



Fungitoxicity of Agricultural Waste-Derived Biochars Against *Fusarium Oxysporum* (Schlect) *f.sp Radicis-Lycopersici* (Jarvis and Shoemaker) Causal Agent of Fusarium Crown and Root Rot of Tomato

Nwaogu GA¹ ; Kolawole OO¹ ; Ogbonna PA¹

¹Department of Plant Health Management, Michael Okpara University of Agriculture, Umudike
PMB 7267 Umuahia, Abia State, Nigeria.

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*Corresponding Author

Nwaogu GA

E-mail: amarachigrace777@gmail.com

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ABSTRACT

Tomato (*Solanum lycopersicon* Mill) an edible fruit is one of the most important tropical vegetable crops widely consumed in several food forms throughout the world. The fruits are rich in essential vitamins, minerals and phytonutrient such as lycopene. The study was conducted at the central Laboratory Unit of the National Root Crop Research Institute (NRCRI) Umudike, and the Screen-house of the University to evaluate the effect of the different agro-waste-derived biochar on the incidence and severity of *Fusarium* crown rot and root rot of tomatoes incited by *Fusarium oxysporum f.sp radicsi-lycopersici* in Umudike. The result showed that biochar sourced from rice husk, saw dust and siam weed substantially ($P \leq 0.05$) reduced the growth *in vitro* and incidence and severity of the disease *in vivo* in a manner comparable to Furadan. Conversely cassava peels-derived biochar was least in fungitoxicity. Similarly, the various sources of biochar demonstrated varied effects on the vine growth and the flower production of tomato plants with increasing days after inoculation (DAI); with saw dust, siam weed, and rice husk supporting a better performance of the crop in the field than the other treatments. However, cocoa husk maintained a moderate but persistent toxicity against *Fusarium oxysporum f.sp radicsi-lycopersici* *in vitro* and *in vivo*. Therefore, low input farmer of sub Saharan Africa could use biochars sourced from rice husks, saw dust, and siam weed to effectively manage *Fusarium* crown and root rot disease of tomato caused by *Fusarium oxysporum f.sp radicsi-lycopersici* so as to improve productivity of the crop.

INTRODUCTION

Tomato (*Solanum lycopersicon* Mill.) (Solanaceae) is a high-value horticultural crop which is considered as one of the most popularly consumed vegetables in tropical, subtropical and temperate regions of the world (Pritesh *et al.*, 2011; Hadian *et al.*, 2011). It constitutes an important dietary component of the food of its consumers contributing valuable nutrients for rural and urban populations (Waiganjo *et al.*, 2006). The ripe fruits may be eaten fresh in salads or cooked as a vegetable or dried before use. They may also be processed into tomato paste (puree), tomato sauce, ketchup or juice. Tomatoes are rich in vitamins A and C and are gaining importance because it contains lycopene – a phyto-nutrient – known to possess strong antioxidant attributes against all forms of diseases induced by reactive oxygen and nitrogen species (ROS and RNS) including prostate cancer, heart diseases as well as age-related conditions (AVRDC, 2003; Enyiukwu, 2019).

Tomato grows well in warm locations with optimum temperature of 15-25°C; and medium rainfall amounts which could be supplemented with irrigation during the off season. Prolonged wet weather conditions increase the chances of fungal disease attacks, cause flower abortion and may also affect fruit ripening of the crop. The crop grows well in a wide range of well-drained soil types rich in organic matter whose pH ranges between 5.0 to 7.5 (Waiganjo *et al.*, 2006). However, many constraints especially fungal diseases have been reported to affect efficient production and quality of tomatoes especially in the humid tropical rainforest agro-ecological zones (Wokocha and Okeke, 2006; Pritesh *et al.*, 2011;). Some of the fungi-induced diseases affecting the crop in the humid tropics include early blight, anthracnose, *Verticillium* wilt and *Fusarium* wilt (Mardi *et al.*, 2006).

Fusarium oxysporum is a cosmopolitan soil-borne pathogen. *Fusarium* crown and root rot (FCRR) caused by *Fusarium oxysporum* Schlecht f. sp. *radicis-lycopersici* Jarvis and Shoemaker is rated as one of the most common, damaging and very destructive soil-borne diseases of tomato in both field and greenhouse production systems (Roberts *et al.*, 2001; Sheu *et al.*, 2006; Amini *et al.*, 2010; Abdel-Monaim, 2012; Szczechura *et al.*, 2013). The fungus invades susceptible plants through wounds and natural openings created by newly emerging roots or nematodes; then it colonizes and plugs the xylem vessel of the affected tomato, interfering with water uptake of the plant (Akher *et al.*, 2016). The disease is symptomized by wilting of older leaves, chlorosis, stunted growth and in severe cases death of the affected crop (Roberts *et al.*, 2001; Peralta *et al.*, 2001; Akher *et al.*, 2016). Usually wilting occurs first during the warmest part of the day, and plants appear to recover at night; and sometimes infected plants may persist in a weakened state,

producing reduced numbers of inferior fruits (Roberts *et al.*, 2001).

Several control measures including good cultural practices such as crop and soil sanitation, use of resistant varieties, biological control techniques and chemical interventions have been attempted for managing the diseases. However, because no one method is without drawbacks, losses are still substantial (Dodson *et al.*, 2002; Besri, 2000). Use of plant-based agricultural waste material or their products such as biochars or wood ashes for soil amendment or treating infected crops remain a veritable least-cost method for the control of soil-borne pathogens and parasites (Maranzru, 2011)

Biochars are very stable in soil systems with a half-life ranging up to thousands of years (Zimmerman, 2010). Recently, it has been reported that soils amended with biochars, activated systemic plant defense systems and suppressed disease severity of some fungal pathogens such as *Botrytis cinerea*, *Colletotrichum acutatum* and *Podosphaera aphanis* and *Leveillula taurica* affecting strawberry, tomato and pepper (Elad *et al.*, 2010; Harel *et al.*, 2012). In soils amended with biochars a gross reduction in root lesions and rot severity from attacks by *Fusarium oxysporum* f.sp. *asparagi* and *F. proliferatum* have been reported (Elmer and Pignatello, 2011). However, there is limited information on the use of biochar in controlling soil borne fungal pathogens affecting tomato production in Umudike, South Eastern Nigeria situated in the humid tropics. Therefore, this work was aimed at evaluating the effectiveness of biochars from many agro-waste sources for controlling tomato caused by *Fusarium oxysporum* f.sp. *radicis-lycopersici* and the performance of the treated crop in Umudike, South-east Nigeria.

MATERIALS AND METHODS

Source and preparation of treatments

Rice husks collected from Uzoakoli rice mill, as well as cassava peels, cocoa husks, saw dust, siam weed collected from Umuariaga village in Ikwuano were used in preparing biochars for this study, while the fungicide (Furadan) was bought from an agro-chemical store at timber market Umuahia, all in Abia State, Nigeria. Each of the biochar-making materials (rice husk, cassava peels, cocoa husk, siam weed) were cured by sun drying for 2 weeks, and then separately and pyrolytically heated under a very high temperature (about 300-400°C) using a locally constructed drum. The biochar from different source materials were separately stored in clean polyethylene bags until required. Thirty (30) grams of each biochar, and Furadan at the recommended rate (20%) were weighed out and separately applied into

each experimental pot while the control experiment had no treatment.

Isolation and identification of the causal pathogen

Isolated leaves and stems of tomato with typical symptoms of Fusarium crown rot and root rot (FCRR) disease (Plate 1A) were collected from the Research farm of the University, enveloped and taken to the Plant Health Laboratory, of the University. They were washed in several changes of running tap water tap to remove debris, air-dried for 30 mins on the laboratory bench and then the infected roots and stems with fungal lesions were cut into small segments. The segments were surface sterilized using 70 % ethanol for three minutes

and rinsed in three changes of sterile distilled water before drying on Whatman no.1 sterile filter paper. Thereafter, the segments were then plated on fresh solidified Potato Dextrose Agar (PDA) medium (Oxoid™ ThermoScientific Product England, UK) and incubated for seven (7) days at about 28°C. Pure cultures of the organisms obtained by repeated sub-culturing were maintained on fresh PDA slants in stock bottles and kept at about 4°C in a refrigerator until required. Slides of the fungal isolate were prepared and mounted under compound microscope and the identity of the isolate which was consistently isolated from the infected crop were determined with reference to monographs of imperfect fungi by Barnett and Hunter (2003), Leslie and Sumerell (2006) and Amin (2009) respectively.



Plate 1: A = Infected tomato growing in the field. B. = *Fusarium oxysporium* f.sp *radicis-lycopersicon* isolated from infected tomato plant growing on PDA. C. = Biochar made from rice husk. D. Tomato (Var. Roma VF) growing in biochar-modified soil. E. = Fruits harvested from biochar treated tomato plant.

Pathogenicity test

Spore suspension of *Fusarium oxysporium* f.sp *radicis-lycopersicon* (Plate 1B) isolated from wilt infected tomato from the Research farm and identified was prepared and adjusted to 1.0×10^6 spore/ml (Amini, 2005). The spore suspension was used to inoculate the healthy seedlings of tomato cultivar (Roma vf) which is susceptible to the *form species* (Bost, 2005). Inoculation was done by inflicting wounds with a sterile needle at the base of the healthy transplanted tomato seedlings and kept well watered. The pots were maintained in a screen-house at about 70% relative humidity and $28^\circ \pm 2^\circ\text{C}$. Symptom of

the disease after 4 weeks showed successive yellowing of the lower leaves, abscission, drooping, wilt and death of seedlings. The infected seedlings (roots, leaves and stems) were later cut, washed severally and plated on fresh molten PDA and incubated at 28°C . The identity of the isolate, re-isolated from the infected tissues were confirmed after slides of the isolates were mounted and viewed using a compound microscope; and ascertained to have the same characteristics with the ones previously isolated from the research farm specimens.

In Vivo Experiment

One (1) gram of each biochar (Fig 1C)) sources namely (rice husk, cocoa husk, siam weed, saw dust and cassava peels) were soaked in 10 ml of sterile distilled water in test tubes and well covered. Each suspension was hand shaken intermittently and allowed to stand for 6 hours. One (1) ml of each biochar suspension was dispersed into sterile Petri plates containing 9 ml of molten PDA media and carefully swirled for even distribution. The agar-biochar mixture was allowed to solidify and then inoculated at the centre with 4 mm mycelial disc of a 7 day old pure culture of the test fungi (FORL). Each treatment was replicated three (3) times. The reference plate had no treatments but the positive control was poisoned with Furadan. After inoculation, plates were incubated at 28°C for 5 days and examined daily for radial growth of the pathogen. Colony diameter was taken as mean growth along two perpendicular directions.

The effectiveness of the biochars in retarding the growth of the pathogen were recorded in terms of percentage growth inhibition which was calculated according to the formula adopted by Amadioha (2006) as:

$$\% \text{ inhibition} = \frac{dc - dt}{dc} \times \frac{100}{1}$$

Where:

dc is the average radial distance of pathogen in control plate

dt is the average radial distances of pathogen in extract incorporated agar plates.

In Vivo Experiment

Preparation of fungal suspension

The spores of the pathogen *Fusarium oxysporum f.sp. radicle-lycopersici* (Plate 1B) were collected from a day old culture- agar stock in Petri dishes by lifting 60 cm² pieces into a beaker containing 200 ml of sterile distilled water. This was sieved through a 4-folds of sterile cheese cloth to remove agar and fungal mycelia fragments and the filtrate centrifuged for ten (10) minutes. The spores suspension was standardized using a haemocytometer counting slide to 10⁵ spores/ml of sterile distilled water. Thereafter it was poured into a round-bottomed flask, stoppered and used to inoculate the relatively disease-free tomato seedlings to run-off.

Field evaluation of biochars for antifungal activity

This experiment was conducted at the screen-house of Michael Okpara University of Agriculture, Umudike. The tomato seeds (Var. Roma VF) obtained from the Research and Training (R&T) Unit of the College of Crop and Soil Sciences of the University were used for the study. A well sterilized garden soil was poured into nursery trays of about 90 cm × 60 cm. The tomato seeds

were sown in drills in the nursery trays kept under shade and watered as when necessary. Three (3) weeks after planting (WAP), the germinated seedlings were transplanted into pots of about 17 cm diameter filled with 20 kg of the sterilized soil. The seedlings were watered daily.

At 8 WAP, the transplanted tomato seedlings were inoculated with the fungal spores suspension as afore-prepared, by making grooves around the base of each seedling and using a sterile inoculation needle, wounds were mildly inflicted around the bases of the seedlings before gently pouring the suspension into the grooved area made around the seedlings. Then thirty grams (30 g) of each biochar (rice husk, cocoa husk, siam weed, saw dust and cassava peels) (Plate 1C) were separately soaked in 100 ml of sterile distilled water in sterile test tubes and covered with foiled cotton wool. Each solution was hand shaken intermittently and allowed to stand for 6 hrs; thereafter, the suspension was sieved through 2-folds of sterile cheese cloth. The biochar solutions thus obtained were poured separately into a small hand sprayer and used to spray-inoculate the leaves surfaces of the seedlings; afterwards, the inoculated plant (Plate 1D) were covered with transparent light-weight polyethylene bags to provide humid condition for 24 hrs. The furadan treated seedlings were set up in a similar manner with the fungicide applied at recommended rate, while the negative control experiment was treated with sterile distilled water. A high relative humidity was maintained around the inoculated plants by continuous watering while the experiment lasted. Records on the number of emerged and established tomato seedlings from 2 weeks after planting (WAP), as well as the vine length, number of flowers and weight of fruits from the matured tomato plants were taken per plant per treatment.

The % wilt incidence on the treated tomato plants was evaluated by visual assessment and calculated based on the formula by adopted Amadioha (2006) as follows;

$$\% \text{ disease incidence} = \frac{\text{No of wilted leaves/plants}}{\text{Total no of leaves/plant}} \times \frac{100}{1}$$

While disease severity was assessed on 0-5 point scale as adopted by Wokocha and Opara (2004) thus;

- 0 - No visible wilt symptom.
- 1 - 1-3 leaves wilted
- 2 - 4-6 leaves wilted
- 3 - 7-9 leaves wilted
- 4 - 10-12 leaves wilted
- 5 - > 12 leaves wilted

Data Analysis

The experiment was laid out in Completely Randomized Design (CRD) made up of 7 treatments and 3 replications. All data were subjected to Analysis of

Variance (ANOVA) using Genstat 2007 Version and the means separated using least significant difference (LSD) at 5% level of probability.

RESULTS

The results presented in Fig. 1 showed that the treatments exhibited appreciable levels of fungitoxic activity against the test fungus. It also showed that

biochar derived from rice husk and Furadan (control), followed by siam weed were the most fungitoxic restricting the radial growth of the fungus to approximately 20 mm while cocoa husks and cassava peel-derived biochars were the least in fungitoxicity to the fungus. Furthermore, the results showed that siam weed, cocoa husk and rice husks persisted in the culture medium such that the radial growth of the test fungus was more or less unity throughout the 7-day study period.

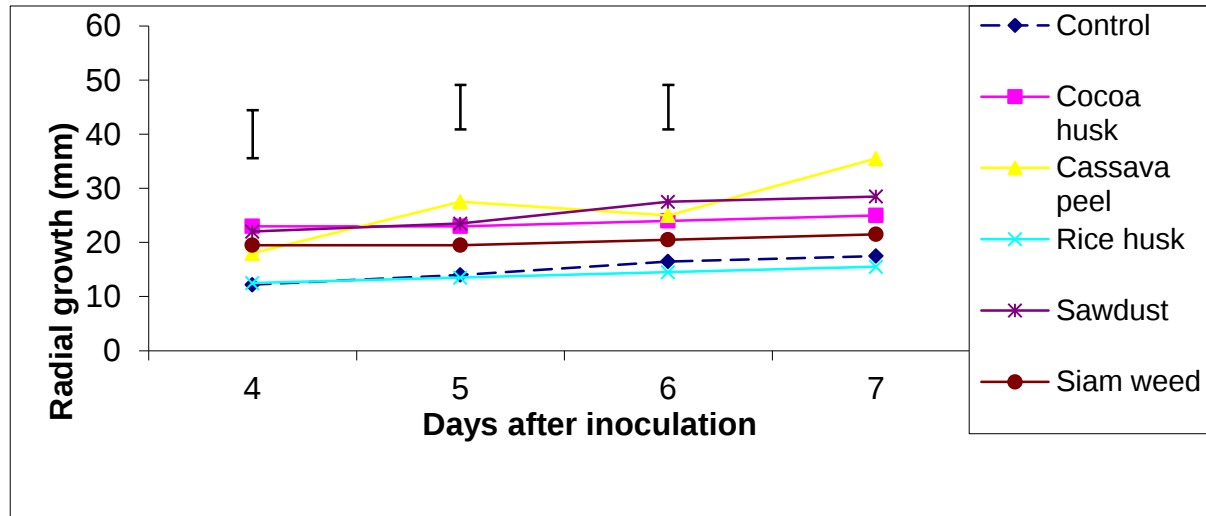


Fig 1: Effect of biochar on the radial mycelial growth *Fusarium sp* inoculated *in vitro*

The results presented in Fig. 2 suggest that the disease incidence on the inoculated tomato more or less increases with increase in DAI. It also clearly depicted that all the treatments were superior in fungitoxic activity *in vivo* than the control and effectively reduced the incidence of FCRR on the treated crop 30 days post inoculation to about 40 %. As with the *in vitro* evaluation,

biochar derived from rice husk, the best reduction of the disease incidence 23-30 DAI, however this was not statistically ($P \geq 0.05$) different from the effects recorded from furadan and siam weed during the same period. On the other hand, biochar derived from cassava peels was the least efficacious in reducing the incidence of the disease.

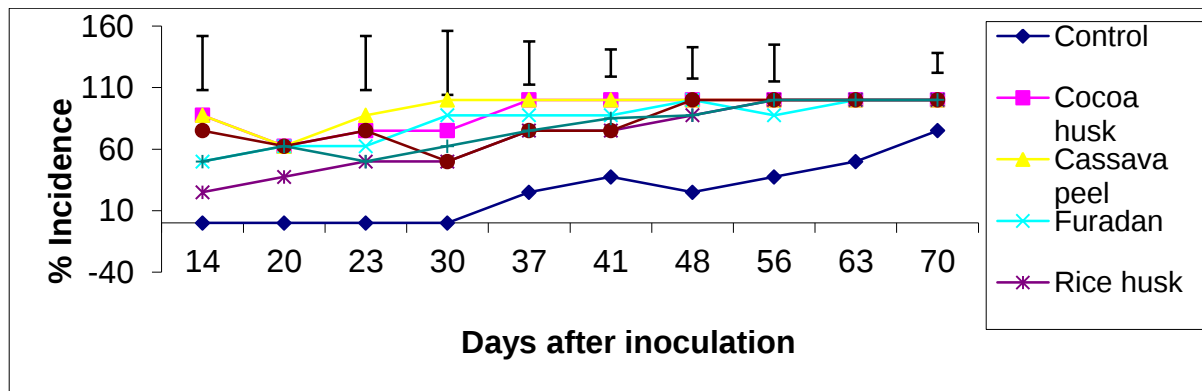


Fig 2: Effect of biochar on the disease incidence of treated tomato seedlings inoculated with *Fusarium oxysporum f.sp. radicis-lycopersici*

In Fig 3, the results showed a time dependent effect, increasing with increase in DAI. It also reveals that with the exception of cassava peels all the biochar treatment substantially reduced the severity of FCRR to more or less than 1.5 on the treated tomato 20-41 DAI in a

manner that compared statistically ($P \leq 0.05$) well with furadan. However, cocoa husk, rice husk and siam weed and saw dust putting up a brilliant performance in reducing the severity of FCRR on the treated crop.

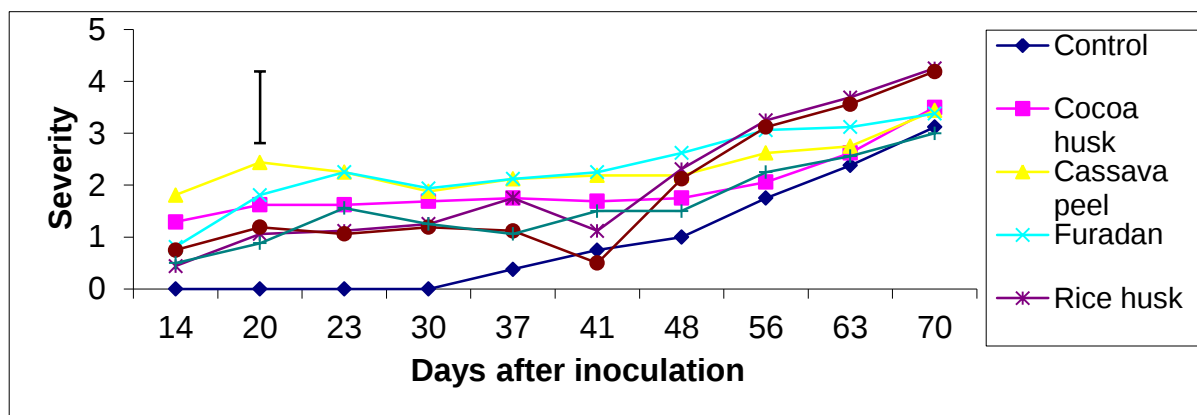


Fig 3: Effect of biochar on the severity of tomato inoculated with *Fusarium oxysporum f.sp radicis-lycopersici*

The results presented in Fig. 4 reveals that seedling emergence and establishment decreases with increase in DAI. It also showed in the overall that 60-80 % established seedlings were recorded from the biochar-treated tomato at 14 DAI. Siam weed (80 %), rice husk (82 %) was very similar to the untreated control 14 DAI

which were the least phytotoxic treatments, while cassava peels which recorded seedling emergence and establishment of about 45 % at 30 DAI was the most phytotoxic, while cocoa husk was a persistent treatment.

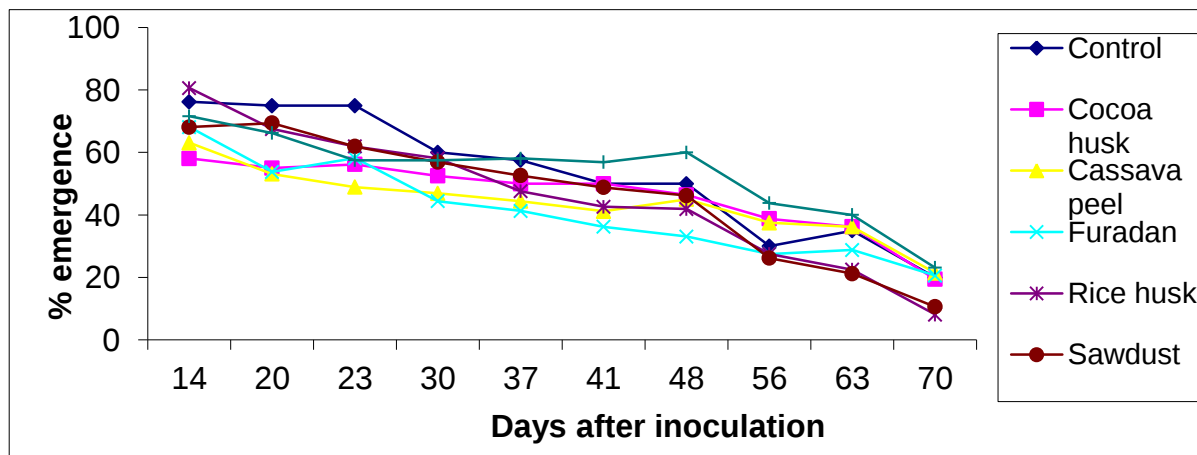


Fig 4: Effect of biochar on the % seedling emergence and establishment of the treated tomato seedlings

In terms of vine length, vine length of 13-18 cm was recorded on the treated crop on 14 DAI which remained somewhat unity with the exception of cassava peels till

30 DAI; comparing well with records obtained from the untreated (un-inoculated) control (Fig. 5).

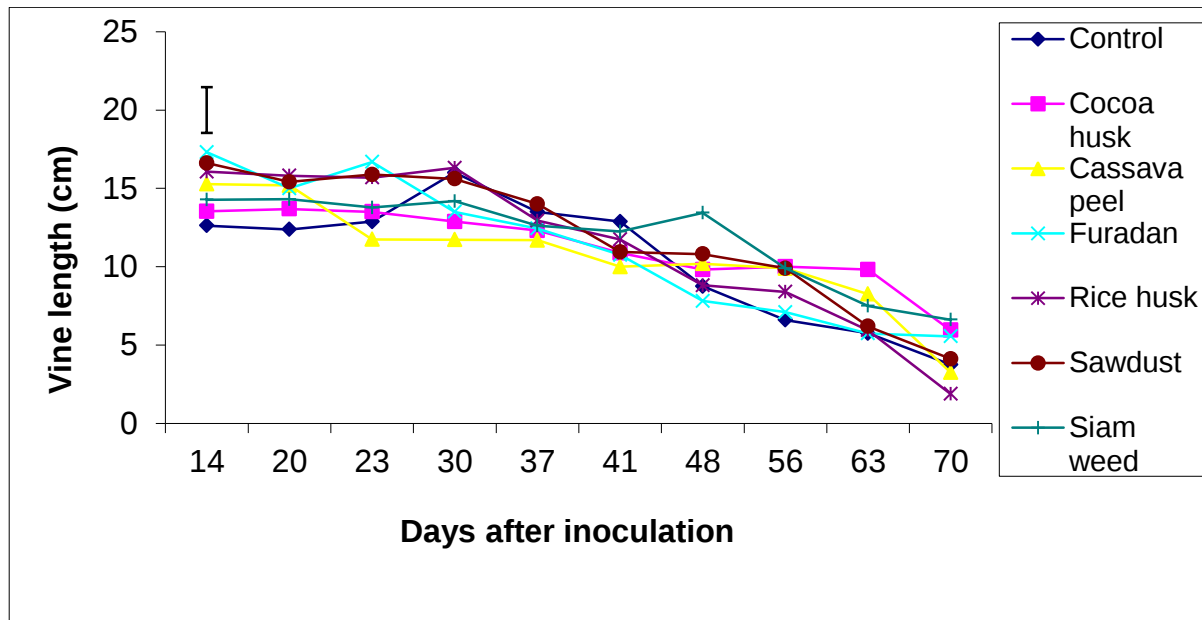


Fig 5: Effect of biochar on the vine length of tomato inoculated with *Fusarium oxysporum f.sp radicle-lycopersici*

Results presented in Fig. 6 showed that all the treatments improved the number of flowers per treated plant compared to the control with up to 12-14 flowers recorded on the furadan, siam weed and rice husk treated crop 41 DAI. However, these decreased to about

6-12 per plant with the exception of furadan which remained at about 13 flowers per plant on 56 DAI. The fluctuations in the number and high rate of flower abortion of the biochar treated crop may have directly translated to the low fruit yield observed in the study.

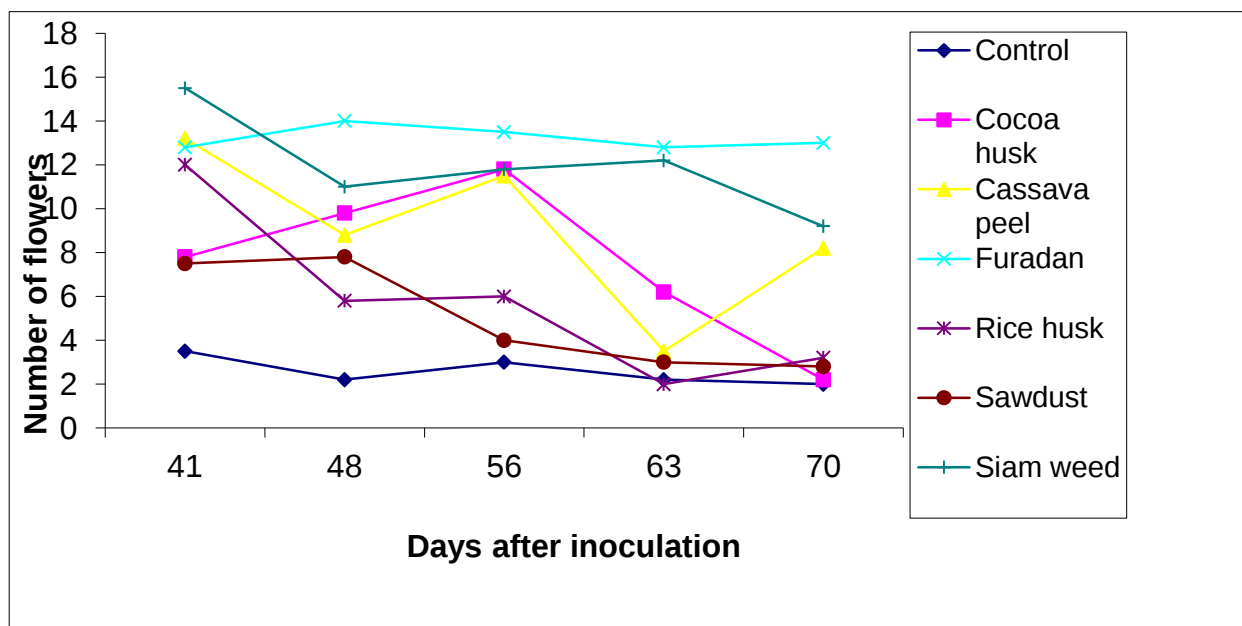


Fig 6: Effect of biochar on the number of flowers of tomato inoculated with *Fusarium oxysporum f.sp radicle-lycopersici*

DISCUSSION

The findings from the *in vitro* study showed that incorporation of biochars in the growth medium resulted

in variable and source-dependent toxicity and growth inhibition of *F. oxysporum f.sp radicle-lycopersici*. This therefore agrees with Jaisawal *et al.* (2015) who reported that biochar was directly toxic to *F. oxysporum*

f.sp radicle-lycopersici in biochar-modified media. Our findings further agree with the submission by Rogoska *et al.* (2016) that the fungitoxicity of biochars against *F. virguliforme* causing root rot disease of soybean was variable being affected by type of plant materials used in preparing the biochars.

Results from Fig. 3 showed that all the biochar treatments effectively and substantially reduced the % disease incidence on the treated tomato plants. This is congruent with the findings of Akher *et al.* (2016) who reported that garden waste-derived biochars and compost when used as soil amendments significantly decreased the populations of *F. oxysporum f.sp radicle-lycopersici* in the treated soil, as well as diminished the infectivity of the pathogen-induced wilt, chlorosis and other physiological aberrations on treated tomato plants.

Bonanomi, *et al.* (2015) from a study on the effect of biochar on 13 fungal pathosystems, reported that biochars effectively decreased the plant disease severity for up to 3-85 % on test crops. In a similar note, Akher *et al.* (2016) reported that garden waste-derived biochars strongly suppressed the incidence and severity of *Fusarium* crown and root rot of tomato caused by *F. oxysporum f.sp radicle-lycopersici* which translated to increased growth of the treated crop.

Results presented in Fig. 4 where the different biochars treatment of the inoculated tomato seedlings significantly reduced the severity of *Fusarium oxysporum f.sp radicle-lycopersici*-induced wilt disease of tomato agrees with the report of these workers.

Changes in soil properties, induction or stimulation of plant systemic resistance have been adduced as underlying the mechanisms of action of biochars against pathogenic fungi (Akher *et al.*, 2016; Rogoska *et al.*, 2016). However, Grabber, (2014) and Rogoska *et al.* (2016) were of the opinion that changes in soil microbial populations occasioned by release of toxic aromatic and organic compounds such as phenol, lactic acid, glycerol, hexadecanoic acid, butyric acids, and benzoic acid into the rhizosphere to the disfavour of the pathogenic fungus may participate in its fungitoxicity. On the other hand, rich supply of certain elements such as potassium and calcium which besides direct toxicity, are known to stimulate and encourage build up of strong structural integrity of plant cells necessary to ward off invading fungus to the tomato plant is a likely mechanism for the antifungal activity of biochars (Amadioha and Enyiukwu, 2019). These therefore may explain the higher fungitoxicity of biochars derived from rice husk, saw dust, siam weed over those from cocoa husks and cassava peels.

The result presented in Fig. 4 showed that there was up to 60-80% seedling germination and emergence 14 days DAI which however, decreased the crop establishment with increase in DAI. This on the one hand is in accord with the reports of Bargmann *et al.* (2013) that biochars

and hydrochars did not negatively affect the germination of spring barley. However, it is in disaccord with Enyiukwu and Ononuju (2016) who reported from a parallel study on legumes that seed treatments with certain phytochemicals derived from some tropical higher plants encouraged better seed germination and crop establishment.

Several workers had submitted that soil amendment using biochars against soil-borne pathogens substantially increased tomato vine length, crop water use efficiency, general crop performance, yield and yield attributes of the crops in the field (Akher *et al.*, 2014; Yilanga *et al.*, 2014). The findings in this trial where the various biochar sources used in the experiment enhanced the performance of the test tomatoes in terms of increased vine length and number of flower production agrees with their submissions. However, the low yield but high quality fruits (Plate 1E) recorded in this study may have been as a result of incessant torrential rainfall during the study and coincident with the fruiting period of the test crop which led to high rate of flower abortion.

CONCLUSION

This study therefore revealed that *Fusarium* crown and root rot (FCRR) disease of tomato caused by *F. oxysporum f.sp radicle-lycopersici* (FORL) could be effectively and sustainably managed with agro-waste derived biochars especially rice husk, saw dust and siam weed which compared very well in fungitoxicity with Furadan in low input farming systems of sub Saharan Africa to reduce the incidence and severity of the disease; so as to improve the performance of the crop in the field and increase its yield.

REFERENCES

- Abdel-Monaim, M. F. (2012). Induced Systemic Resistance in Tomato Plants Against *Fusarium* Wilt Disease. *Int. Res. Journal Microbiology* 3(1); 014-023.
- Akher, A., Hage-Ahmed, K., Soja, G. and Stein-Kelner, S. (2016). Potentials of *Fusarium* wilt inducing chlamydospores, in vitro behavior in root exudates and physiology of tomato in biochar and compost amended soil. *Plant and Soil* 406(1-2): 425-440.
- Akhtar, S. S., Li, G., Andersen, M. N. and Liu, F. (2014). Biochar enhances yield and quality of tomato under reduced irrigation. *Agric. Water Management* 138: 37-44.
- Amadioha, A. C. (2006). Fungitoxic effects of some leaves extracts against *Rhizopus oryzae* causing tuber rot of potato. *Arch. Phytopathol. plant protect.* 33:499-50.
- Amadioha, A. C. and Enyiukwu, D. N. (2019). Alterations of the biochemical composition of leaf and stem of

- cowpea (*Vigna unguiculata* L. Walp.) by *Colletotrichum destructivum* O'Gara in Nigeria. *J. Experimental Agric.Int.* 33(2): 001-007.
- Amini, J. (2009). Physiological Race of *Fusarium oxysporum* F. sp. *Lycopersici* in Kurdistan province of Iran and reaction of some tomato cultivars to race 1 of pathogen. *Plant Pathology Journal.* 8: 68-73.
- Amini, J. and Sidovich, D.F. (2010). The effects of fungicides on *Fusarium oxysporum* f. sp. *lycopersici* associated with Fusarium wilt of tomato. *Journal of Plant Protection Research* 50 (2), 175.
- AVRDC (2003). Asian Vegetable Research and Development Corporation, Progress Report. Variations of anti-oxidants and their activity in tomato. 70-115.
- Barnett, H.L. and B. B. Hunter, (2003). Illustrated genera of Imperfect fungi. 4th ed. Burgess Publishing Company Minneapolis 15, Minn.
- Besri, M. (2000). Tomatoes in Morocco: Integrated pest management and grafted plants. In: 'Case studies on environment impact'. UNEP, Division of technology, industry and economics, Ozone Action Programme, pp: 14-17.
- Bost, S. (2005). Plant Diseases - Tomato Wilt Problems. UT Extension – SP370-C. <http://www.utextension.utk.edu/>
- Di Primo, P. and G. Cartia, (2001). Solarizzazione e biofumigazione del terreno per il contenimento di *Fusarium oxysporum* f.sp. *melonis* su melon nel sud-Italia. Atti del Convegno ioTecnica alternative alla fumigazione dei terreni con bromuro di metile in fragola e ortive. Metaponto, 30 ottobre, 2001. *L'Informatore Agrario*, pp: 3-6.
- Dodson, M., Bachmann J. and Williams P. (2002). Organic greenhouse tomato production Horticulture Production Guide. Appropriate Technology Transfer for Rural Areas (ATTRA), the University of Arkansas in Fayetteville, AR. <http://attra.ncat.org/publication.html> [cited 10/08/2005].
- Elad, Y., Rav. David, D., Meller Harel, Y., Borenshtein, M., Ben Kalifa, H., Silber, A., Graber, E.R., (2010). Induction of systemic resistance in plants by biochar, a soil applied carbon sequestering agent. *Phytopathology* 100, 913-921.
- Elmer, W. H.; Pignatello, J. J. (2011). Effect of biochar amendments on mycorrhizal associations and Fusarium crown and root rot of asparagus in replant soils, *Plant Disease.* 95: pp.960–966.
- Enyiukwu, D. N. (2019). Nature's Pharmacy Vol. 1: A Focus on *Carica papaya* L. Lagos, Nigeria, GS Publications 64Pp
- Enyiukwu, D. N. and Ononuju, C. C. (2016). Comparative priming effects of phytochemicals from *Piper guineense* and *Alchornea cordifolia* on cowpea (*Vigna unguiculata* L. Walp.) seed. *J. Pest Plant Science* 3(1): 001-004.
- Graber, E. R.; Frenkel, O.; Jaiswal, A. K.; Elad, Y. (2014a). How may biochar influence severity of diseases caused by soil borne pathogens?, *Carbon Management* 5: 169–183.
- Hadian S, Rahnama K, Jamali J, Eskandari A (2011) Comparing neem extract with chemical control on *Fusarium oxysporum* and *Meloidogyne incognita* complex of tomato. *Advances in Environmental Biology* 5: 2052-2057.
- Jaiswal, A. K.; Elad, Y.; Graber, E. R.; Frenkel, O. (2014). *Rhizoctonia solani* suppression and plant growth promotion in cucumber as affected by biochar pyrolysis temperature, feedstock and concentration, *Soil Biology & Biochemistry* 69: 110–118.
- Kim J.T., Park I.H, Oung I.H., Yu S.H. (2001). Crown and root rot of greenhouse tomato caused by *Fusarium oxysporum* f. sp. *radicis-lycopersici* in Korea. *Plant Pathology Journal.* 17 (5): 290–294
- Lehmann, Johannes, and Jose Pereira da Silva Jr., Christoph Steiner, Thomas Nehls, Wolfgang Zech, & Bruno Glaser (2003). "Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments", 249 *Plant & Soil* ,pp343 – 355.
- Leslie, J. F. and Sumerell, B. A. (2006): *Fusarium – Laboratory manual*. Blackwell Publishing Ltd, UK, 387 pp.
- Maranzu, J. O. (2011). Control of wilting in eggplant caused by *Fusarium oxyporum* using some agro-waste products for amendment. A thesis submitted to the Department of Plant Health Management, Michael Okpara University of Agriculture, Umudike, September, 2011.
- Mardi M., Pazouki L., Delavar H., Kazemi M.B., Ghareyazie B., Steiner B., Nolz R., Lemmens M. and Buerstmayr H. (2006). QTL analysis of resistance to Fusarium head blight in wheat using a 'Frontana'-derived population. *Plant Breeding.* 125: 313–317.
- Peralta DI, Iris E, Spooner GC, David M. (2001). "Granule-bound starch synthase (GBSSI) gene phylogeny of wild tomatoes (*Solanum* L. section *Lycopersicon* [Mill.Wettst.subsection *Lycopersicon*)". *American Journal on Botany.* 88 (10): 1888–1902.
- Pritesh, P. and Subramanian, R.B. (2011). PCR based method for testing Fusarium wilt resistance of Tomato. *African Journal of Basic and Applied Sciences* 3 (5), 222.
- Robert, R.W. (2005). Growing tomatoes. University of Georgia College of Agricultural and Environmental Sciences. Bulletin 1271.
- Ron, E. Z., Rosenberg, E. (2001). Natural roles of biosurfactants. *Environmental Microbiology* 3, 229e236.
- Rogoska, N., Liard, D., Leandro, L. and Aller, D. (2016). Biochar effects on severity of soybean root rot disease caused by *Fusarium virguliforme*. *Plant and Soil* 413(1-2): 111-116
- Samonin, V.V., Elikova, E.E. (2004). A study of the adsorption of bacterial cells on porous materials. *Microbiology* 73, 696e701.

- Sheu, Z.M. and Wang, T.C. (2006). First Report of Race 2 of *Fusarium oxysporum* f. sp. *lycopersici*, the causal agent of Fusarium wilt on Tomato in Taiwan. *The American Phytopathological Society* Vol.90, No.111.
- Silber, A.; Levkovitch, I.; Graber, E. R. (2010). "pH dependent mineral release and surface properties of corn straw biochar: Agronomic implications". *Environmental Science & Technology*. 44: 9318–9323.
- Ślusarski C. (2000). Choroby odglebowe pomidorów (cz. II). W bezglebowej uprawie pod osłonami. *Hasło Ogródnicze* 2: 46–49.
- Steiner, C., Teixeira, W. G., Lehmann, J., Zech, W. (2004). Microbial response to charcoal amendments of highly weathered soils and Amazonian Dark Earths in Central Amazonia e preliminary results. In: Glaser, B., Woods, W.I. (Eds.), *Amazonian Dark Earths: Explorations in Time and Space*. Springer, Berlin, Germany, pp. 195e212.
- Steinkellner S., Mammertler R., Vierheilig H. (2005). Microconidia germination of the tomato pathogen *Fusarium oxysporum* in the presence of root exudates. *Journal of Plant Interaction*. 1 (1): 23–30.
- Szczuchura W. Stanlaszek M, Habdas H (2013). *Fusarium oxysporum* f. sp. *radicis* – *lycopersici* – the cause of Fusarium crown and root rot in tomato cultivation. *Journal of Plant Protection and Resources*. 53:2.
- Thangavelu R., Palaniswami, A. and Velazhahan, R. (2003). Mass production of *Trichoderma harzianum* for managing Fusarium wilt of banana. *Agricultural Ecosystem and Environment*, 103, pp 259-263.
- Waiganjo, M. M., Wabule, N. M., Nyongesa, D., Kibaki, J. M., Onyango, I., Webukhulu, S. B. and Muthoka, N.M. (2006). Tomato production in Kiriyaanga District, Kenya. A baseline survey report. KARI/IPM-CRSP Collaborative project.
- Wokocha, R. C. and Opara, F., (2004). Fungi associated with Tomato wilt in the tropical Humid lowlands of South Eastern Nigeria and Preliminary Evaluation for Disease Tolerance in the crop. *Global Journal of Agricultural Sciences* 3 (1&2): 59-62.
- Yilanga, M. R., Manu, A. S., Pinean, W., Mailumo, S. S. Okeke-Agulu, K. I. (2014). The effects of biochar on the growth and yield of tomato (*Lycopersicum esculenta* Mill) in Jos, North central Nigeria. *Curr. Agric. Res.* 2(1); 815: doi;http://dx.doi.org/10.12944/CARJ.2.1.05
- Zimmerman, A. R. (2010). Abiotic and microbial oxidation of laboratory produced black carbon (biochar). *Environ. Sci. Technol.* 44: 1295–1301.

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