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Physicochemical Properties of Biochar Derived from Agricultural and Forestry Processing Wastes as Cultural Medium Substance and Its Effect on Growth Quality of Vegetable Plug Seedlings

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This study used biochar derived from agricultural and forestry processing wastes as a portion of culture medium to investigate its effect on the growth quality of vegetable plug seedlings. The yield of biochars was 31.02–89.02%, the content of element C was 18.94–85.79%, the Japanese cedar sawdust biochar (JCSBC) had the highest content, followed by the sorghum distillery residue biochar (SDRBC). The SDRBC had higher N content (6.46–11.73%), and its pH, iodine value, and electrical conductivity (EC) were 6.53–8.74, 71.01–210.33 mg/g, and 0.10–0.37 ds/m. The FTIR results of the SDRBC and cultivation waste bag biochar (CWBBC) in the spectrum had more C–H stretching vibration hydrophilic functional groups at 2875 cm⁻¹ and 2995 cm⁻¹ than these of JCSBC or pulp sludge biochar (PSBC). The air-filled porosity, container capacity, and total porosity of the culture medium with biochar were 9.71–13.79%, 61.27–63.11%, and 70.02–74.01%. The pH was 6.34–6.87, and the EC was 0.96–1.22 ds/m, approaching the requirements for general perfect medium. According to the growth quality results of *Cucumis sativus* plug seedlings, on Day 28 after seeding, the seedling index I and II of the peat with perlite were 0.1379 and 0.2790, respectively; both with SDRBC were the highest at the carbonization temperature of 450°C (SDRBC–450), which were 0.1654 and 0.3376, significantly different from the peat with perlite and other biochar media. Moreover, because the SDRBC–450 had higher cation exchange capacity (CEC) than the others in day of seedling period during cultivation, the vegetable plug seedlings had better growth quality.

Key words: Agricultural and Forestry Processing Wastes, Biochar, Culture Medium, Plug Seedling, Seedling Index

INTRODUCTION

Biomass wastes are the most abundant renewable organic resources on earth (Balat and Ayar, 2005), such as agricultural and forestry processing wastes (AFPW). According to statistics, Taiwan's annual output of AFPW is about 1.28 million MT (Agricultural statistics, 2012). The sorghum distillery residue, cultivation waste bag, forestry waste, and pulp sludge are characterized by easy procurement, low price, and large quantity, and the carbonization technology, which places biomass wastes in oxygen-free environments for low temperature pyrolysis, has been gradually applied. One of the products of this preparation is biochar, which is a porous material with high carbon content, an aerobic functional group, and aromatic compounds (Kolodynska *et al.*, 2012; Regmi *et al.*, 2012; Shrestha *et al.*, 2010; Jiang *et al.*, 2012; Yu *et al.*, 2009).

Using biochar in agriculture is one of the popular environmental resource subjects at present, and is regarded as a soil improvement material due to its porosity and absorbability, which improves the physical and chemical properties of soil, enhances the soil structure, aggregates stability and water conductivity, absorbs soil heavy metal ions and organic contaminants, increases the microbial activity in the soil, reduces nutrient leaching loss, promotes plant growth, and enhances soil carbon sequestration (Joseph *et al.*, 2010; Lehmann and Joseph, 2009). Furthermore, biochar has a wide range of feedstock, including cellulose, hemicellulose, lignin, mineral constituents, protein, carbohydrates, and other extracts. The cellulose, hemicellulose, and lignin can determine the content of volatile matter and fixed carbon in the pyrolysis, and influence the final chemical composition and structure of biochar (Joseph *et al.*, 2007). Lua *et al.*, (2004) mentioned that, when the pyrolysis temperature increases from 250 to 500°C, the released volatile matter increases, which promotes the formation of pores in the biochar structure; thus, the specific surface area is enlarged, and the value of cation exchange capacity (CEC) and pH value increase. In the agricultural applications, the pH, CEC value, and water retaining capacity of soil with biochar are enhanced (Glaser *et al.*, 2002). In addition, the application of biochar improves the availability of moisture and mineral constituents during crop growth. With an appropriate biochar addition, the nutrient content in soil increases, which is absorbed by crops to increase the yield (Hidetoshi *et al.*, 2009). The sur-

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face area of internal pores is larger than other materials due to the porous structure resulted from the pyrolysis of biochar; therefore, the absorption effect is good, the organic contaminants in the soil can be absorbed, and the contaminant absorption of crops is reduced (Yu *et al.*, 2009). Tsakalimi (2006) indicates that the three major functions of culture medium are water retention, nutrient preservation, and diffusion of oxygen to the root. The main constituents of general plug culture medium include peat, perlite (or vermiculite, sea sand) and a little organic substance or compound fertilizer. Peat accounts for 30–80% of the plug medium, it has strong water-holding capacity, high CEC, and mostly subacid pH. The perlite increases the aeration degree of the medium, but it has no buffering power and very low CEC (Ho *et al.*, 2011).

For sustainable utilization and environmentally friendly treatment of biomass wastes, and with the intention of developing an added value to wastes, this study used AFPW, including sorghum distillery residue, cultivation waste bags, Japanese cedar sawdust, and pulp sludge, as the feedstocks for preparing biochar at different carbonization temperatures. The physicochemical properties of the derived biochars were investigated. The biochar, as a cultural substrate to substitute perlite, was mixed with peat to form a culture medium for property analysis and plug seedlings. The investigations were also carried to evaluate the effect of biochar derived from AFPW as a portion of culture medium on the growth quality of vegetable plug seedlings.

MATERIALS AND METHODS

Feedstock specimens and test materials

Two types of agricultural processing wastes were as feedstocks, sorghum distillery residue (SDR) from K Liquor Inc., and cultivation waste bag (CWB) from Sinshe Township, Taichung County. And two sorts of feedstocks from forestry processing wastes were Japanese cedar thinning sawdust (JCS) from woodworking factory, NCYU, and pulp sludge (PS) from a paper mill, Cheng Loong Pulp, Taiwan. The feedstock specimens were pulverized to 5–10 mesh for future use.

Perlite was perlite #4, produced by Taiwan Nan Hai Vermiculite Industrial Co. Ltd., which was over 55.16 % with 5–10 mesh. The bamboo vinegar, collected at 80–150°C, has been placed for 3 years, and diluted 10⁴ times as the irrigated solution use during the seedling period (Lin *et al.*, 2011). Peat was Klasmann select peat, produced by the German Klasmann–Deilmann company, which was used as the main of cultural medium to be mixed with biochar, and its pH was 5.5–6.5. *Cucumis sativus* L. (cucumber), bought from the Known–You Seed Co., Ltd., was as the vegetable for seedling testing.

Test methods

Basic properties of feedstocks

For the elements analysis of feedstocks, an elements analyzer (Elementar vario EL) was used for measurement according to the NIEA R409.21C standard. For

the chemical composition analysis, the alcohol–toluene extractives was measured according to the CNS4713 standard, the holocellulose content was measured according to the CNS 6948 standard, the lignin content was measured according to CNS 2721 and CNS 12108 standards, and the ash content was measured according to the CNS3084 standard.

Preparation and properties of biochar

The feedstocks were absolutely dried. About 20 g specimen was put in the crucible, and placed in a vertical high temperature activation furnace (Chi–How Heating Co., Ltd.). After vacuum pumping, the inside furnace was free of oxygen, carbonization was set at different temperatures (200, 250, 300, 350, 400, and 450°C) and the heating rate was 10°C/min. The nitrogen was put into the carbonization process, the gas flow was 200 mL/min, and the temperature was maintained for 60 min. Finally, the nitrogen was flowed into the furnace for cooling to room temperature, and then the biochar specimen was taken out and weighed. The biochars (BC) were coded agricultural and forestry processing wastes biochar–carbonization temperature.

Biochar yield was calculated by yield (%) = (oven dry weight of biochar/oven dry weight of feedstock) × 100. pH value was measured by pH meter (SUNTEX TS–1) after the solution of various biochars with distilled water mixed in ratio of 1:5 (v/v%) was kept still for 2 h. Iodine value was evaluated according to JIS K 1474 (1991). The EC of each BC was same as the acid–alkali mixed solution ratio, measured by pen type EC meter (SUNTEX SC–120). For the Fourier transform infrared spectrum (FTIR) analysis, various biochars were pulverized, sieved through 20–40 mesh screen and completely dried in oven. The infrared spectrum was analyzed by Fourier transform infrared spectroscopy (Bio–Rad FTS–40), the detector was the deteatered triglycine sulphate (DTGS), the resolution was 4 cm⁻¹, the number of scans was 64, the spectrum scanning area was 400–4000 cm⁻¹, in order to analyze the surface functional group of feedstock and biochar.

Physicochemical properties of culture medium with biochar

For preparation of culture medium with biochar, various derived biochars were uniformly mixed with peat in a volume ratio of 15:85 (v/v%) (Lin *et al.*, 2010). The control group used commercially available peat and perlite. The physical properties of culture medium (Bragg and Chambers, 1988) with biochar were investigated. 1) Air–filled porosity (AFP): the drain hole in the bottom of the plug was covered, and the plug was placed in water bath, where the medium absorbed moisture from the bottom up till the plug surface was full of moisture. The plastic cushion clung to the plug bottom, the plug was removed from the water bath, placed on the scale, and weighed (W_1 , g). Afterwards, the plug was removed and kept still to drain, and the medium surface was covered with preservative film to prevent the moisture from evaporating. The medium was weighed when it no longer drips (W_2 , g), and AFP was calculated by equation. AFP (%) = $(W_1 - W_2) / V \times 100$. V (mL) was the volume of the

plug full of moisture. 2) Container capacity (CC, also known as medium moisture capacity): the medium (W₂) was placed in the oven cabinet and completely dried at 105°C, and weighed after 24 h (W₃, g), and CC was calculated by equation. $CC (\%) = (W_2 - W_3) / V \times 100$. 3) Total porosity (TP): sum (%) of AFP and CC. 4) Bulk density (BD): it was calculated from the weight (W₃) and volume of the completely dry medium.

In each seedling investigation, the culture media of three plugs were taken, and measured by pH measuring method (the same as the measurement of biochar properties). The culture media of another three plugs were taken for measuring EC. CEC was investigated from the culture media of the other three plugs that was placed in the oven cabinet and dried. The detail experimental steps of CEC refer to (Hendershot and Duquette, 1986).

Plug seedling and biomass investigation

Biochars derived at different carbonization temperatures were used as the portion of culture medium, which was mixed with commercially available peat as the plug seedling medium, and the cucumber was used as the test vegetable. The seedlings were planted in the isolation chamber of the Department of Horticulture, Chiayi University on November 11, 2014. In the seedling period, in addition to general cultivation management, the seedlings were irrigated once every 7 days with nutrient solution Peters (Peters professional, Scotts Company, USA), which contained the ratio of nitrogen phosphorous and potassium being 20:20:20 and then was diluted 1000 times. In order to reach the pH range of the ideal culture media, they were irrigated with bamboo vinegar diluted 10⁴ times once every 3 days (Lin *et al.*, 2011), the physicochemical properties of the culture medium and the seedling growth were investigated on the day following irrigation, and the plug seedling growth quality was evaluated according to the investigation of seedling index.

The growth quality of cucumber was investigated using the methods of Bilderback *et al.* (1982) and Fonteno (1990), when the seedlings have been cultivated for 1, 2, 3, and 4 weeks, six seedlings are randomly selected from the different processes for seedling investigation. The investigated items were as follows:

1) Character, involving (a) stem length (cm): length of plant from the culture soil to the stem tip growing point; (b) stem diameter (mm): diameter of stem

between the plant stems base and the top of cotyledon.

2) Mass, including (a) fresh weight of whole plant: the whole plant (including root system) was cleaned; (b) fresh weight of above-ground part: the stem base was cut off the plant, the surface moisture was sucked up by gauze; (c) fresh weight of underground part: the underground root system was cleaned of culture soil. The surface moisture of whole plant, above-ground part and underground part was individually sucked up by gauze, and the mass was weighed; (d) dry weight of whole plant: the whole plant (including root system) was placed in the kraft bag, dried in a 70°C oven for 48 h, and the mass was weighed.

3) Two seedling indexes were used to evaluate the growth quality of vegetable seedlings. Seedling index I = (stem diameter/stem length) * dry weight of whole plant; Seedling index II = [(stem diameter/stem length) + (fresh weight of underground part/fresh weight of above-ground part)] * dry weight of whole plant.

Statistical analysis

The test results were represented by a mean (standard deviation), and the control group and test group were compared by Duncan's multiple range tests. If the ρ value is smaller than 0.05, meaning a significant difference between the test group and the control group, it is represented by different superscript upper case letters.

RESULTS AND DISCUSSION

Basic properties of feedstocks

The contents of C, N, S, H, and O elements in the agricultural processing waste SDR were 47.97, 3.31, 0.08, 6.51, and 42.12%, respectively, and those in CWB were individually 41.22, 2.22, 0.85, 4.89, and 50.81%. The contents in the forestry processing waste JCS and PS were respectively 50.99, 0.04, 0.05, 6.63, 42.29%, and 32.14, 0.31, 0.22, 3.85, 63.49%. The SDR had the highest N content, and the four feedstocks had significant differences in accordance with Duncan's multiple range tests (Table 1). This is similar to the results of SDR (Diao *et al.*, 2002; Lin *et al.*, 2014) and JCS (Peng and Lin, 2015). These feedstocks can be regarded as potential biomass wastes for preparing biochar as the portion of culture medium.

Table 1. Elemental analysis of each feedstock

Feedstock		C (%)	N (%)	S (%)	H (%)	O (%) ¹⁾
Agriculture Processed Residue	SDR ²⁾	47.97 (0.25) ³⁾	3.31 (0.08) ^d	0.08 (0.01) ^a	6.51 (0.13) ^c	42.12 (0.41) ^a
	CWB	41.22 (0.65) ^b	2.22 (0.05) ^c	0.85 (0.30) ^b	4.89 (0.08) ^b	50.81 (0.83) ^b
Forestry Processed Residue	JCS	50.99 (0.43) ^d	0.04 (0.01) ^a	0.05 (0.09) ^a	6.63 (0.22) ^c	42.29 (0.71) ^a
	PS	32.14 (0.58) ^a	0.31 (0.17) ^b	0.22 (0.07) ^a	3.85 (0.47) ^a	63.49 (0.52) ^c

¹⁾ O (%) = 100 - (C + N + S + H)

²⁾ SDR: sorghum distillery residue; CWB: cultivation waste bag; JCS: Japanese cedar sawdust; PS: pulp sludge

³⁾ Mean (standard deviation) with the different superscripts at the same element is significantly different ($p < 0.05$) by Duncan's multiple range tests

The holocellulose content in the chemical composition of various feedstocks (Table 2) was 34.79–68.40%; the CWB had the highest holocellulose content. This is because it is the waste from papermaking. PS had the lowest content. Its main composition is holocellulose, and it is generally treated by coagulant sedimentation. The lignin content was 18.29–34.63%, the JCS was the highest, and PS was the lowest. P. Carrott and M. Carrott (2007) indicate that lignin has high carbon, its molecular structure is similar to soft coal, the charcoal is formed mainly from lignin and cellulose, and the hemicellulose

is a volatile matter. Therefore, the higher the lignin, the higher the charcoals yield (Reed and Williams, 2004). The alcohol–toluene extractives in the four feedstocks were 1.59–13.12%, and SDR had the highest content. The alcohol–toluene extractives consist of resin, wax, and tannin, and it influences the yield in the carbonization process (Peng and Lin, 2015). The SDR had high alcohol–toluene extractives because the sorghum husk contains tannin (Awika and Rooney, 2004). The ash was 0.63–7.73%, CWB had the highest content, and JCS had the minimum content. It may be because the CWB has a

Table 2. Basic chemical compositions of each feedstock

Feedstock		Holocellulose (%)	Lignin (%)	Ethanol–toluene extractives (%)	Ash (%)
Agriculture Processed Residue	SDR ¹⁾	47.30 (0.24) ²⁾	31.50 (0.34)	13.12 (0.52)	6.05 (0.50)
	CWB	68.40 (0.80)	21.95 (0.39)	5.12 (0.45)	7.73 (0.35)
Forestry Processed Residue	JCS	63.32 (1.20)	34.63 (0.40)	1.59 (0.30)	0.63 (0.02)
	PS	34.79 (0.69)	18.29 (0.64)	7.48 (0.44)	3.93 (0.45)

¹⁾ see Table 1²⁾

²⁾ Mean (standard deviation)

Table 3. Yield, pH, iodine and EC values of various biochars

Specimen ¹⁾	Yield (%)	pH value	Iodine value (mg/g)	EC (ds/m)
SDRBC–200	70.02 (0.02) ^{a,2)}	6.53 (0.04) ^a	71.01 (5.14) ^a	0.37 (0.11) ^a
SDRBC–250	51.05 (0.03) ^b	6.79 (0.17) ^{ab}	75.32 (3.47) ^a	0.28 (0.13) ^{ab}
SDRBC–300	42.01 (0.01) ^c	7.25 (0.01) ^b	146.44 (7.43) ^b	0.21 (0.08) ^b
SDRBC–350	36.11 (0.01) ^d	7.94 (0.13) ^b	176.41 (0.36) ^c	0.10 (0.04) ^c
SDRBC–400	32.05 (0.01) ^d	8.27 (0.08) ^c	193.02 (5.85) ^{cd}	0.11 (0.01) ^c
SDRBC–450	31.25 (0.04) ^e	8.74 (0.04) ^c	210.33 (6.85) ^d	0.11 (0.01) ^c
CWBBC–200	88.35 (0.02) ^a	7.34 (0.09) ^a	130.05 (7.42) ^a	3.44 (0.42) ^a
CWBBC–250	76.40 (0.01) ^{ab}	8.08 (0.04) ^{ab}	136.69 (7.56) ^a	2.93 (0.51) ^a
CWBBC–300	64.06 (0.04) ^b	9.37 (0.12) ^{ab}	244.19 (9.13) ^b	2.26 (0.34) ^a
CWBBC–350	63.33 (0.03) ^b	10.34 (0.07) ^b	263.54 (7.24) ^b	1.79 (0.23) ^b
CWBBC–400	59.25 (0.02) ^c	10.97 (0.02) ^{bc}	326.30 (8.02) ^c	1.92 (0.27) ^{bc}
CWBBC–450	54.60 (0.02) ^c	11.73 (0.03) ^c	341.39 (9.50) ^d	2.09 (0.15) ^c
JCSBC–200	75.43 (0.02) ^a	6.46 (0.10) ^a	42.54 (7.71) ^a	0.18 (0.03) ^a
JCSBC–250	41.30 (0.01) ^b	6.84 (0.11) ^a	51.39 (7.32) ^{ab}	0.15 (0.04) ^{ab}
JCSBC–300	35.40 (0.01) ^{bc}	7.51 (0.08) ^b	92.07 (6.99) ^b	0.12 (0.08) ^b
JCSBC–350	32.06 (0.01) ^c	8.05 (0.10) ^c	104.39 (6.44) ^b	0.12 (0.03) ^b
JCSBC–400	30.49 (0.02) ^{cd}	8.28 (0.04) ^{cd}	139.45 (9.04) ^c	0.07 (0.01) ^c
JCSBC–450	28.88 (0.01) ^d	8.63 (0.04) ^d	158.08 (9.81) ^d	0.07 (0.02) ^c
PSBC–200	89.35 (0.01) ^a	7.07 (0.06) ^a	145.64 (0.47) ^a	1.88 (0.10) ^a
PSBC–250	77.24 (0.01) ^{ab}	7.24 (0.04) ^{ab}	159.84 (6.16) ^a	0.51 (0.05) ^b
PSBC–300	70.05 (0.02) ^b	7.64 (0.09) ^b	184.06 (7.14) ^a	0.41 (0.06) ^b
PSBC–350	69.38 (0.01) ^b	8.31 (0.09) ^c	187.65 (8.35) ^a	0.77 (0.01) ^c
PSBC–400	66.41 (0.04) ^{bc}	9.03 (0.10) ^d	204.45 (9.54) ^b	0.45 (0.02) ^d
PSBC–450	65.60 (0.01) ^c	9.64 (0.08) ^e	217.27 (4.22) ^b	0.40 (0.01) ^e

¹⁾ see Table 1²⁾; BC–200: Biochar–carbonization temperature

²⁾ Mean (standard deviation) with the different superscripts at the same specimen is significantly different ($p < 0.05$) by Duncan's multiple range tests

high content of inorganic substance (Peng and Lin, 2015).

Properties of derived biochars

The yields of various biochars decreased as the carbonization temperature increased (Table 3). Teng and Hsu (1999) indicate that this is due to the volatile matter in the feedstock, tar dissipation, and the increased gasified quantity of carbon. Walker and Almagro (1995) indicate that the higher the carbonization temperature, the larger the gasified quantity, and in the pyrolysis, the CO, CH₄, formaldehyde, methanol, and hydrogen compounds are likely to form by degradation as the temperature increases. As shown in the Table 3, the four feedstocks were relatively subacid (6.46–7.34) at 200°C. When the carbonization temperature was 450°C, they became weakly alkaline or alkaline (8.63–11.73) as the temperature increased. When the feedstock is carbonized at high temperature, the organic compounds is decomposed by the heat, the different compounds are generated and discharged, while the inorganic matter

remain, such as alkali metal elements Ca, K, and Mg, and a higher temperature is required for the reaction to form oxides, which may be because its pH is subalkaline (Gundale and Deluca, 2006; Neary *et al.*, 1999). Joseph *et al.* (2010) indicates that the soil pH suitable for plant growth is 6.5–7.5. Therefore, weakly alkaline or alkaline biochar can improve the pH of acid soil to promote the root system development of crops to increase crop yield. The iodine value of SDRBC was 71.01–210.33 mg/g; that of CWBBC was 130.05–341.39 mg/g; that of JCSBC was 42.54–158.08 mg/g; that of PSBC was 145.64–217.27 mg/g. The EC is generally lower than 1 ds/m (Koranski, 1993). The results showed that the EC of various biochars decreased as the carbonization temperature increased. However, while the EC of CWBBC is higher than the other three, it is still in the comfort range for fruit vegetable seedlings (Norrie *et al.*, 1994).

Table 4 shows the results of SDRBC elements analysis. The C content was 51.91–69.49%. The N content was 3.17–4.66%, and there was no significant difference

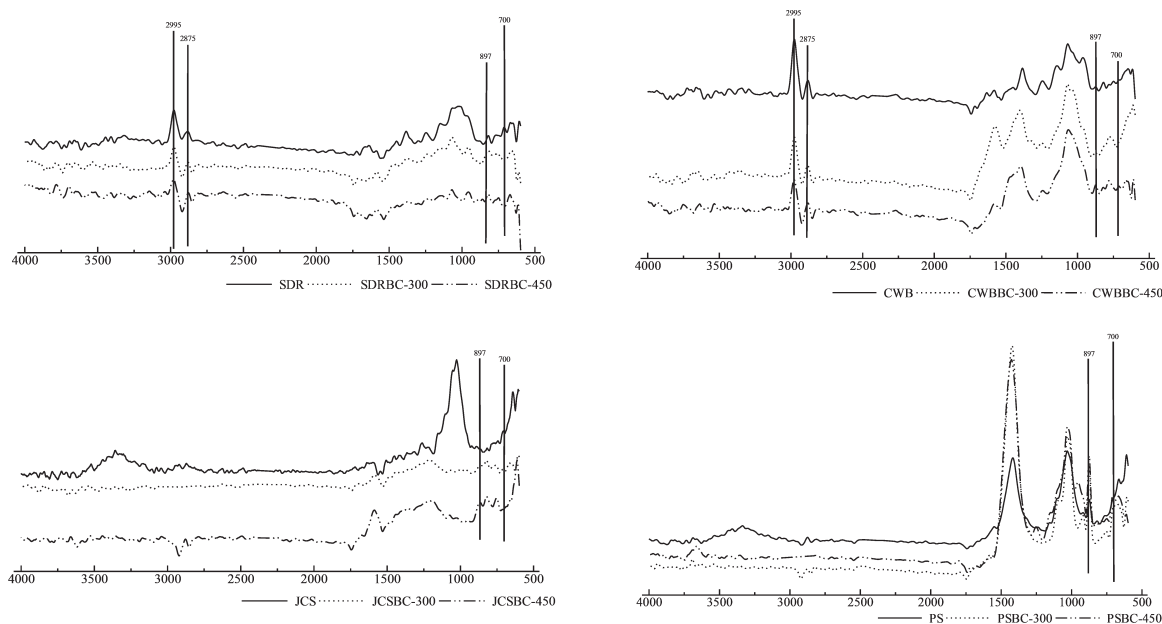


Fig. 1. FTIR analysis of each feedstock and biochar derived at 300 and 450°C of carbonization temperature.

Table 4. Elemental analysis of each biochar

Specimen ¹⁾	C (%)	N (%)	S (%)	H (%)	O ²⁾ (%)
SDRBC-200	51.91 (6.71) ^{a3)}	3.17 (0.89) ^a	0.10 (0.08) ^a	4.77 (1.52) ^b	40.05 (9.21) ^d
SDRBC-250	60.18 (1.05) ^b	4.05 (0.11) ^b	0.03 (0.01) ^a	4.47 (0.10) ^b	31.27 (1.20) ^c
SDRBC-300	65.54 (0.15) ^c	4.44 (0.05) ^b	0.54 (0.51) ^b	4.47 (0.06) ^b	25.02 (0.64) ^b
SDRBC-350	65.90 (0.71) ^c	4.43 (0.08) ^b	0.11 (0.02) ^a	3.87 (0.02) ^{ab}	25.69 (0.83) ^b
SDRBC-400	67.28 (0.40) ^c	4.46 (0.14) ^b	0.04 (0.01) ^a	3.36 (0.04) ^a	24.85 (0.60) ^b
SDRBC-450	69.49 (0.75) ^c	4.66 (0.14) ^b	0.02 (0.02) ^a	2.95 (0.03) ^a	22.88 (0.97) ^a

¹⁾ see Table 3¹⁾

²⁾ O (%) = 100 - (C + N + S + H)

³⁾ Mean (standard deviation) with the different superscripts at the same specimen is significantly different (*p* < 0.05) by Duncan's multiple range tests

Table 5. Physical properties of biochar culture media

Culture media ¹⁾ (Substance + Peat)	Physical properties ²⁾			
	AFP (%)	CC (%)	TP (%)	BD (g/cm ³)
Perlite + Peat	9.03 (2.03) ^{a2)}	65.88 (3.55) ^c	72.74 (1.33) ^b	0.13 (0.01) ^{bc}
SDRBC-200 + Peat	11.11 (0.14) ^b	61.87(2.13) ^a	71.08 (1.55) ^a	0.12(0.01) ^b
SDRBC-250 + Peat	12.14 (2.40) ^c	62.94 (3.64) ^b	72.09 (1.37) ^b	0.12 (0.01) ^b
SDRBC-300 + Peat	12.30 (3.26) ^c	62.86 (1.71) ^b	72.66 (1.54) ^b	0.13 (0.01) ^{bc}
SDRBC-350 + Peat	12.21 (1.42) ^c	62.54 (3.70) ^b	72.84 (1.65) ^b	0.13 (0.01) ^{bc}
SDRBC-400 + Peat	12.75 (0.68) ^c	62.23 (5.10) ^b	73.44 (2.09) ^c	0.14 (0.01) ^c
SDRBC-450 + Peat	12.19 (0.54) ^c	62.74 (4.31) ^b	73.12 (2.10) ^c	0.14 (0.01) ^c
CWBBC-450 + Peat	12.67 (1.56) ^c	62.83 (3.37) ^b	73.34 (1.21) ^c	0.15 (0.01) ^d
JCSBC-450 + Peat	13.79 (1.27) ^c	63.07 (3.08) ^b	74.01 (2.33) ^c	0.15 (0.01) ^d
PSBC-450 + Peat	12.05 (1.33) ^c	62.89 (3.35) ^b	72.76 (2.36) ^b	0.13 (0.01) ^{bc}

¹⁾ Each biochar was 15% of ground substance + 85% of Peat at v/v%

²⁾ Physical properties, including AFP: Air-filled porosity; CC: Container capacity; TP: Total porosity; BD: Bulk density

³⁾ Mean (standard deviation) at the same specimen with Perlite + Peat is significantly different ($p < 0.05$) by Duncan's multiple range tests

above the carbonization temperature of 300°C. The H content was 2.95–4.77%, which decreased as the carbonization temperature increased. Delfine *et al.*, (2001) indicates that N is one of the constituents of organic compounds in a plant. The organic compounds include amino acid, protein, coenzyme, nucleic acid, and chlorophyll. The primary function of S is to take part in the synthesis of some organic compounds in the plant, such as amino acid, protein, coenzyme A, and partial vitamins. Together with carbon, H composes the organic matter in a plant, and it plays an important role in the cation exchange between the plant root system and soil particles. O is one of the compositions of organic matter in a plant, which plays an important role in the anion exchange between the plant root system and soil particles, and acts as the intermediate acceptor of hydrogen ions when the plant performs aerobic respiration. Therefore, when biochar is used as a portion of medium for cultivating plants, it is highly correlated with the elements in the products of high and low carbonization temperature pyrolysis in the degree of nutrient preservation.

Figure 1 shows the FTIR of the various feedstocks and biochars derived at carbonization temperatures of 300 and 450°C. According to the results of the various feedstocks, the vibration absorption band of the hydroxyl group occurs at 3000–3600 cm⁻¹; the vibration peaks of CH and CH₂ occur at 2850–3000 cm⁻¹; the carbohydrate characteristic absorption peaks are at 1736 cm⁻¹, 1370 cm⁻¹, and 897 cm⁻¹; the aromatic compound characteristic absorption peaks of lignin are at 1510 cm⁻¹, 1453 cm⁻¹, and 1232 cm⁻¹ (Yamada and Ono, 1999). The characteristic absorption peak of the β-anomeric linkage in the cellulose glucose structure is at 897 cm⁻¹ (Chang *et al.*, 1998). The broadband had many small peaks at 3000–3700 cm⁻¹ due to the OH functional group, SDR and CWB had a small frequency band at 2700–

3000 cm⁻¹. The peaks 2875 cm⁻¹ and 2995 cm⁻¹ were in the C–H stretching vibration hydrophilic functional group. Schmidt and Noack (2000) indicates that, if biochar is used during the plant growing soil to hold moisture, the hydrophilic functional group is suitable, and the peaks are at 700 cm⁻¹, 897 cm⁻¹, 2875 cm⁻¹, and 2995 cm⁻¹. According to Figure 1, SDRBC, CWBBC, JCSBC, and PSBC had the C–H deformation vibration hydrophilic functional group at 700 cm⁻¹ and 897 cm⁻¹, 2875 cm⁻¹ and 2995 cm⁻¹, but the hydrophilic functional group at 2875 cm⁻¹ and 2995 cm⁻¹ was not detected in JCSBC or PSBC. The SDRBC and CWBBC might; therefore, have better water retention than JCSBC and PSBC.

Physicochemical properties of various biochar media

Physical properties

Table 5 shows the physical properties of the culture media mix of SDRBC and peat at different carbonization temperatures. The AFP, CC, TP, and BD of the culture media were perlite and peat (control group) were 9.03, 65.88, 72.74%, and 0.13 g/cm³, respectively. When the culture media were SDRBC and peat, the AFP was 11.11–12.75%. According to Duncan's multiple range tests, the SDRBC (at different temperature) and control group had significant difference; CC was 61.87–62.94%; TP and BD were respectively 71.08–73.44% and 0.12–0.14 g/cm³.

The results of statistical analysis showed that, the perlite and SDRBC media conform to the requirements for general perfect medium, the AFP is 10–25%, CC is 40–60%, TP is 54–80% (Bunt, 1991; Bures *et al.*, 1991; Fonteno, 1996), and the various biochars have the same trend. Fonteno (1996) indicates that the culture medium particle size is directly correlated with the air permeability and water-holding capacity of the culture medium. When there are a lot of coarse particles, there are a lot

of non-capillary pores in the culture medium, and air permeability is enhanced; however, the moisture is likely to be lost through the pores, reducing the water-holding capacity. When there are a lot of fine particles, there are a lot of capillary pores in the culture medium, and the water-holding capacity is enhanced. The TP is the sum of AFP and CC; as a medium with large pores contributes to increasing the oxygen diffusion rate, the crops obtain more oxygen. The smaller the container (plug) for cultivating plants, the stricter the requirement for pores; otherwise, the stuffiness during watering is likely to cause poor growth of the plant root. According to the aforesaid results, the AFP, CC, and TP of various biochars and control group conform to the general perfect medium; whereas, BD is a little lower than the perfect medium range 0.30–0.75 g/cm³ (Gabriels and Vrdonck, 1991).

Chemical properties

Table 6 shows the pH changed of various culture media in the cucumber plug seedling period. In the initial seedling period (Day 0), in terms of the pH of the culture medium mix of biochar or perlite and peat, the pH of the culture medium with perlite was 6.34, that with SDRBC200 to SDRBC450 was 6.39–6.78, and that with CWBBC450, JCSBC450, and PSBC450 was 6.87, 6.75, and 6.83, respectively. The results are close to the pH 6.5 of the general perfect medium (Joseph *et al.*, 2010). According to the results of Day 28 of the seedling period, the pH of the medium with perlite was 6.28, that with SDRBC was 6.58–7.28, and that with WBBC450, JCSBC450, and PSBC450 was 6.87, 7.23, and 7.31, respectively. Lin *et al.* (2011) reports that the pH of the culture medium irrigated with bamboo vinegar is lower than that of the culture medium not irrigated, thus, 10⁴ diluted bamboo vinegar can effectively reduce the pH of the culture medium. In the seedling period, the medium was irrigated with 500 mL of 10⁴ diluted bamboo vinegar every three days. The results in Table 6 indicated that

the pH of the biochar as a partial culture medium in the seedling period can be effectively controlled.

Generally, the EC represents the amount of soluble salts in the culture medium solution. A higher value represents a higher nutrient content. If the EC is too high, the culture medium contains much soluble salts, the osmotic pressure is high, and the plants find it difficult to absorb moisture and nutrients (Delfine *et al.*, 2001). The comfort range of the EC of the fruit vegetable culture medium is 1.0–4.0 ds/m (Norrie *et al.*, 1994). The EC of the general plug culture medium should be lower than 1.0 ds/m (Koranski, 1993). The initial EC of various culture media in the cucumber plug seedling period (Day 0). The EC of a medium with perlite (control group) was 1.02 ds/m, that with SDRBC derived at different temperatures was 1.02–1.10 ds/m, and that with CWBBC450, JCSBC450, and PSBC450 were 1.22, 1.01, and 0.96 ds/m, declining markedly compared with the initial value as the seedling period extends to 7, 14, 21, to 28 days (results not shown in Table). It may be because the soluble salts are released or almost exhausted by the plants, namely, the concentration of soluble salts decreases (Lin *et al.*, 2011). However, on Day 28 after seeding, the EC of various culture media increases slightly, which may be because the hemicellulose, cellulose, and lignin in the culture media are decomposed slowly (Raig, 1998).

The CEC is closely related to the nutrient preserving capability of the medium. The organic matter in the culture medium is negatively charged, absorbing cations, such as ammonium nitrogen, K, Ca, Mg, and Fe, reducing the loss of cations. A high CEC represents high nutrient preserving capability (Lemaire, 1995). Regarding the CEC of a culture media with different biochars in the cucumber plug seedling period; on Day 7 of the seedling period, that of the medium with perlite was 51.91 cmol/kg, that of SDRBC derived at different temperatures was 50.16–60.51 cmol/kg, and that with CWBBC450,

Table 6. pH value of different biochar cultural media during cucumber plug seedling period

Culture media ¹⁾ (Substance + Peat)	Day of seedling period (in days)				
	0	7	14	21	28
Perlite + Peat	6.34 (0.02) ²⁾	6.27 (0.01) ^b	6.22 (0.05) ^a	6.19 (0.02) ^a	6.28 (0.02) ^b
SDRBC-200 + Peat	6.45 (0.07) ^a	6.49 (0.03) ^a	6.51 (0.11) ^a	6.43 (0.09) ^a	6.58 (0.04) ^b
SDRBC-250 + Peat	6.39 (0.07) ^a	6.59 (0.11) ^{bc}	6.43 (0.06) ^{ab}	6.61 (0.06) ^{bc}	6.73 (0.13) ^c
SDRBC-300 + Peat	6.55 (0.10) ^b	6.68 (0.06) ^b	6.62 (0.13) ^b	6.38 (0.09) ^a	6.68 (0.11) ^b
SDRBC-350 + Peat	6.64 (0.11) ^b	6.96 (0.03) ^c	6.88 (0.12) ^{bc}	6.48 (0.03) ^a	7.04 (0.05) ^c
SDRBC-400 + Peat	6.78 (0.13) ^b	7.04 (0.04) ^c	7.11 (0.10) ^c	6.37 (0.06) ^a	7.11 (0.13) ^c
SDRBC-450 + Peat	6.76 (0.07) ^a	6.92 (0.10) ^{ab}	7.21 (0.03) ^b	6.87 (0.15) ^a	7.28 (0.08) ^b
CWBBC450 + Peat	6.87 (0.05) ^a	6.94(0.08) ^{ab}	7.08 (0.13) ^b	7.11 (0.02) ^b	6.87 (0.05) ^a
JCSBC450 + Peat	6.75 (0.12) ^a	6.87 (0.07) ^b	7.17 (0.03) ^c	7.21 (0.09) ^c	7.23 (0.11) ^c
PSBC450 + Peat	6.83 (0.02) ^a	7.20 (0.09) ^c	6.91 (0.06) ^a	7.29 (0.13) ^c	7.31 (0.10) ^c

¹⁾ see Table 5¹⁾

²⁾ Mean (standard deviation) at the specimen with Perlite + Peat is significantly different ($p < 0.05$) by Duncan's multiple range tests

JCSBC450, and PSBC450 were 50.94, 52.13, and 51.00 cmol/kg, respectively. The maximum CEC occurred in SDRBC450, and statistical analysis of perlite, SDRBC450, CWBBC450, JCSBC450, and PSBC450 showed that SDRBC450 was significantly different from the other four (Table 7). The result of Day 28 of the seedling period shows that the medium with SDRBC400 had the maximum CEC value, and there were significant differences among the biochars derived at 450°C. Helling *et al.* (1964) indicates that the proportion of CEC in the soil from organic matter increases with the pH. A comparison between this result and Table 6 showed that the pH increased, and the plants still grow well in a wide CEC range. However, an appropriate medium CEC makes the plant cultivation management easier (Bunt, 1991).

Chan *et al.* (2007) indicates that biochar is a soil improvement material with low nutrient content, as compared to other organic materials. However, when soil is mixed with biochar, the water retention and nutrient preserving capability of the soil can be effectively improved, and the soil carbon sequestration capacity is enhanced, thus, the pores (Yu *et al.*, 2007) and functional groups (Figure 1) have better physicochemical absorption, and the nutrients in the culture medium can be relatively retained.

Growth quality of plug seedling

The results of seedling index I and II of various culture media of biochar, as derived at the carbonization temperature of 450°C in the cucumber plug seedling

Table 7. CEC of different biochar cultural media during cucumber plug seedling period

Unit: cmol/kg

Culture media ¹⁾ (Ground substance + Peat)	Day of seedling period (in days)				
	0	7	14	21	28
Perlite + Peat	42.75 (7.38) ^{aA2)}	51.91 (3.49) ^{aA}	52.86 (8.22) ^{aA}	56.59 (9.15) ^{aA}	60.89 (7.09) ^{aA}
SDRBC-200 + Peat	43.82 (4.05) ^a	57.81 (5.83) ^{ab}	64.62 (2.45) ^{ab}	66.57 (9.52) ^{ab}	73.47 (9.57) ^b
SDRBC-250 + Peat	43.71 (2.54) ^a	50.16 (3.58) ^a	59.17 (6.25) ^{ab}	65.36 (8.10) ^{ab}	70.29 (1.66) ^b
SDRBC-300 + Peat	46.96 (6.17) ^a	55.78 (5.64) ^{ab}	65.57 (2.19) ^{ab}	68.11 (9.40) ^{ab}	75.37 (4.68) ^b
SDRBC-350 + Peat	48.22 (3.12) ^b	55.32 (6.00) ^{ab}	64.36 (8.38) ^{ab}	69.44 (6.63) ^{ab}	77.55 (5.44) ^b
SDRBC-400 + Peat	47.33 (0.76) ^{ab}	57.43 (4.31) ^b	65.29 (5.79) ^b	70.49 (5.16) ^{bc}	80.13 (2.09) ^c
SDRBC-450 + Peat	48.14 (5.19) ^{bb}	60.51 (4.39) ^{bb}	62.36 (6.32) ^{bb}	72.82 (0.62) ^{bcB}	79.46 (3.43) ^{cb}
CWBBC450 + Peat	42.38 (1.21) ^{aA}	50.94 (6.76) ^{abA}	58.43 (1.10) ^{baB}	61.95 (6.15) ^{ba}	65.43 (1.92) ^{ba}
JCSBC450 + Peat	43.89 (3.59) ^{aA}	52.13 (4.31) ^{abA}	59.86 (6.29) ^{baB}	62.34 (0.98) ^{ba}	65.89 (3.48) ^{ba}
PSBC450 + Peat	41.92 (4.37) ^{aA}	51.00 (3.43) ^{abA}	57.12 (3.67) ^{baB}	62.73 (4.73) ^{ba}	64.31 (2.89) ^{ba}

¹⁾ see Table 5¹⁾

²⁾ Mean (standard deviation) with the different small alphabets at the specimen and Perlite + Peat, and the different large alphabets at the specimen with 450 °C of carbonization temperature and Perlite + Peat is significantly different ($p < 0.05$) by Duncan's multiple range tests

Table 8. Seedling index of different biochar cultural media during cucumber plug seedling period

Culture media ¹⁾ (Substance + Peat)	Day of seedling period (in days)							
	7		14		21		28	
Seedling index	I	II	I	II	I	II	I	II
Perlite + Peat	0.0159 (0.0014) ^{ab2)}	0.0221 (0.0028) ^{ab}	0.0468 (0.0066) ^{aA}	0.0992 (0.0128) ^{aA}	0.0982 (0.0197) ^{aAB}	0.2128 (0.0383) ^{aAB}	0.1379 (0.0178) ^{ab}	0.2790 (0.0412) ^{aA}
SDRBC-450 + Peat	0.0230 (0.0041) ^{bc}	0.0401 (0.0068) ^{bd}	0.0590 (0.0048) ^{bb}	0.1341 (0.0141) ^{bb}	0.1230 (0.0128) ^{ac}	0.2435 (0.0131) ^{bb}	0.1654 (0.0552) ^{bc}	0.3376 (0.0942) ^{bb}
CWBBC450 + Peat	0.0116 (0.0012) ^A	0.0162 (0.0018) ^A	0.0463 (0.0045) ^A	0.0873 (0.0097) ^A	0.0799 (0.0052) ^A	0.2032 (0.0097) ^{AB}	0.1379 (0.0185) ^B	0.2756 (0.0508) ^A
JCSBC450 + Peat	0.0208 (0.0024) ^C	0.0307 (0.0032) ^C	0.0495 (0.0059) ^A	0.0969 (0.0058) ^A	0.1074 (0.0062) ^{BC}	0.1689 (0.0209) ^A	0.1260 (0.0214) ^{AB}	0.2467 (0.0269) ^A
PSBC450 + Peat	0.0146 (0.0031) ^{AB}	0.0208 (0.0042) ^B	0.0497 (0.0118) ^{AB}	0.1000 (0.0224) ^A	0.1053 (0.0198) ^{BC}	0.2169 (0.0424) ^B	0.0995 (0.0362) ^A	0.2213 (0.0765) ^A

¹⁾ see Table 5¹⁾

²⁾ Mean (standard deviation) with the different small alphabets at the Perlite + Peat and SDRAC450+Peat, and the different large alphabets at the specimen with 450 oC of carbonization temperature and Perlite + Peat is significantly different ($p < 0.05$) by Duncan's multiple range tests

period, are shown in Table 8. The seedling index I of the medium with perlite was 0.0159 on Day 7 of the seedling period; and that with SDRBC450 was 0.0230; that with CWBBC450, JCSBC450, and PSBC450 was 0.116, 0.0208, and 0.0146, respectively., the medium with perlite was significantly different from that with SDR-450, and that with perlite was not different from SDRBC450 and JCSBC450 with biochars derived at 450°C; however, the CWBBC450 had the minimum index, according to Duncan's multiple range tests. In terms of the seedling index I on Day 21 and Day 28 of the seedling period, the seedling index of various culture media was markedly increased, and SDRBC450 was the best.

The seedling index I took the stem diameter, stem length, and dry weight of the whole plant as the evaluation items. The fresh weight of underground part and fresh weight of above-ground part were put into the calculation basis of this study, which was seedling index II, according to which, the effect of various culture media on the growth quality of cucumber was evaluated. The results are also as shown in Table 8. The seedling index of the medium with perlite was 0.0221 on Day 7 of the seedling period; that of SDRBC450 was 0.0401; and that of the other three was respectively 0.0162, 0.0307, and 0.0208. According to Duncan's multiple range tests, the medium with perlite was significantly different from SDR450, the SDRBC450 was also the best, and that with perlite and 450°C biochar. SDRBC450 were different from others; however, that with perlite was insignificantly from PSBC450, and CWBBC450 was the minimum. For the seedling index II on Day 28 of the seedling period, it with perlite was 0.2790, SDRBC450 was 0.3376; and CWBBC450, JCSBC450, and PSBC450 were 0.2756, 0.2467, and 0.2213. The seedling index II of various culture media was markedly increased. According to statistical analysis, SDRBC450 was significantly different from perlite, CWBBC450, JCSBC450, and PSBC450.

CONCLUSION

This study used four types of AFPW to prepare different biochars, and investigate the effect as the portion of culture mediums on vegetable plug seedling quality. The elements analysis of the feedstocks showed that the C, N, and H contents were 32.14–50.99, 0.04–3.31, and 3.85–6.63%. The holocellulose, lignin, alcohol-toluene extractives, and ash contents were 32.30–68.40, 16.50–34.63, 1.59–13.12, and 0.63–7.73%. The yield of biochar derived at different carbonization temperatures decreased as the temperature increased, whereas, the pH and iodine value increased with the temperature. The elements analysis of various biochars showed that JCSBC has the highest C content, followed by SDRBC, but SDRBC had the highest N content. The FTIR results show that C–H stretching vibration hydrophilic functional groups at 2875 cm and 2995 cm⁻¹ in the spectrum were undetected in the spectrum of JCSBC and PSBC. The physicochemical properties of culture medium with biochar were close to the requirements for the general perfect medium. According to the seedling biomass

investigation, on Day 28 after seeding, SDRBC450 had maximum sound seedling indexes I and II, and was significantly different from perlite, CWBBC450, JCSBC450, and PSBC450. In the scope of this study, the physicochemical properties of the SDRBC450 as the portion of culture medium and the mixture of 15% biochar and peat were better than the perlite only and the other three biochars with peat and, thus seedling growth quality was better.

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AUTHOR CONTRIBUTION

Wei-Ru KUO performed the experiments, analyzed the data and the statistical analysis. Jian-Jhong HUANG assisted the experiments. Noboru FUJIMOTO participated in the design of the study and supervised the works. Han Chien LIN designed this study and wrote the paper. The authors assisted in editing of the manuscript and approved the final version.

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