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

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**A B S T R A C T**

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 against 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+Bv, Bsd+Bv, Bpw+Bsd+Fv, and control) as soil amendments. Additional treatments consisted of fungicide (Cibaplu), poultry faecal waste (Pw), sawdust (Sd), Bpw+Fungicide, Bsd+Fungicide, Bpw+Bsd+Fungicide, Fungicide + Fv, and Sd. The Bpw and Pw at 1.2 and 3 kg/m² each, Bsd and Sd (0.50, 1.00 and 1.50 kg/m²) 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, Bpw+Sd, Bsd+Fv, Bsd+Bsd+Fungicide, Bpw+Bf, Bsd+sd+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.

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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 fumonisins in grain 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
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 been 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 continuous 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 = Pw + Fv
T2 = Bsd + Fv
T3 = Pw + Bsd + Fv
T4 = Fungicide + Fv
T5 = Fv alone
T6 = Pw alone
T7 = Bsd alone
T8 = Pw + Bsd
T9 = Fungicide alone
T10 = Pw + Fungicide
T11 = Bsd + Fungicide
T12 = Pw + Bsd + Fungicide
T13 = Control (Untreated maize)
T14 = Pw alone
T15 = Sd alone
T16 = Pw + Sd

Where; Pw = Poultry faecal waste biochar, Bsd= Sawdust biochar, Fv= Fusarium verticillioides, Pw = Poultry faecal waste, Sd = Sawdust.

The experiment was laid out in a randomized complete block design (RCBD). On each respective mini plots, Pbw 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
component was applied with respect to the number of components involved. Similar application rate was employed for treatments involving the feedstocks, poultry faecal 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 was then counted using haematocytometer and adjusted with sterile distilled water to $1 \times 10^7$ 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 (Ciplasus) 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 appropriate 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]:

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

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

3.5. Data analysis

All the data obtained in this study were analyzed using Statistical Analysis System, SAS version 9.1 [27] software and
Table 2

| Treatments            | Concentration 1 kg/m² | Concentration 2 kg/m² | Concentration 3 kg/m² |
|-----------------------|-----------------------|-----------------------|-----------------------|
|                       | Plant height (cm)     | Plant width (cm)      | Plant girth (cm)      |
|                       | No of leaves          | No of leaves          | No of leaves          |
| Bwp + Fv              |                        |                       |                       |
| Bsd + Fungicide       | 21.17±0.13abc         | 20.64±0.13ab          | 19.80±0.13bc          |
| Bpw = Sawdust biochar | 21.14±0.12abc         | 20.63±0.12ab          | 19.81±0.13bc          |
| Fv only               | 21.14±0.14abc         | 20.63±0.14ab          | 19.81±0.14bc          |

Means with the different letters across the column are significantly 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 their order of significant (p < 0.05) as; poultry faecal waste biochar (Bwp) > 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/m² showed the highest plant height in (Bwp + 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 Bwp + Bsd (1.44 cm), while no significant difference occurred in number of leaves among the treatments. Bwp + Fv (61.24 cm) and Fungicide alone (not yet applied) (5.12 cm) produced the most significant (p < 0.05) results in the leaf length and width respectively. At 2 kg/m² biochar concentration, treatments with Poultry waste (Pw) only recorded the most significant growth across the parameters measured. Also, at 3 kg/m² 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 inoculated the pathogen and fungicide application at the 7th WAP, results at 1 kg/m² concentrations showed Bwp + 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 Bwp + 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 + Bsd + Fungicide (149.50 cm), Pw + Sawdust (148.28 cm) and Bwp + Bsd (147.18 cm) produced a more significantly higher plant height results that other treatments. Bwp + 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 Bwp + Fv (8.40 cm), Bsd + Fungicide (8.14 cm), Bp + Bsd + 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/m² (89.30 cm), the leaf area increased with increasing concentrations while no significant difference was recorded across the levels in...
| Treatments                              | Plant height (cm) | Stem girth (cm) | No of leaves | Leaf length (cm) | Leaf width (cm) | Stem girth (cm) | No of leaves | Leaf length (cm) | Leaf width (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           | 139.38ab        | 1.58abc      | 9.56a           | 73.03a          | 7.65b           | 123.42def    | 1.48d          | 8.33d          | 68.58b-d       |
| Bsd + Fv                               | 152.66a           | 1.60a           | 9.00a        | 68.98b          | 7.65b           | 118.41cl        | 1.52d         | 9.31abc         | 62.12b          | 7.07b           | 143.82ab     | 1.87d          | 9.17a          | 77.14ab        |
| Bpw + Bsd + Fv                         | 126.86ab          | 1.59a           | 9.19a        | 64.21abc        | 7.39a           | 113.85abc       | 1.57abc       | 8.22c           | 59.92bc         | 7.27b           | 140.13bcd    | 1.87bc         | 9.17a-d        | 77.14ab        |
| Fungicide + Fv                         | 139.78ab          | 1.50a           | 9.44a        | 62.63abc        | 8.02a           | 131.66bc        | 1.79b         | 8.33bc          | 65.78abc        | 7.50b           | 150.30a      | 1.56abc        | 9.83abc        | 80.80a         |
| Bpw alone                              | 139.53ab          | 1.47a           | 9.44a        | 63.46abc        | 7.50a           | 132.64ab        | 1.84a         | 9.29abc         | 68.44a          | 8.40b           | 123.85cd     | 1.51d          | 9.17a-d        | 85.65a         |
| Bsd alone                              | 137.23ab          | 1.59a           | 9.50a        | 65.39abc        | 7.70a           | 127.41bc        | 1.66abc       | 9.29abc         | 68.36abc        | 7.66b           | 133.62cd     | 1.79a          | 9.83abc        | 70.03cd        |
| Bpw + Bsd                              | 147.18a           | 1.55a           | 9.50a        | 55.33abc        | 7.60a           | 131.34bc        | 1.65abc       | 9.44abc         | 69.46a          | 7.93b           | 129.93c      | 1.64cd         | 8.50c          | 77.87ab        |
| Fungicide alone                        | 145.33ab          | 1.47a           | 9.33a        | 66.67abc        | 7.57a           | 124.24bc        | 1.45c         | 9.25abc         | 58.41abc        | 7.05b           | 133.80cd     | 1.53d          | 9.33a-d        | 87.41bc        |
| Bpw + Fungicide                        | 139.7ab           | 1.69a           | 9.29a        | 54.37abc        | 7.19b           | 113.45d         | 1.49b         | 8.38abc         | 63.60abc        | 7.44b           | 117.07def    | 1.62d          | 8.17a          | 57.52f         |
| Bsd + Fungicide                        | 149.50a           | 1.50a           | 9.06a        | 64.24abc        | 7.90a           | 136.81bc        | 1.67abc       | 9.78a           | 67.67a          | 7.20b           | 129.27bc     | 1.59d          | 9.33a-d        | 59.00ef        |
| Control (Untreated)                    | 117.88b           | 1.41a           | 8.33a        | 50.74abc        | 6.26b           | 131.87bcd       | 1.52c         | 9.31abc         | 64.26abc        | 7.47b           | 157.43a      | 1.88a          | 10.17a         | 81.78a         |
| Poultry fecal waste (Pw)               | 146.75a           | 1.70a           | 15.13a       | 63.67abc        | 7.93a           | 135.91a         | 1.81a         | 9.22abc         | 63.58abc        | 8.10b           | 151.45d      | 1.88a          | 10.17a         | 81.78a         |
| Sawdust only                           | 150.54a           | 1.63a           | 9.25a        | 69.34ab         | 8.21a           | 123.53bc        | 1.53abc       | 9.22abc         | 62.71ab         | 14.23a          | 121.14ef     | 1.48d          | 8.38d          | 61.08abcdef    |
| Fv only                                | 149.29a           | 1.46a           | 9.00a        | 65.57abc        | 7.43b           | 140.97ab        | 1.65abc       | 8.89abc         | 72.26a          | 7.97b           | 131.56de     | 2.18a          | 10.50a         | 61.05def       |

Bpw = Poultry waste biochar, Bsd = Sawdust biochar, Fv = Fusarium verticillioides, Pw = Poultry fecal 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 (cm²) |
|------------|--------------------------------|--------------------|------------------|-----------------|-----------------|
| 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                      | 91.70bc            | 8.86bcd          | 5.35a           | 335.94abc       |
| Biochar alone | Bpw alone                           | 92.02b             | 9.31bc           | 5.30b           | 349.96ab        |
|             | Bsd alone                           | 85.16def           | 8.96bcd          | 9.20a           | 314.55abc       |
|             | Bpw + Bsd                           | 91.59bc            | 9.38b            | 5.14b           | 330.43abc       |
| Biochar + Fungicide | Bpw + Fungicide                  | 85.21cdfe          | 8.87bcde         | 4.69b           | 359.30a         |
|             | Bsd + Fungicide                     | 84.95def           | 8.56de           | 4.66b           | 300.11bc        |
|             | Bpw + Bsd + Fungicide              | 87.24bdef          | 9.12bcd          | 4.96b           | 317.87abc       |
| Controls    | Fungicide alone                     | 85.41cdef          | 9.00bcd          | 4.79b           | 330.43abc       |
|             | Fv only                            | 78.56g             | 8.42e            | 4.15b           | 228.44d         |
| Feedstock   | Poultry faecal waste (Pw)          | 98.65a             | 9.88a            | 5.26b           | 344.44abc       |
|             | Sawdust (So)                       | 83.80f             | 8.76cd           | 4.76b           | 350.44ab        |
|             | Pw + Sd                            | 90.31bde           | 8.97bcde         | 11.79a          | 318.48abc       |

Bpw = Poultry faecal waste biochar, Bsd = Sawdust 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 (cm²) |
|--------------|--------------------|------------------|-----------------|-----------------|
| 1 kg/m²      | 89.30a             | 8.99a            | 5.54a           | 310.04b         |
| 2 kg/m²      | 87.65ab            | 9.14a            | 4.96a           | 331.59a         |
| 3 kg/m²      | 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 (cm²) |
|-----------------|--------------------|------------------|-----------------|-----------------|
| 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 (cm²) |
|-------------|--------------------|------------------|-----------------|-----------------|
| 4           | 20.19c             | 7.59c            | 4.07c           | 184.05c         |
| 8           | 117.35b            | 10.41a           | 5.99b           | 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.

The 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 were recorded in the number of leaves and leaf area at 8th WAP (Table 8).

At 1 kg/m² 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/m² 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/m², 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/m² 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

| Treatment                  | 1 kg/m² Concentration | 2 kg/m² Concentration | 3 kg/m² 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                 | 4.00c                 | 44.44                 |
| Fungicide + Fv             | 9.00a                 | 5.00b                 | 55.56                 | 6.00c                 | 0.00g                 | 0.00                  | 9.00a                 | 0.00e                 | 0.00                  |
| Bpw alone                  | 9.00a                 | 2.00e                 | 22.22                 | 9.00a                 | 2.00e                 | 22.22                 | 4.00f                 | 0.00e                 | 0.00                  |
| Bsd alone                  | 7.00d                 | 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                  | 3.75                  | 9.60                  | 2.93                  | 3.00                  | 6.51                  | 0.71                  |                      |

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

Table 10

| Treatment                  | 1 kg/m² Concentration | 2 kg/m² Concentration | 3 kg/m² Concentration |
|----------------------------|-----------------------|-----------------------|-----------------------|
|                            | Ear length (cm)       | Diseased length (cm)  | Ear rot severity (%)  |
| Bpw + Fv                   | 13.67c                | 2.75b                 | 7.41c                 |
| Bsd + Fv                   | 10.92b/cd             | 3.25a/b                | 5.47c/d               |
| Bpw + Bsd + Fv             | 14.65ab               | 1.23b                 | 2.96c/d               |
| Fungicide + Fv             | 15.28ab               | 4.40ab                | 16.98bc               |
| Bpw alone                  | 16.49a                | 3.50ab                | 15.43ac               |
| Bsd alone                  | 14.73ab               | 3.35ab                | 15.87bc               |
| Bpw + Bsd                  | 10.80bcde             | 3.17ab                | 16.27ab               |
| Fungicide alone            | 15.03ab               | 2.75b                 | 3.83cd               |
| Bpw + Fungicide            | 12.44a/d              | 0.00c                 | 13.81a/d              |
| Bsd + Fungicide            | 8.37d                 | 3.75ab                | 14.79a/d              |
| Bpw + Bsd + Fungicide      | 12.49a/d              | 3.35ab                | 12.58a/d              |
| Control                    | 11.48a/d              | 8.00a                 | 25.03d               |
| Poultry feacal waste (Pw)  | 15.43ab               | 5.77ab                | 13.07bcd              |
| Sawdust                    | 16.11a                | 4.60a                 | 2.47cd               |
| Pw + Sawdust               | 8.74c                 | 0.00c                 | 16.37a                |
| Fv only                    | 12.10a/d              | 6.05a/b                | 14.73a/d              |
| Error Mean Square          | 15.80                 | 14.90                 | 180.67               |

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.

The results show that the treatment of maize plants with higher concentrations of Bpw + Fv (37%) and Bsd + Fv (37%) had a significantly lower rate of infection compared to the control (32.4%). The significant difference in ear rot severity was also observed in Po. The 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 lower 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,
and Fungicide + Fv, while other treatments in the third and fourth quadrant 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.
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; Bwp alone, Bsd alone and Bsd + Fungicide at 3 kg/m² 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 %) afforded 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 contribu-

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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Author statement

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