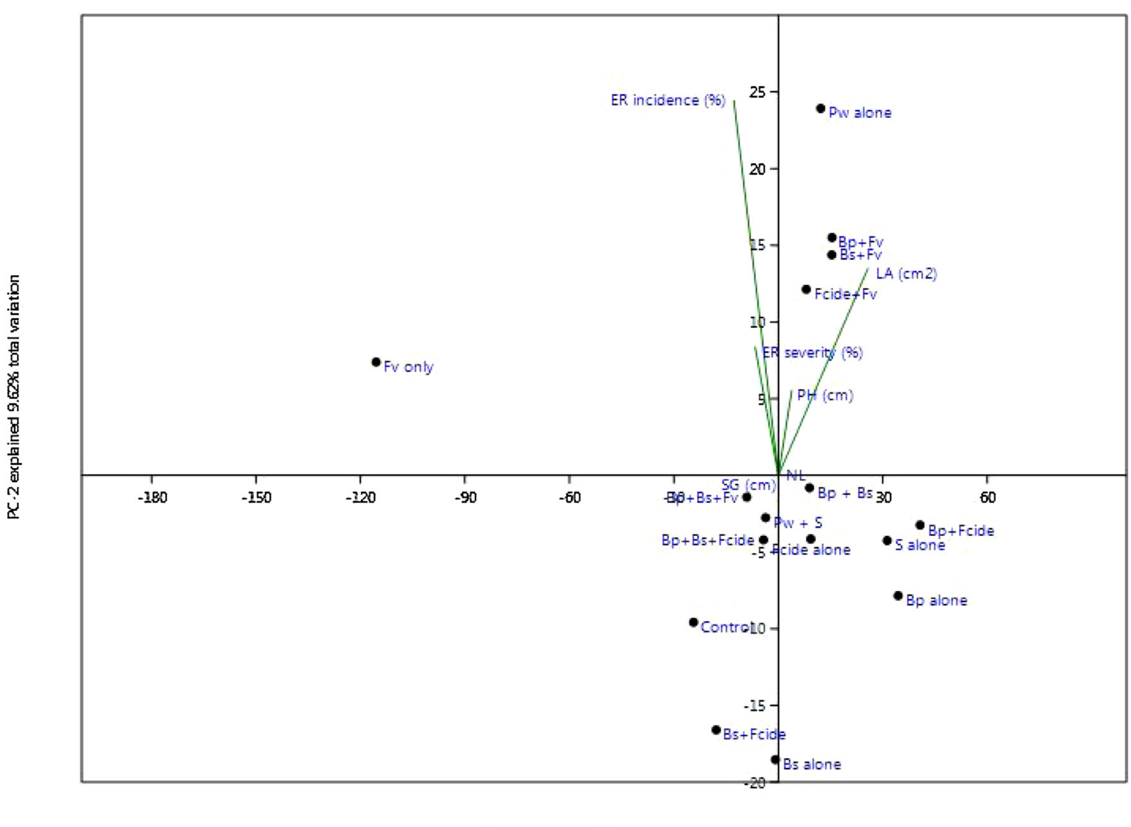

Fig. 6. Principal component analysis (PC 1 and PC 2) showing varying effects of biochar, feedstocks and *F.verticillioides* treatments on the growth and disease of maize.
Bpw = Poultry biochar, **Bsd** = Sawdust biochar, ***Fv*** = *Fusarium verticillioides*, **Fcide =** Fungicide, **PH=** Plant height, **SG =** Stem girth, **NL =** Number of Leaves, **LA =** Leaf area.

in controlling pollution and plant diseases [32,37,38]. The mechanism for the success of biochar has been linked to its ability to influence soil microbial populations and communities to influence an increase in beneficial microorganisms that directly protect against soil pathogens by; producing antibiotics, out-competing the pathogens, or grazing on the pathogens [37]. Also, the performance of fungicide in mitigating the effect of *F. verticillioides* was not significantly different from those of biochar treatments, and efficacy of these treatments in managing ear rot was further proved with their results which were better than those of control experiment. The efficacy and popular choice of fungicide in plant disease control could be associated with its role as abiotic inducers. Fungicide induces plant to develop enhanced resistance to pathogen infection, since it acts at various points in the signalling pathways involved in disease resistance [39,40].

Biochar was also found as an effective soil treatment in managing the resident pathogens, as uninoculated biochar treatments did not produced any disease occurrence in the treatments; Bpw alone, Bsd alone and Bsd + Fungicide at 3 kg/m^2 concentration. This result validates the claim that biochar induces plant systemic resistance responses against disease micro-organisms [41,42]. Since individual effect of biochar and fungicide was effective against pathogenic *F. verticillioides* and activities of resident pathogens, the disease incidence and severity were rather observed to be slightly pronounced contrary to expectations of the combined effect to completely eradicated occurrence of any disease. This phenomenon could possibly be explained with the report of Cabrera et al. [43] that biochar addition may negatively impact the efficacy of soil-applied pest products, including fungicides, insecticides, and herbicides. This is due to the high adsorption affinity and capacity that many biochars exhibit towards numerous organic compounds. Furthermore, strong adsorption of pesticides on applied biochar can result in pesticide inactivation such that greater pesticide amounts may be needed to obtain the same level of protection against pests [44,45].

Despite poultry faecal waste (Pw) enhancement of maize growths, its high disease occurrence in relation to the control treatment has been associated with the presence of resident microbes which serves a potential source of pathogenic microorganisms [46]. Whereas, sawdust (Sd) treatment was effective in managing resident pathogens in the soil. The efficacy of sawdust as antimicrobial agent can be attributed to the antimicrobial properties shared by the parent materials; *Gmelina arborea* [47,48], *Khaya senegalensis* [49], *Irvingia gabonensis* [50] and *Cordia* sp. [51,52].

In the principal component analysis conducted, PC 1 which accounted for highest variation (88.54 %) affirmed the delineation of growth parameters with respect to efficacy of applied treatments while the negative contribution to ear rot incidence and severity further ascertained the impact of biochar and fungicide treatments in reducing the virulence and disease caused by *F. verticillioides*. While the strong association existing between ear rot incidence and severity has been established [53,54], the contribution of PCA that accounted for reduction in the severity level of *F. verticillioides* by application of biological agents [55,56], botanicals [57,58], or resistance of some maize genotype have been reported [59,60].

Generally, all the biochar and fungicides treatments reduced ear rot severities compare to control treatment while the capability of biochar in altering the soil's physico-chemical properties in favour of plants' health requirement was observed. With regard to human and environmatal safety, this investigation revealed the preference of biochar over fungicide in the management of maize ear rot. Hence, poultry faecal waste biochar and sawdust biochar were effective in the management of *Fusarium* ear rot of maize and could be used as soil amendments.

Author statement

All the authors have read and approve the submission of this corrected version.

This work has neither been published not presently under consideration in any other journal.

Declaration of Competing Interest

The authors declare no conflict of interest as regards this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.btre.2020.e00474.

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