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RESEARCH ARTICLE

Effects of Date Palm Biochar on Growth, Yield and Photosynthetic Capacity of Cucumber (*Cucumis sativus* L.) Under Glasshouse Conditions

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ABSTRACT

The vast tree trash from date palm is generally burnt or dumped. However, recycling date palm biomass has attained great attention in recent years. The present study was, therefore, designed to produce biochar through pyrolysis using leaf and stem feedstocks of date palm and to find out its suitability as a soil conditioner under glasshouse conditions. The pot experiment was laid out according to a completely randomized design having three soil media (1) sandy loam soil, (2) sandy loam soil + 2.5% date palm leaf biochar and (3) sandy loam soil + 2.5% date palm stem biochar with five replicates in each treatment. The recommended dose of NPK (300:130:270 kg. ha^{-1}) was applied to all replicates. Results showed that the date palm leaf and stem biochar significantly ($P \leq 0.05$) improved cucumber vine length, stem diameter, leaf number, leaf area, number of fruits per vine, fruit length, fruit diameter, fruit volume, fruit fresh and dry weight, stem dry weight, leaf fresh and dry weight, fruit circumference, fruit surface area and yield per plant, fruit pH, total soluble solids, intercepted radiation, chlorophyll content, net photosynthesis, stomatal conductance, transpiration rate and water use efficiency. While the intercellular CO_2 concentration was reduced with leaf and stem biochar treatments. However, there was a non-significant response of cucumber plants to any of the treatments regarding plant spread, leaf area index, days to flower, fruit setting, fruit maturity, stem fresh weight and fruit, stem, leaf and whole plant moisture content. In conclusion, the application of 2.5% of leaf and stem biochar mixed with sandy loam soil medium is recommended to get improved soil water holding capacity, plant growth, plant yield and physiological traits of cucumber under glasshouse conditions.

INTRODUCTION

Date palm is grown on 1.34 million hectares and produced 8.17 million tonnes of fruit across the globe (FAOSTAT, 2017). There are more than 84 million date trees in the Arab world including Saudi Arabia, Egypt, Iran, Algeria, Iraq, Morocco, Tunisia and UAE (Abd-Rabou and Radwan, 2017). Saudi Arabia has more than 23 million date trees, which produce about one million tons of dates annually (Al-Abdoulhadi et al., 2011). The agricultural wastes such as dry leaves, seeds, stems, fruit bunches, leaf sheath are hugely produced by date palm trees. It is estimated that a typical palm can produce about 20 kg of dry leaves annually excluding 10% waste from date seeds. Some studies reported that Saudi Arabia alone generates more than 200,000 tons of date palm waste annually (Hussain et al., 2014). Generally, the date palm wastes are burnt or buried in landfills, which directly or indirectly pollute the environment. A small quantity of date palm biomass is used in making animal feed or compost or used as raw material for the industries such as for the production of pulp and paper, particle boards and lumber-like products (Ghosh and Nag, 2009; Mansur, 2010). Therefore, date palm waste is considered a renewable natural resource (Zafar, 2018).

Chemical analysis of date palm biomass showed that it contains cellulose, hemicelluloses, lignin, volatile solids and low moisture content (Nasser et al., 2016). These characteristics make date biomass the best recycle material in date palm growing regions. Therefore, many thermal and biochemical technologies emerge to convert the energy accumulated in date palm biomass into useful forms of energy (Balat, 2006). Date palm wastes contained low moisture content that makes them suitable for thermochemical conversion technologies such as pyrolysis, gasification and combustion, which produced biochar, steam, syngas and biofuel (Anonymous, 2013; Tanger et al., 2013; Demirbas, 2017; Choong et al., 2018). Biochar produced from pyrolysis of plant biomass such as date palm, rice husk, wheat straw etc. is a solid, stable, black and carbon-rich material. It is a soil carbon sequester for a substantial length of time (Smith, 2016). The application of biochar in agriculture to improve soil quality and water conservation is advocated in many agronomic studies. Paetsch et al. (2018) determined maximum soil organic carbon mineralization, soil water holding capacity, carbon use efficiency and native substrate availability using biochar. Bonanomi et al. (2018) reported that biochar promoted plant growth and inhibited microbial growth. Kumar et al. (2018) stated that the addition of biochar to zinc contaminated soils could immobilize excess Zn and promote plant growth. In pesticides (Aldrin or dieldrin) contaminated soils, biochar did not allow the toxic compounds to pass on to the cucumber fruits (Saito et al., 2012). Kang et al. (2018) reported that soils treated with biochar alone and in combination with NPK fertilizers lowered bulk density and higher porosity than those in the control treatment. Similarly, after the addition of biochar, soil chemical properties such as pH, total nitrogen, available phosphorus and potassium, and CEC were also improved. The results obtained by Ghorbani and Amirahmadi (2018) showed that rice husk biochar had a significant increase in acidic soil pH, organic carbon content, EC, soluble, exchangeable and non-exchangeable potassium. Lima et al. (2018) reported that water use efficiency, specific surface area, nutrient and water retention properties of biochar amended soil and maize growth were significantly improved.

Cucumber is one of the most important salad vegetables in the world. It is cultivated on 3.51 million ha and produce 148.60 million tonnes of fruit across the globe (FAOSTAT, 2017). The rising demand of the crop is due to the awareness of its health benefits. Various scientific approaches adopted to sustain and enhance the availability of the crop. Cucumber is the second largest vegetable crop after tomato cultivated in glasshouse in Saudi Arabia, which has arid and semi-arid climate with infrequent rainfall (Fiaz et al., 2018). Therefore, it is necessary to use innovative techniques in crop production not only to save water, but also to enhance productivity. Soil amendment is one of the techniques to improve soil quality resulting in better conditions for water conservation, root development and soil ecosystems. For that purpose, various organic materials are used including biochar (Deem and Crow, 2017). Keeping in view the properties and benefit of biochar, a study was designed to convert date palm wasted biomass such as leaf and stem to a value-added product (biochar). The main aims of the study were to produce biochar from date palm waste material and to assess its physicochemical properties, role in soil water retention and suitability to amend sandy soil for cucumber cultivation.

MATERIALS AND METHODS

Experimental site

The research was conducted at Training and Research Station, King Faisal University, Al-Ahsa, Kingdom of Saudi Arabia (Latitude 25° 16' 24.4524" N and Longitude 49° 42' 28.5948" E) during 2017-2018, to study the effects of different soil amendments of biochar, produced from date palm waste (leaf and stem) on growth and development of cucumber crop.

Biochar production

In this study, the pyrolysis technique was adopted to produce biochar from date palm residues. For that purpose, the department of ‘Advanced Precision Technologies for Date Palm’ Date Palm Research Center of Excellence, King Faisal University built a prototype furnace, as shown in Fig. 1. The biochar furnace has consisted of 1) A cylindrical waste processing chamber/drum with a diameter of 78 cm and a length of 81 cm) made from galvanized steel sheets with a thickness of 0.15 cm, 2) A-frame constructed with dimensions of 121 × 111 × 121 cm for length, width, and height, respectively, made from square shape steel (0.04 × 0.04 m) welded together to hold the processing chamber/drum and for installing the furnace cover on it, 3) Fire system which consisted of tubes and its accessories, and 4) Control system to control the temperature in the processing chamber/drum. The furnace has a gate to date palm waste entry and the exit of the biochar after production. The furnace was loaded from the top and unloaded from the bottom by rotating the processing chamber/drum towards the bottom. The furnace was needed electricity only for the controlling system. The time of batch-processed was depending on the size and moisture content of the wasted biomass. The maximum load capacity of the processing chamber/drum was 0.27 m^3 of the date palm waste. This capacity can produce 50 to 80 kg of biochar based on the waste density. The furnace was tested for all safety standards.

The wasted residue of date palm leaf and stem was collected from orchard No. 1 of Date Palm Research Center of Excellence (Latitude 25° 16' 05.6" N and Longitude 49° 42' 30.5" E). The wasted material was chopped into 5 cm pieces with an electric chipper. The material was dried for 24 h in the oven at 60 °C before pyrolysis. Fifty kilograms of each date palm wasted material was pyrolysed at 300 °C for 2 h, using a gas-fired furnace, which yielded 20 kg (40%) of biochar. The carbonised material was allowed to cool at room temperature, which was ground using 2 mm stainless steel sieve and was stored in sealed plastic bags at room temperature until used.

Soil and biochar analysis

To determine the physico-chemical properties of sandy loam soil, composite soil samples were taken before seeds sowing and were analyzed (Homer and Pratt, 1961). The sandy loam soil had organic matter 0.02%, total nitrogen 0.05%, phosphorus 1.32 ppm, exchangeable potassium 190 ppm, calcium 2.10 $mEq.L^{-1}$, magnesium 0.70 $mEq.L^{-1}$, sulphate 0.99 $mEq.L^{-1}$, sodium 0.37 $mEq.L^{-1}$, chlorine 1.33 $mEq.L^{-1}$, copper 0.025 ppm, iron 0.419 ppm, manganese 0.329 ppm, zinc 0.20 ppm, sodium adsorption ratio 0.312 $mEq.L^{-1}$, bicarbonate 1.18 $mEq.L^{-1}$, and calcium carbonate 7.35 $mEq.L^{-1}$. Leaf biochar properties recorded were; dry matter (94.7%), total nitrogen (5.43 $kg.t^{-1}$), available N (240 $mg.kg^{-1}$), phosphorus (1.56 $kg.t^{-1}$), potassium (23.14 $kg.t^{-1}$), magnesium (6.84 $kg.t^{-1}$), calcium (20.47 $kg.t^{-1}$), sulphur (5.37 $kg.t^{-1}$), zinc (70.14 $mg.kg^{-1}$), copper (5.04 $mg.kg^{-1}$), molybdenum (1.01 $mg.kg^{-1}$), nickel (3.01 $mg.kg^{-1}$), sodium (5.07 $kg.t^{-1}$), pH 7.5, EC (3.44 $mmhos.cm^{-1}$), and NV 5.1%. Similarly, the analysis of stem biochar indicated dry matter (92.2%), total nitrogen (4.41 $kg.t^{-1}$), available N (213 $mg.kg^{-1}$), phosphorus (1.03 $kg.t^{-1}$), potassium (18.45 $kg.t^{-1}$), magnesium (6.35 $kg.t^{-1}$), calcium (17.24 $kg.t^{-1}$), sulphur (4.14 $kg.t^{-1}$), zinc (85.27 $mg.kg^{-1}$), copper (2.42 $mg.kg^{-1}$), molybdenum (0.91 $mg.kg^{-1}$), nickel (3.35 $mg.kg^{-1}$), sodium (5.31 $kg.t^{-1}$), pH 7.7, EC (3.47 $mmhos.cm^{-1}$), and NV 4.5%.

The physical characteristics of pot media (sandy loam soil, date palm leaf and stem biochar) were determined by standard laboratory method (Table 1). The pH was measured in a 1:10 suspension ratio of sand/biochar to distilled water using pH meter (HI-99121, Hanna Instruments, UK) (Sun et al., 2014). The EC value was measured in a 1:10 extract of sand/biochar to distilled water using portable electric conductivity meter (470, Jenway, UK) (Yang et al., 2016). The moisture content was determined by heating 5 g sample at 105 °C in the oven (Model ED-260, Binder, Germany) for 24 h. Bulk density was determined by the gravimetric method from oven-dried samples using pycnometer. Solid space was calculated by bulk density divided by particle density multiplied by 100. Total porosity was calculated from particle density and bulk density of the samples. Water holding capacity (WHC) were measured as described by Péron et al. (2007). Each sample was saturated with slowly applied water to each container, while gently whisking, until excess water was observed. The contents were then allowed to settle for 24 h to assure homogeneity of water content throughout the sample. The mixtures were drained by gravity for another 24 h through a Whatman CFP4 qualitative filter paper. Each sample was weighed using a three decimals digital balance to determine wet mass. The samples were then dried at 105 °C for 24 h in an oven and remassed to determine the dry mass. The results yielded the amount of water being held by each sample. The hydraulic conductivity was measured using K_{sat} Saturated Hydraulic Conductivity Apparatus (Meter Environment, USA).

Glasshouse condition

Temperature, relative humidity and light data loggers (Hobo U12-006, Onset, USA) were installed at 1.5 m height inside glasshouse. Mean diurnal temperature (25.24 °C), relative humidity (56.01%), and solar radiation (432 $W.m^{-2}$) were recorded throughout the growing season whereas intercepted radiation was measured using TES-1333R datalogging solar power digital meter (TES Electrical Electronic Corporation, Taiwan).

Crop husbandry

One hundred seeds of cucumber cultivar ‘Marketmore’ were obtained from Marshalls Seeds Co., Cambridgeshire, UK and were soaked in water for half an hour and were sown in modular trays containing peat based seed compost and were placed in the climatic cabinet (Microclima 1000, Snijders Scientific B.V. Tilburg, Holland) at 25 °C temperature, 60% relative humidity and 16 h photoperiod. After two true leave emergence, the seedlings were transferred into pots (26 cm diameter, 10 litres volume). Three seedlings were planted into a single pot and there were five pots for each treatment. After one week, the healthy and well-established single seedling in each pot was left to grow while the rest were thinned out. Standard field soil medium (sandy loam) was used in all pots alone or in combinations with leaf and stem biochar (2.5%). Pots were irrigated immediately after seedlings transplantation. All doses of phosphorus (130 $kg.ha^{-1}$) and potassium (270 $kg.ha^{-1}$) were mixed with the media at pot filling time. However, nitrogen (300 $kg.ha^{-1}$) was applied in two splits i.e. (1) 150 $kg.ha^{-1}$ at transplantation time and (2) 150 $kg.ha^{-1}$ after one month of transplantation. All cultural practices were followed accordingly.

Plant growth parameters studied

Plant growth variables were recorded at harvest time by standard laboratory procedures. The vine length, (cm) stem diameter (mm), fruit length (cm), and fruit diameter (mm) were measured by digital Vernier calliper. Plant spread (cm) was measured by laser distance measuring tool (GLM 50 C, Bosch, USA).

Table 1: Media properties of sandy loam soil, date palm leaf and stem biochar.

Treatments	pH	EC $dS.m^{-1}$	Moisture content (%)	Bulk density ($g.cm^{-3}$)	Solid space (%)	Porosity (%)	WHC (%)	Hydraulic conductivity (K_S $cm.d^{-1}$)
Sandy loam	7.18^c	2.51^b	0.34^b	1.64^a	61.95^a	38.05^b	26^b	789^a
Leaf biochar	7.91^b	2.87^a	1.76^a	0.62^b	19.66^b	80.40^a	41^a	203^b
Stem biochar	8.39^a	2.93^a	1.64^a	0.64^b	20.09^b	80.04^a	37^a	215^b
$LSD_{(5\%)}$	0.25	0.15	0.18	0.09	1.57	2.08	6.54	30.08

Means followed by similar letters in a column are non-significant at 5% level of probability

Days taken to flowering were recorded at fully opening of corolla of first flower and the days taken to fruit setting were noted when the corolla were dried and rudimentary fruit was visible. Days to fruit maturity, number of fruits per vine, and leaf number were counted from transplanting date to harvest. Leaf area (cm^2) was estimated using Leaf area meter (ADC BioScientific Ltd., UK) and then the leaf area index was calculated using plant spread and leaf area data. Fruit volume (ml) was calculated by xylometric method. In this method, the cucumber was submerged in a graduated container contained water and the displaced water was measured (Concha-Meyer et al., 2018). Fruit circumference (mm) and fruit surface area (cm) were calculated using 2π*radius and $\pi \times$ diameter $\times$ (diameter/2+height) formulae, respectively. Fruit yield per plant (g), fruit fresh and dry weight (g), stem fresh and dry weight (g), leaf fresh and dry weight (g) were measured by Sartorius electric balance. Fruit, stem and leaf dry weight (g) and moisture content (%) were estimated by putting the respective biomass in an oven at 80 °C for 72 h (Model ED-260, Binder, Germany). Fruit pH and total soluble solids were recorded by pH meter (HI-99121, Hanna Instruments, UK) and digital refractometer (HI96801, Hanna Instruments, UK). Thirty days after transplantation, the photosynthetic and allied parameters (net photosynthesis, stomatal conductance, intercellular CO_2 concentration, and transpiration rate) of fully expanded middle leaves were measured at 11 o'clock morning using Li-6400XT portable photosynthesis system (LiCor Inc., USA). The reference and sample CO_2 of Infra-Red Gas Analyser was set at 380 $\mu mol.m^2.s^{-1}$ with an airflow of 500 $mL.min^{-1}$ and photosynthetically active radiation at 548 $\mu mol.s^{-1}.m^{-2}$. The chlorophyll content was determined by SPAD 502Plus chlorophyll meter (Konica Minolta, Japan).

Experimental treatments and statistical design

Three soil media i.e. (T_1) Sandy loam soil alone (control), (T_2) Sandy loam soil + 2.5% date palm leaf biochar and (T_3) Sandy loam soil + 2.5% date palm leaf biochar were used. The experiment was laid out according to completely randomized design having five replications for each treatment. The recorded data was analysed statistically using one-way analysis on variance (ANOVA) technique to assess the significant difference between treatments regarding soil and plant growth and yield parameters. The computer software GenStat version 18 (VSN International Ltd, Hemel Hempstead, UK) was used for the data analysis. Mean separation was done using Least Significant Difference (LSD) test after the treatments were found significant at 5% probability level.

RESULTS

Data in Table 1 revealed that there was a significant ($P\leq0.05$) difference among means of sandy loam control, leaf and stem biochar media regarding pH, EC, moisture content, bulk density, solid space, porosity, water holding capacity and hydraulic conductivity. All three media had alkaline nature i.e. pH 7.18 (sandy loam), 7.91 (leaf biochar) and 8.39 (stem biochar). Electric conductivity was higher in stem (2.93 $dS.m^{-1}$) and leaf (2.87 $dS.m^{-1}$) as compared to sandy loam medium alone (2.51 $dS.m^{-1}$). Similarly, leaf and stem biochar have 80 and 76% more moisture content than sandy loam control. Due to small particle size, the bulk density and solid space of leaf and stem biochar media was lower as compared to sandy loam medium. Similarly, their porosity percentage was higher, which was significantly lower in sandy loam medium. On the other hand, leaf and stem biochar have 37% and 30% more water holding capacity than sandy loam control, whereas the hydraulic conductivity was 74% and 72% lower in leaf and stem biochar when compared to sandy loam control.

Fig. 2 indicated a significant ($P\leq0.05$) difference among means of sandy loam control, leaf and stem biochar media regarding vine length (Fig. 2a), stem diameter (Fig. 2b), leaf number (Fig. 2c) and leaf area (Fig. 2d), however, leaf area index (Fig. 2e) and plant spread (Fig. 2f) were non-significant statistically. Cucumber plants grown in leaf biochar medium produced maximum vine length (163.40 cm), stem diameter (12.13 mm), leaf number (61.60) and leaf area (88.27 cm^2), which were statistically at par with stem biochar medium. However, plant in control produced minimum vine length (155.40 cm), stem diameter (8.80 mm), leaf number (53.80) and leaf area (74.66 cm^2). Regarding other non-significant variables, maximum plant spread (55.40 cm) and leaf area index (1.60) were recorded in plants grown in leaf biochar. Figure 3 showed that the days taken to flowering (Fig. 3a), fruit setting (Fig. 3b) and maturity (Fig. 3c) were non-significant whereas number of fruits per vine (Fig. 3d), fruit length (Fig. 3e), fruit diameter (Fig. 3f), fruit volume (Fig. 3g) and yield per plant (Fig. 3h) were significantly affected by different media.

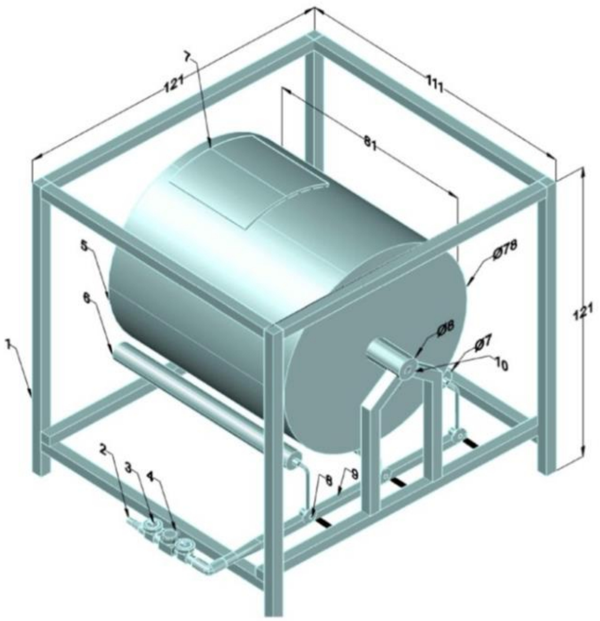

Fig. 1: Schematic diagram of the designed furnace prototype to produce biochar from date palm waste. (1) Frame, (2) Gas inlet pipe, (3) Pressure gauge, (4) Pressure regulator, (5) biochar processing chamber/drum (78 cm diameter, 81 cm length), (6) Fire tube (5 cm diameter, 80 cm length), (7) Door of the chamber/drum to put in date palm waste and to take out biochar, (8) Control valve of the gas supply, (9) Gas distribution tube, and (10) Holder with rotation axis for the processing chamber/drum.

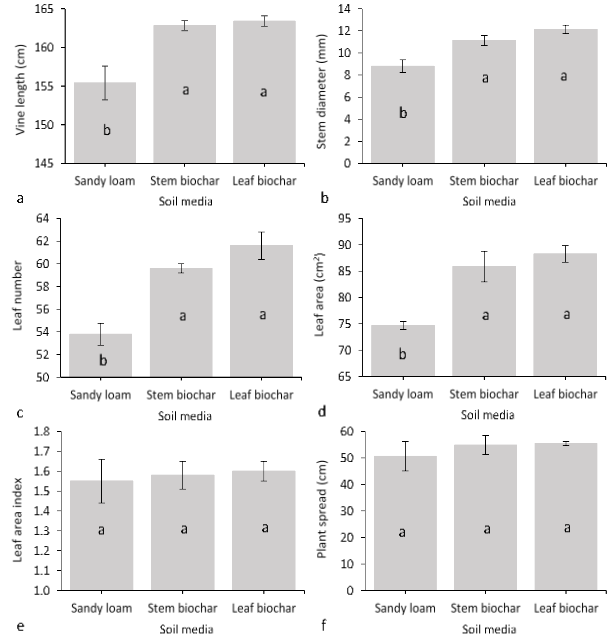

Fig. 2: Effect of sandy loam soil alone and in combination with date palm leaf and stem biochar on (a) vine length (cm), (b) stem diameter (mm), (c) leaf number, (d) leaf area (cm^2), (e) leaf area index, and (f) plant spread (mm) of cucumber cv. Marketmore. Same letters in a graph are not significant at 5% probability. Y-bars indicate the variation within replicates.

Maximum days to flower (27.80), days to fruit setting (31.20) and days to maturity (55) were recorded in stem biochar treatment. Similarly, plants grown in sandy loam soil medium incorporated with leaf biochar produced maximum number of fruits per vine (11.80), fruit length (16.24 cm), fruit diameter (35.15 mm), fruit volume (137.40 ml), and yield per plant (1773.30 g).

Data presented in Figure 4 depicted that apart from stem fresh weight (Fig. 4c) all other parameters such as fruit fresh (Fig. 4a) and dry weight (Fig. 4b), stem dry weight (Fig. 4d), leaf fresh (Fig. 4e) and dry weight (Fig. 4f) were significantly varied. Highest fruit fresh weight (150.02 g), fruit dry weight (19.22 g), stem fresh weight (165.19 g), stem dry weight (26.19 g), leaf fresh weight (132.92 g), and leaf dry weight (30.17 g) were recorded in leaf biochar amended medium, which was closely followed by stem biochar medium. Fig. 5 indicated that fruit circumference (Fig. 5a), fruit surface area (Fig. 5b), fruit pH (Fig. 5c), and total soluble solids (Fig. 5d) were significantly affected by different soil media. However, fruit (Fig. 5e), stem (Fig. 5f), leaf (Fig. 5g) and plant (Fig. 5h) moisture content were non-significant statistically. Maximum fruit circumference (110.38 mm), fruit surface area (179.37 cm), total soluble solids (3.75 Brix) were recorded in fruits obtained from leaf biochar medium whereas fruit pH was higher (7.88) in plants grown in stem biochar medium. All these variables were minimal when plants were raised in sandy loam control medium. Although the moisture content of the fruit, stem, leaf, and plant was non-significant, it was higher in plants grown in control medium.

Data regarding intercepted radiation (Fig. 6a), chlorophyll content (Fig. 6b), net photosynthesis (Fig. 6c), stomatal conductance (Fig. 6d), intercellular CO_2 concentration (Fig. 6e), transpiration rate (Fig. 6f), and water use efficiency (Fig. 6g) are shown in Figure 6, which indicated a significant variation between means of different treatments. Highest intercepted radiation (85.03%), chlorophyll content (36.83 SPAD), net photosynthesis (15.05 $\mu mol.m^{-2}.s^{-1}$), stomatal conductance (0.18 $mol.m^{-2}.s^{-1}$), transpiration rate (3.17 $mmol.m^{-2}.s^{-1}$), and water use efficiency (5.07) were recorded in leaf biochar treated plants, whereas intercellular CO_2 concentration (178.54 $\mu mol.mol^{-1}$) was minimum in plants grown in the same medium. These parameters were statistically at par with stem biochar medium. Data regarding these parameters were significantly minimal when plants were grown in control (sandy loam soil) medium.

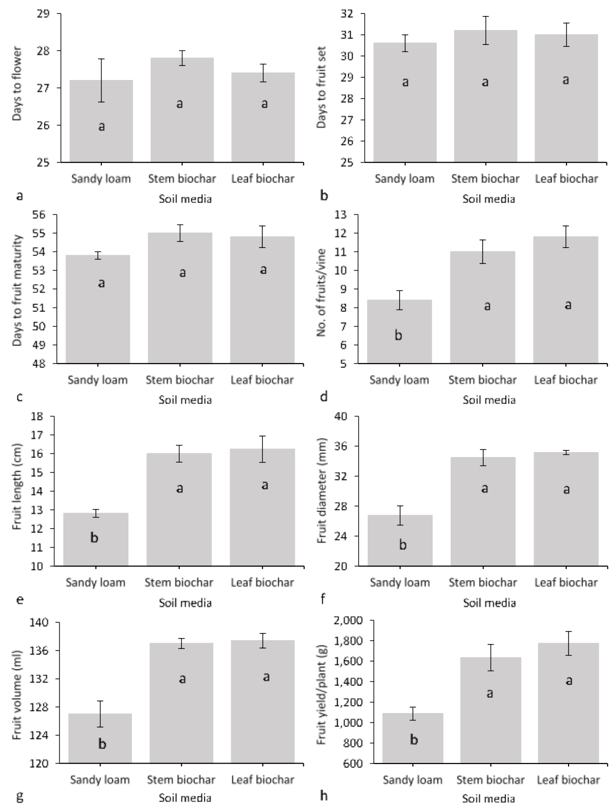

Fig. 3: Effect of sandy loam soil alone and in combination with date palm leaf and stem biochar on (a) days to flower, (b) days to fruit set, (c) days to maturity, (d) No. of fruits/vine, (e) fruit length (cm), (f) fruit diameter (mm), (g) fruit volume (ml) and (h) fruit yield/plant (g) of cucumber cv. Marketmore. Same letters in a graph are not significant at 5% probability. Y-bars indicate the variation within replicates.

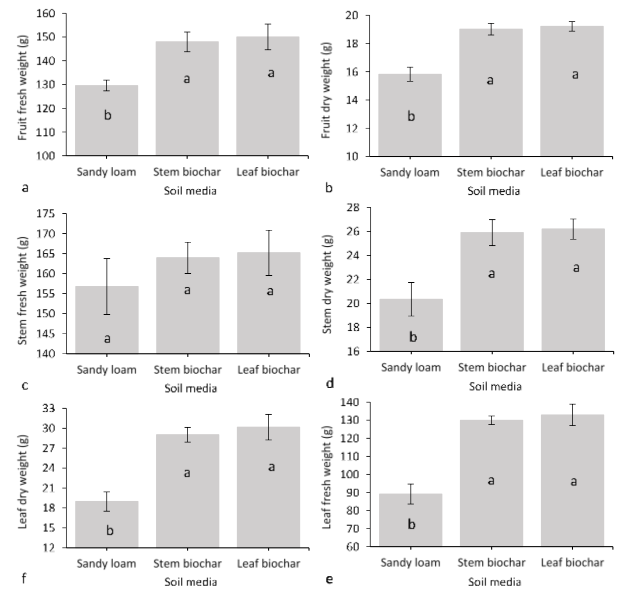

Fig. 4: Effect of sandy loam soil alone and in combination with date palm leaf and stem biochar on (a) fruit fresh and (b) dry weight (g), (c) stem fresh and (d) dry weight (g), and (e) leaf fresh and (f) dry weight (g) of cucumber cv. Marketmore. Same letters in a graph are not significant at 5% probability. Y-bars indicate the variation within replicates.

DISCUSSION

Recycling of plant biomass is a green practice that turned the waste material into usable one (Cigolotti, 2012). In present study, the date palm biomass that comes from pruning (leaf) and dead stubbles (stem) had taken into account to reuse them as useful material. After building a prototype oven, date palm leaf and stem waste was turned into biochar, which was used in pots to grow cucumber and to study its agronomic suitability for the growth and production of cucumber but also for the purpose of water conservation. The improvement of soil physical and chemical properties by applying biochar has been recommended in previous research studies (Chan et al., 2007; Jien and Wang, 2013). In present research, it was found that although leaf and stem biochar had slightly pH (alkaline) however it had lower bulk density, higher moisture content, higher water holding capacity and lower hydraulic conductivity, which not only improved soil physico-chemical properties but also enhanced crop growth. The increased bulk density leads to soil compaction that reduces air volume, which creates unfavourable growing conditions for roots. Due to it, water and nutrients are not translocated to the areal part of the plants and plant growth is negatively affected. Therefore, in present study, the decreased bulk density by using leaf or stem biochar increased media porosity that improved soil water holding capacity and nutrient uptake. Reduction in soil bulk density by the addition of leaf and stem biochar in the present study is agreed with the previous report (Nelissen et al. 2015), who reported that biochar addition into the soil medium reduced bulk density that correspondingly increased total porosity of soil. In another study on garden pea, application of biochar showed highly significant effects on bulk density and particle density (Bhattarai et al., 2015). Our results are also in line with Chen et al., (2011) who stated that the soil had apparent improvement in its physical and chemical properties when it was amended with biochar. It could be due to the reason that biochar effectively maintain soil organic matter, soil aggregation stability and increase fertilizer-use efficiency (Jien and Wang, 2013). Our findings showed also that biochar derived from leaf and stem waste at 300 °C had 52% higher porosity than the sandy loam soil medium. Batista et al. (2018) obtained higher porosity (≤10 μm) from sugar cane bagasse, orange peel,

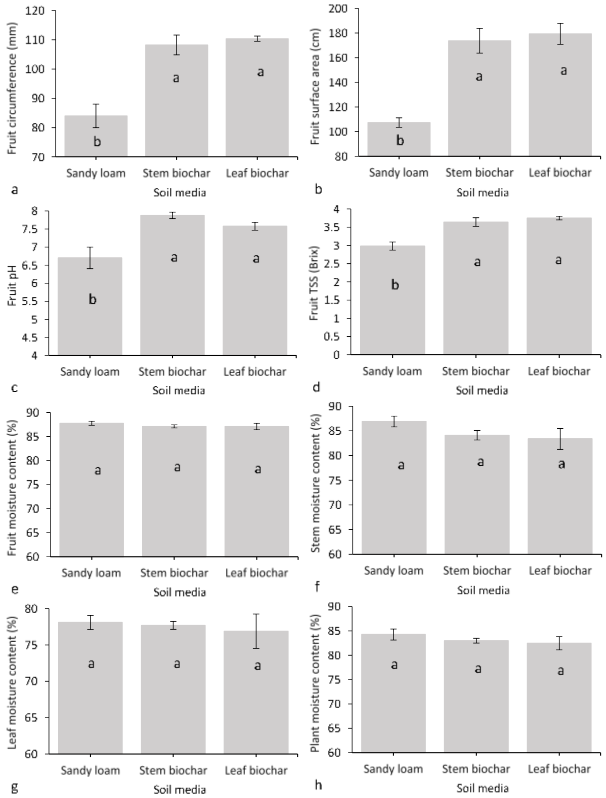

Fig. 5: Effect of sandy loam soil alone and in combination with date palm leaf and stem biochar on (a) fruit circumference (mm), (b) fruit surface area (cm), (c) fruit pH, and (d) fruit TSS (brix), (e) fruit, (f) stem, (g) leaf and (h) plant moisture content (%) of cucumber cv. Marketmore. Same letters in a graph are not significant at 5% probability. Y-bars indicate the variation within replicates.

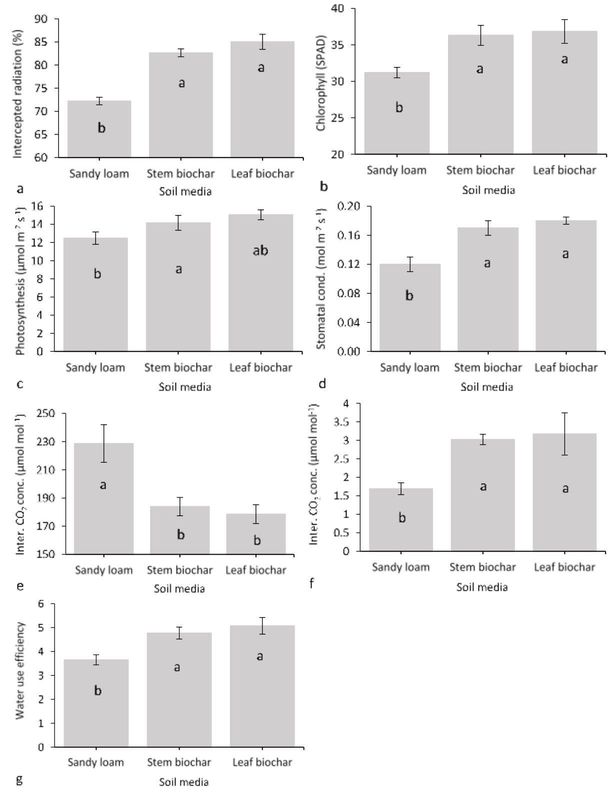

Fig. 6: Effect of sandy loam soil alone and in combination with date palm leaf and stem biochar on (a) intercepted radiation (%) , (b) chlorophyll content (SPAD), (c) net photosynthesis ((μmol.m^{-2}.s^{-1}), (d) stomatal conductance (mol.m^{-2}.s^{-1}), (e) intercellular CO_2 concentration (μmol.mol^{-1}), (f) transpiration rate (mmol .m^{-2}.s^{-1}), and (g) water use efficiency of cucumber cv. Marketmore. Same letters in a graph are not significant at 5% probability. Y-bars indicate the variation within replicates

and water hyacinth biochars produced by slow pyrolysis at 350 °C. In present study, the water holding capacity in leaf and stem biochar was 37 and 30% respectively higher than the sandy loam soil medium. Yu et al. (2013) stated that higher percentage of pine wood biochar increased water holding capacity dramatically. An opposite but significant trend was regarding hydraulic conductivity, which indicated that moisture retained by leaf and stem biochar was higher than sandy loam alone. Studied on date palm leaf biochar, Khalifa and Yousef (2015) recorded 0.4 g.cm^{-3} bulk density and 20% water retention, which had significant effects on soil and plant properties.

Present findings also showed that the growth and developmental attributes were positively influenced when cucumber plants were grown on leaf or stem biochar amended media. The enhancement of cucumber yield and yield related traits could be due to the increase in soil available water and retention of soil mineral content. Micheal et al. (2017) reported that biochar from different hard wood species significantly enhanced vine length, fruit length, fruit numbers and yield. Similarly, cucumber plants grown on media containing poplar biochar with wood vinegar increased plant height (29.7%), root length (117%), root volume (121%) and root tips (76.1%) (Pan et al., 2017). However, in present study, there was a 5% increase in vine length of cucumber grown on leaf and stem biochar media that could be because of the difference in biochar feedstocks, which was not treated with vinegar that usually lower the pH value. Similarly, Njoku et al. (2017) reported that cucumber cv. Point Set produced highest plant height, leaf numbers, leaf area index, fruit number, fruit length, fruit diameter, fruit circumference and yield per hectare. The results of present study agreed with these findings. As mentioned above, one of the apparent characteristics of biochar is the ability to hold more water in the rhizosphere, which is essential for better plant growth and development (Basso et al., 2013). Moreover, many essential crop nutrients are also integrate with biochar carbon, which are slowly released afterward during different crop growth stages. It also minimize the possibility of run-off water content and plant nutrients, which is required at a specific phase of development. Cucumber plants grown in leaf and stem biochar produced 15% more chlorophyll content than the control plants. It could be due to the water holding efficiency and intrinsic nutrient retention properties of biochar, which provide ample water and soluble plant nutrients during various plant growth stages (Basso et al., 2013; Hossain et al., 2020). Sidra et al. (2018) reported that biochar significantly improved chlorophyll of wheat crop. Similarly, leaf biochar medium increased net CO_2 assimilation (17%), stomatal conductance (33%), transpiration rate (15%), whereas decreased intercellular CO_2 concentration (28%) as compared to the plants grown in control (sandy loam soil). More of less similar trend was observed when stem biochar was used as growing medium. Previous studies reported that biochar promote net photosynthesis of tomato (Zhu et al., 2016). Liao et al. (2019) reported that the net photosynthetic rate was of sugarcane was accelerated at elongation and maturity stages when grown in biochar medium. The lower concentration of intercellular CO_2 in leaf and stem biochar could be due to the maximum utilization and assimilation of CO_2 in the photosynthetic system. The lower stomatal conductance and transpiration rate in control plants might be due to the low water retention by the sand particles, which slowed down the photosynthetic capacity hence more CO_2 was trapped in the intercellular spaces of leaf. It is concluded from the present research that despite higher pH of leaf and stem biochar, it has lower bulk density, higher moisture content, water holding capacity and lower hydraulic conductivity as compared to sandy loam alone medium. Similarly, the yield and yield attributes were significantly enhanced when cucumber plants were grown in a sandy loam medium containing 2.5% leaf or stem biochar. It is also suggested that the future research studies are conducted to minimize pH of biochar, standardize application rates, application of alkaline nature biochar to acidic soils, relationship of biochar with different crop nutrients availability, etc.

Authors' contributions

MM, MRA, MSE conceived the research idea, deigned the project, did statistical analysis and prepared manuscript. MAAM build-up the prototype furnace for biochar production. HSG produced leaf and stem biochar and helped in laboratory work. MME, FIZ did the laboratory analysis of soil, leaf and stem biochar. AMA helped in data collection and glasshouse maintenance. All authors read and approved the final manuscript.

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Authors' Contribution

All authors contributed equally to this study.

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