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Blending Agricultural and Forestry Wastes in Wine Sludge to Develop Degradable Sludge Biochar Medium Pellet

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This study blended different proportions of Sorghum Distillery Residue (SDR) and Japanese Cedar Sawdust (JCS) in Wine Sludge (WS), extruded by a self–made mold and developed into Sludge Biochar Medium Pellet (SBMP). SDRMP (WS with SDR) and JCSMP (WS with JCS) were derived at different carbonization temperatures. The property, porosity and water absorption/desorption of both pellets were evaluated. The iodine value of SDRMP and JCSMP were 73.93–185.87 mg/g and 110.46–214.45 mg/g. The water absorption of SDRMP–40–450 (40% SDR with WS at carbonization temperature 450°C) was 129%, while that of JCSMP–40–300 was 191%. The pH of SDRMP was 6.81–9.63, while that of JCSMP was 7.02–9.50. The CEC of SDRMP–40–450 was 35.24 cmol/kg, while that of JCSMP–40–450 was 35.21 cmol/kg. To investigate the degradability, and feasibility of being a functional culture medium in agriculture, all SBMPs were mixed with peat to obtain Sludge Biochar Medium Pellet Peats (SBMPP), including SDRMPP and JCSMPP. The physicochemical properties of various SBMPPs could meet the standard of an ideal culture medium. According to one month's test for degradability, JCSMP was still kept a higher percent weight, but it was lower for SDRMP.

Key words: Sorghum Distillery Residue (SDR), Japanese Cedar Sawdust (JCS), Sludge Biochar Medium Pellet (SBMP), Degradability

INTRODUCTION

The disposal of agricultural and forestry wastes, such as rice husk, distillery residue, sludge, and sawdust, is one of the most important topics in Taiwan in recent years. The Council of Agriculture, Executive Yuan indicated that about 2 300 000 MT of agricultural and forestry wastes were yielded in 2014, and that how to handle them is related to waste reduction or environmental pollution. Sludge refers to the solid precipitate derived from the purification or wastewater treatment process (Chen, 2011). In addition, Sorghum Distillery Residue (SDR) is the fermentation waste resulting from winery. Wine Sludge (WS) is derived from the anaerobic digestion, sludge activation, and chemical precipitation of wet spent grains in the brewing process. According to the statistics of the Industrial Waste Report and Management System of the Ministry of Environment Protection Administration (EPA), Executive Yuan, Taiwan, the monthly average output of WS is about 1 000 MT in 2017. In comparison to other sludge, such as industrial wastewater sludge, WS is less toxic or even non–toxic, contains organic matter, and more nutrients may remain after sintering treatment (Liu *et al*., 2014). Therefore, if the WS can be fully recycled, channel for the circulation of ecological environment can be provided, and the cascade utilization of the wastes from agriculture and forestry and wine industry can be enhanced.

Different sludge presently can be derived into functional materials; such as reservoir sludge is granulated to prepare filter material (Chang, 2004), and organic and heavy metal sludge are burned into environmentally friendly bricks and eco–cement (Lin, 2007). With different blend material, rice husk and distillery residue, the porosity of bricks increases during the brick pyrolysis process, and there are pores left in bricks to make them lightweight, porous, and water absorption (Chou, 2008; Russ *et al*., 2005). These characteristics are formed from the loss on burn–off of mixtures, and high sintering makes the product more consistency and has greater compressive strength (Yuan *et al*., 2015). According to the physicochemical properties of biochar that is derivered from sewage sludge, when the sludge is pyrolyzed into biochar, the formation of pathogen and odor can be reduced, and the heavy metal can be concentrated (Hwang *et al*., 2007). The sludge biochar has different alkalinities and acidities for different carbonization temperatures, it can regulate super–acid or per–alkali soil (Yuan *et al*., 2015), and it has micronutrient elements as well. The soil is; therefore, mixed with sludge biochar as a culture medium, then the soil property can be improved (Hossain *et al*., 2010; Gasco´ *et al*., 2012; Waqas *et al*., 2014).

The culture medium is the material for cultivating plants and for fixing and supporting the crops. However,

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most of the common culture media on the market are limited natural resources, but with decreasing resources and waste recycling, only a few studies have used wastes to develop culture media. For example, a Japanese cedar biochar mixture is used for cultivating *Mentha canadensis* (Lin *et al*., 2013). SDR, cultivation waste bag, Japanese Cedar Sawdust (JCS), and pulp sludge are used to prepare biochar as a culture medium (Huang, 2015). In addition, the burn–off technology is used to prepare the mixture of reservoir sludge and rice husk into a granular medium with container capacity (Huang, 2007), and also the mixture of reservoir sludge and rice husk, as a blend material, to develop the granular medium with different particle sizes (Yang, 2008). The mixtures are blended in the reservoir sludge to prepare "porous granular medium"; the increased container capacity is much higher than the matrix materials of such inorganic media as culture medium matrices–perlite and expanded clay.

SDR and JCS were therefore powdered and blended in WS to develop SBMP. Different chemical composition results in different organic matter burn–off properties, such as hemicellulose (250°C), cellulose (325–375°C), and lignin (380–500°C) (Raveendran *et al*., 1996), and pores are left, leading to differences in water absorption and desorption (Chou, 2008; Russ *et al*., 2005). WS was mixed with different proportions of JCS or SDR as the blend material to prepare high porosity of Sludge Biochar Medium Pellet (SBMP) at different carbonization temperatures, whereas the container capacity and organic matter left in the pores might provide the nutrient for plants. The research and development method blended different proportions of JCS and SDR in WS; the mixture was extruded by a self–made mold and then developed into SDRMP (WS with SDR) and JCSMP (WS with JCS) at different carbonization temperatures (300, 450, 600 °C). The follow basic properties were measured: the yield, ash content; water absorption/desorption of physical properties; pH, electrical conductivity (EC), and cation exchange capacity (CEC) of chemical properties. Besides, the SBMP was mixed with peat to prepare Sludge Biochar Medium Pellet Peats (SBMPP), and the physical properties were investigated, including air–filled porosity, container capacity, total porosity, total volume density; as well as pH, EC, and CEC of chemical properties. To develop SBMP as a portion of culture medium in agriculture, SBMP, SDRMP and JCSMP next put in the plug with peat, and general cultivation management was implemented for quality determination on time–dependent degradability. It is expected that the benefits of using fermentation and agricultural and forestry wastes can be increased, and as a functional application to growing soil crops. In other words, the fermentation and agricultural/forestry wastes can play a more important issue in the environmental carbon cycle.

MATERIALS AND METHOD

Test materials

SDR

It was taken from K Liquor Inc. Taiwan, where the sand and soil impurities are filtered with deionized water (DI water), and air dried and pulverized, and then the powder above 40 mesh (the powder above 40 mesh likely forms fresh pellet according to the preliminary test) was taken.

JCS

It was taken from National Chiayi University (NCYU), Taiwan, dried by air, and then derived JCS powder through the above SDR process.

WS

It was also taken from K Liquor Inc. Taiwan, where the specimen was collected by referring to the test method (NIEA S102.63B) of the National Institute of Environmental Analysis: the soil sampling method and air–dried in an oven at 30±4°C.

Peat

Wosong No. 1 Peat, pH 5–6, produced by Dayi Corp. Taiwan, was used as a subsequent mixed culture medium.

Test methods

Development of SBMP with JCS or SDR

JCS and SDR were blended in WS uniformly according to different proportions of 0/100, 20/80, and 40/60% (V/V%), respectively. The 60% DI water was blended in (using 60% DI water to form a fresh pellet has the best effect according to the preliminary test), and the mixture was extruded by the self–made mold and dried. When the sludge lump was formed, it was squeezed into the self–made straw (about ϕ 5 mm) and extruded by a wooden chopstick to form such a stick, and about a 5–6 mm long identical fresh pellet (FP) was cut off by a scraper and air–dried in an oven at 30±4°C. FP was absolutely dried in an oven at 103±2°C and put in a carbonization furnace. Nitrogen was led in at a gas flow of 200 mL/min, and the heating rate was set at 10°C/min to the required 300, 450, and 600°C of carbonization temperature and maintained for 60 min of refined duration. Finally, the temperature was reduced to room temperature by natural cooling. The specimen code is a SBMP type – mixture proportion (%) – carbonization temperature (°C). For example, SDRMP–20–300 represents SDRMP blended SDR 20% and derived at carbonization temperature 300°C.

Determination of preparing SBMP

Basic properties of test materials

Moisture content: determined according to the Wood – Determination of moisture content for physical and mechanical tests (CNS452). Ash content determined according to the Method of test for ash in wood (CNS3084).

Properties of FP and SBMP

SBMP Yield was calculated by yield (%) = (absolute dried mass of SBMP / absolute dried mass of FP) × 100. FP moisture content was the formula from moisture content (%) =[(air–dried mass of FP – absolute dry mass of FP) / absolute dry mass of FP×100. pH value was measured by pH meter (SUNTEX TS–1) after the solution of various specimens with DI water mixed in volume ratio of 1:5 (v/v%) that was kept still for 2 h. Iodine value was evaluated according to JIS K 1474 (2014) – Test methods for activated carbon. The EC of SBMP (SDRMP and JSCMP) was same as the acid–alkali mixed solution ratio, measured by pen type EC meter (CD4301). CEC was investigated from some of SBMP that were placed in the oven cabinet and dried. The detail experimental steps of CEC refer to (Hendershot and Duquette, 1986).

Water absorption was tested from the Method of test for density, relative density (specific gravity), and absorption of fine aggregate (CNS487). An absolute dried mass of 1.5 g was sampled, and the SBMP specimens were immersed in DI water for 3, 6, 9, 15, 30 min and 1, 3, 6, 12, 24, 48 h respectively, and then taken out and weighed. According to the formula: water absorption (%) =[(S–A)/A] ×100. Here, S: mass (g) of each specimen after water absorption; and A: mass (g) of absolutely dried specimen. For water desorption, the SBMP specimens of absolute dried mass of 1.5 g was immersed in DI water for 72 h, taken and weighed, and then reweighed after 3, 6, 9, 15, 30 min and 1, 3, 6, 12, 24, 48 h respectively. According to the equation, water desorption (%) =[(I–A) / A] ×100. Here, I: mass (g) of immersed specimen; and A: mass (g) of absolutely dried specimen.

Preparation of SBMPP

For preparation of the experimental culture medium, various derived SBMPs with different carbonization temperature and different proportions of JCS and SDR in WS were uniformly mixed with peat in the volume ratio of 15:85 (v/v%) (Lin *et al*., 2010). The specimen code is a SBMPP type – mixture proportion (%) – carbonization temperature (°C). For example, SDRMPP–0–300 represents SBMP blended SDR derived at carbonization temperature 300°C without peat (the control group: SDRMP only).

Physicochemical properties of SBMPP

The physical properties of culture medium with SBMPP were investigated, including Air–filled porosity (AFP), Container capacity (CC), Total porosity (TP) and Bulk density (BD). The detail experimental steps of AFP, CC, TP and BD refer to (Bragg and Chambers, 1988). The test methods of the chemical properties (pH, EC and CEC) of SBMPP are same as above that of SBMP.

Degradability of SBMP

Degradation was implemented in plug, where the mass (W_1) of each SBMP specimen was measured, mixed with peat according to the volume ratio of 15/85% (Lin *et al*., 2010), and placed at woodworking factory, NCYU, Taiwan. The test period was 28 days from October 25, 2017 to November 22, 2017. It was watered in the morning and evening every day, it was taken out of the plug to leach peat after 1, 3, 7, 14, 21, and 28 days, the SBMP was placed in an oven at 103±2°C for 24 h for absolutely dried, and the mass (W_o) was measured, and the percent weight was calculated. Equation: Percent weight (%) =[(W_1–W_o) /W_1] ×100.

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 tested specimens

The moisture content (MC) of WS was 86.73%, that of SDR was 10.02%, and that of JCS was 9.40%. The ash content of WS was 14.26%, that of SDR was 4.81%, and that of JCS was 0.66%. Hong *et al*. (2013) indicates that the main ash content are Ca, K, and Si, with a lower ash content representing less inorganic matters. In addition, WS and SDR are derived from the wine brewing process. WS is treated with physical and chemical precipitation, and mixed with coagulant, which may be the source of ash content. The SDR contains rice husk and has high silicon content (Chou, 2008), which may lead to the high ash content of SDR. The MC of various FPs (SDRFP and JCSFP) was 43.50–55.09%. All FPs had slightly different MC. This is because the DI water quantity for preparing FPs is 60%.

Determination of SBMP

Basic properties

The yield of SBMP decreased as the different proportions of SDR and JCS increased. The yield of carbonization temperature 300°C was 60.28–68.68% when both them at different proportations was 0–40%, that of 450°C was 41.46–44.70%, and that of 600°C was 36.92–38.91% (Table 1). It is indicated that the yield of 40% SDR at high carbonization temperature is lower, because when the carbonization temperature increases, the organic matters in the volatile matter and tar of the raw material has a loss on ignition, and the yield decreased (Teng and Hus, 1999). The pH value of the SBMP with different proportions of SDR or JCS was 6.81–7.20 when the carbonization temperature was 300–450°C and 9.32–9.63 at 600°C. When the charcoal is treated at high temperature, the organic compositions are decomposed by heat and released, leaving inorganic matters, such as Ca, K, and Mg (Shiah *et al*., 2003).

EC and iodine value

The EC value increased with the SDR proportion, but decreased as the carbonization temperature increased (Table 1). The EC is the concentration of soluble salts in the solution (Tseng *et al*., 1997), whereby the higher the value is, the higher is the concentration of soluble salts (Huang, 2004). The iodine value of SDRMP decreased from 185.87 to 73.93 mg/g as the carbonization temperature increased, but that of JCSMP was 110.46–214.45 mg/g and higher than SDRMP. Russ *et al*. (2005) indicates that as the carbonization temperature increases, the blend materials meets with pyrolysis loss on ignition,

Table 1. Properties of sludge biochar medium pellets with different proportions of blend materials

Specimen[1)]	Yield (%)	pH value	EC (ds/m)	Iodine value (mg/g)
SBMP–0–300	68.68 (0.02)[C2)]	7.06 (0.07)[Bb3)]	0.14 (0.00)[Ab]	166.49 (10.10)
SDRMP–20–300	66.25 (0.03)[C]	6.81 (0.04)[Aa]	0.43 (0.01)[Cc]	152.48 (6.65)
SDRMP–40–300	60.28 (0.02)[C]	6.85 (0.04)[Aa]	0.32 (0.01)[BCc]	185.87 (4.02)
SBMP–0–450	44.70 (0.01)[B]	6.89 (0.06)[Aa]	0.05 (0.00)[Aa]	113.19 (6.30)
SDRMP–20–450	42.67 (0.01)[B]	7.20 (0.04)[Bb]	0.09 (0.00)[Ca]	141.91 (5.34)
SDRMP–40–450	41.46 (0.00)[B]	7.17 (0.04)[Bb]	0.09 (0.01)[Ca]	86.95 (8.77)
SBMP–0–600	38.91 (0.01)[A]	9.45 (0.07)[AB]	0.14 (0.01)[Cb]	16.43 (5.64)
SDRMP–20–600	37.48 (0.01)[A]	9.63 (0.05)[Cc]	0.21 (0.01)[Db]	89.96 (10.82)
SDRMP–40–600	36.92 (0.01)[A]	9.57 (0.10)[BC]	0.10 (0.01)[ABb]	73.93 (43.68)
JCSMP[6)]–20–300	67.26 (0.02)[BC]	7.09 (0.04)[Ba]	0.19 (0.00)[ABc]	177.29 (16.21)
JCSMP–40–300	62.65 (0.03)[AB]	7.02 (0.03)[Ba]	0.20 (0.00)[ABc]	206.05 (8.33)
JCSMP–20–450	43.44 (0.01)[B]	7.12 (0.01)[Ba]	0.07 (0.01)[Ba]	110.46 (9.19)
JCSMP–40–450	42.90 (0.00)[B]	7.17 (0.03)[Bb]	0.07 (0.00)[Ba]	144.27 (12.40)
JCSMP–20–600	38.58 (0.01)[AB]	9.50 (0.05)[BC]	0.13 (0.01)[BCb]	134.86 (51.32)
JCSMP–40–600	38.24 (0.00)[AB]	9.32 (0.02)[Ac]	0.09 (0.01)[Ab]	214.45 (26.94)

[1)] Sludge Biochar Medium Pellets (SBMP) with Sorghum Distillery Residue (SDR) or Japanese Cedar Sawdust (JCS)–different proportion–carbonization temperature

[2)] Mean (standard deviation) separation within columns by Duncan's multiple range tests at 5% significant level. Upper cases express the different proportion at the same carbonization temperature

[3)] Mean (standard deviation) separation within columns by Duncan's multiple range tests at 5% significant level. Lower case express the different carbonization temperature at the same proportion

and the pellet is more consistency. It may result in the decreased in the iodine value of SDRMP. In addition, at a low carbonization temperature, the higher the proportion of SDR was, the higher was the iodine value. This is because SDR generates more pores after pyrolysis. For SDRMP preparing at the carbonization temperature was 450°C, the iodine value was lower, which might be related to the ignition loss temperature of hemicellulose, cellulose, and lignin of SDR, which is 250–500°C (Raveendran *et al*., 1996). Therefore, when the carbonization temperature increases from 300 to 450°C, the hemicellulose, cellulose, and partial lignin of SDR are burned out before the pellet structure turns stable. The pores left such as consistency due to high temperature, and so the measured iodine value is lower than that at 300°C. JCSMP is free of this phenomenon, likely because the lignin content of JCS is 34.63%, and that of SDR is 21.98% (Jhao, 2017). It is said that JCS and SDR have different contents of lignin, resulting the SDRMP and JCSMP have different porosities and iodine values after pyrolysis.

Water absorption

The water absorption of SBMP, and SDRMP and JCSMP (with the different proportions of 20–40% SDR and JCS) at different carbonization temperatures was higher than 40% after 1 h, was 68–153% after 24 h, and was 69–191% after 72 h. The water absorption curves increased linearly in 1 h, increased slowly in 12 h, and became a plateau after 48 h (Figure 1). Besides, SDRMP and JCSMP had better water absorption performance than SBMP, where the higher the carbonization temperature was, the higher was the water absorption – namely, the blend materials of SDR and JCS with different proportions were able to increase the water absorption after carbonization. It is suggested that a higher carbonization temperature can result in higher water absorption in a short period of time, and the carbonization temperature affects the formation of pores, leading to a difference in water absorption curves. Moreover, the blend materials mainly influence the water absorption. According to Table 1, JCSMP had a higher iodine value than SDRMP, and JCSMP had more multiple pores than SDRMP. It is indicated that the SDR and JCS have different losses on ignition at different carbonization temperatures, and the curves in Figure 1 show different results.

Water desorption

The water desorption is related mainly to the pore characteristics and surface roughness. It is inferred that when the water is adsorbed to the pellet surface, the moisture is to be transpired quickly, so the water desorption is high. When the water is permeated in the pores of pellet, the transpiration is relatively slow. According to the upper left portion of Figure 2, SBMP had a higher water desorption than SDRMP at 300°C of carbonization temperature, whereby the water desorption of SDRMP–20–300 and SDRMP–40–300 were about 51 and 50% after 12 h, the water desorption of SDRMP–20–450 and SDRMP–40–450 were 72 and 70% after 12 h (middle left figure), and the water desorption of SDRMP–20–600 and SDRMP–40–600 were 71 and 57% after 12 h (lower left figure). This is because they have more pores (results of the iodine values in Table 1); the moisture is permeated in pores. However, when the carbonization temper-

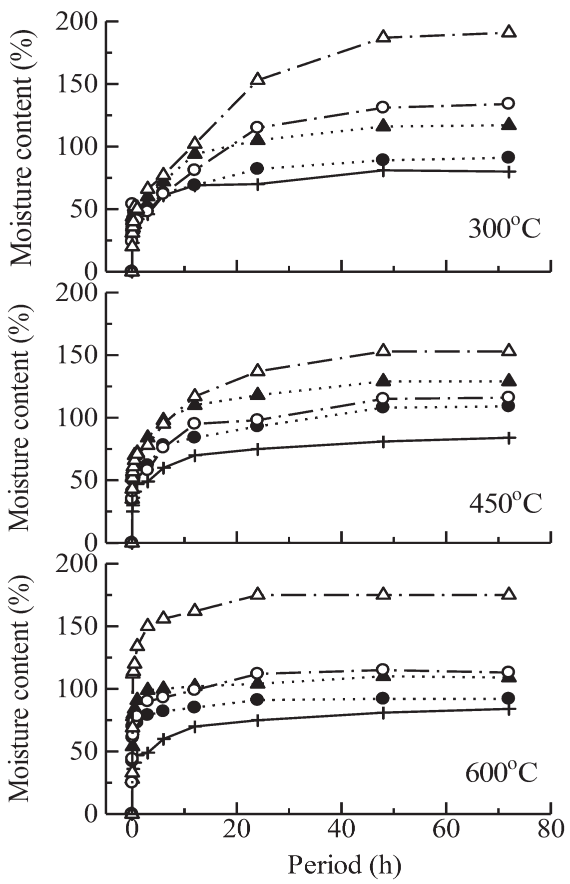

Fig. 1. Water absorption of various sludge biochar medium pellets at different carbonization temperatures.
Legends: —+—: SBMP–0,
---●---: SDRMP–20, ---▲---: SDRMP–40,
—○—: JCSMP–20, ---△---: JCSMP–40
Notes: SBMP, SDRMP and JCSMP see Table1[1], –0, –20 and –40: blended different proportions of SDR and JCS

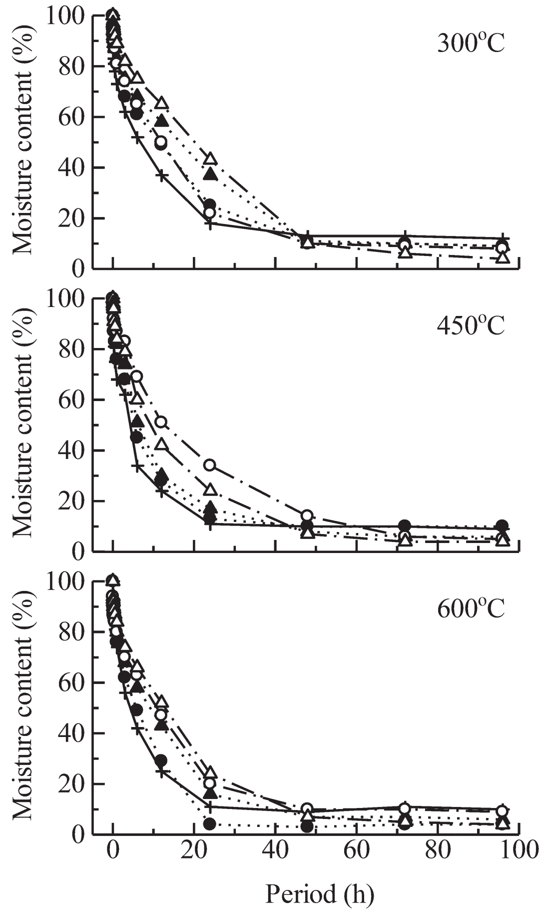

Fig. 2. Water desorption of various sludge biochar medium pellets at different carbonization temperatures.
Legends and Notes see Fig. 1.

ature was high (600°C), the water desorption of SDRMP was high, the pores might be consistency, resulting the iodine value was low (Table 1), and the moisture was mostly adsorbed to the pellet surface, and so the water desorption was higher than that at low carbonization temperature. According to the right portion of Figure 2, the water desorption of JCSMP–20–300 and JCSMP–40–300 were about 42 and 35% after 12 h, that of JCSMP–20–450 and JCSMP–40–450 were 49 and 58%, and that of JCSMP–20–600 and JCSMP–40–600 were 53 and 48%. In comparison to the left portion of Figure 2, JCSMP had a lower water desorption than SDRMP within 48 h, which might because JCSMP had better pore characteristics than SBMP and SDRMP. From the result in the Table 1, JCSMP had a higher iodine value (110.46–214.45 mg/g) than SBMP (16.43–166.49 mg/g) and SDRMP (73.93–185.87 mg/g).

CEC value

The CEC value represents the negatively charged organic matter in medium that can adsorb cations, such as ammonia nitrogen, K, Ca, and Mg cations, meaning that the loss of cations is reduced. Therefore, a high CEC value represents high nutrient preserving capability (Lemaire, 1995). The CEC value of SBMP–0–450 was 6.84 cmol/kg, that of SDRMP–20–450 was 7.64 cmol/kg, and that of SDRMP–40–450 was 35.24 cmol/kg, resulting significant differences among them. The result of SBMP with JCS (JSCMP–20–450 was 10.55 cmol/kg, and JSCMP–40–450 was 35.21 cmol/kg) was close to the above result, meaning the pellet with a higher proportion of SDR or JCS has a higher CEC value. This may be related to the amount of residual organic matter in the pores of pellet at different carbonization temperatures.

Determination of SBMPP

Physical properties

The AFP, CC, TP, and BD of SBMPP are shown in Table 2. Peat is the control group, and peat and either SDRMP or JCSMP is mixed at a per volume ratio of 15/85%. The AFP of 12.99–16.01% for SBMPP, SDRMPP, and JCSMPP was higher than 11.48% of peat, and the CC was a little lower than the control group. The TP were 67.45–75.03% and there was closely same as 75.92% of the peat. It is said that the volume ratio and carbonization temperature have a slight effect on the physical properties, meeting the AFT of 10–25% (Chen, 1996), CC of 40–60% (Yang, 2008) and TP of 54–80% (Hsueh, 2000) of an ideal culture medium. The BD of all SBMPs was 0.12–0.20 g/cm^3, and higher than 0.07 g/cm^3 of peat.

Table 2. Physical properties of sludge biochar medium pellets with peat

Specimen [1)]	AFP (%) [2)]	CC (%)	TP (%)	BD (g/cm^3)
Peat	11.48 (0.00)	64.44 (0.00)	75.92 (0.01)	0.07 (0.01)
SBMPP–0–300 [3)]	14.36 (0.01)	55.90 (0.00)	70.26 (0.01)	0.12 (0.00)
SDRMPP–20–300	15.56 (0.01)	56.01 (0.00)	71.58 (0.01)	0.11 (0.00)
SDRMPP–40–300	16.01 (0.02)	59.02 (0.01)	75.03 (0.01)	0.10 (0.00)
SBMPP–0–450	14.80 (0.01)	52.66 (0.03)	67.45 (0.03)	0.16 (0.00)
SDRMPP–20–450	12.99 (0.00)	56.37 (0.02)	69.37 (0.02)	0.15 (0.00)
SDRMPP–40–450	14.13 (0.01)	59.13 (0.01)	73.26 (0.01)	0.12 (0.01)
SBMPP–0–600	13.39 (0.00)	56.82 (0.02)	70.21 (0.02)	0.14 (0.01)
SDRMPP–20–600	14.51 (0.00)	55.91 (0.01)	70.42 (0.02)	0.14 (0.01)
SDRMPP–40–600	15.66 (0.00)	53.14 (0.02)	68.80 (0.02)	0.11 (0.01)
JCSCPPS3)–20–300	14.09(0.01)	56.53(0.01)	70.62(0.01)	0.10(0.00)
JCSCPPS–40–300	14.00(0.01)	59.17(0.01)	73.17(0.01)	0.11(0.00)
JCSCPPS–20–450	14.23(0.01)	55.82(0.01)	70.06(0.01)	0.12(0.02)
JCSCPPS–40–450	14.08(0.00)	60.20(0.02)	74.28(0.02)	0.10(0.00)
JCSCPPS–20–600	13.78(0.00)	59.89(0.02)	73.66(0.01)	0.11(0.01)
JCSCPPS–40–600	14.14(0.00)	58.06(0.04)	72.20(0.04)	0.12(0.03)

[1)] Each specimen was 15 % of pellet + 85 % of Peat at v/v%
[2)] Physical properties, including AFP: Air–filled porosity; CC: Container capacity; TP: Total porosity; BD: Bulk density
[3)] See Table 1 [1)], for example, SDRMPP–0–300 represents SBMP blended SDR prepared at carbonization temperature 300°C without peat (the control group: SDRMP only)

Table 3. Chemical properties of sludge biochar medium pellets with peat

Specimen [1)]	pH value	EC (ds/m)
Peat	5.51(0.05)$^{Aa2)}$	0.15(0.08)^{a}
SBMPP–0–300 [3)]	6.05(0.02)^{Aa}	0.44(0.01)^{ABc}
SDRMPP–20–300	6.12(0.03)^{ABa}	0.51(0.03)^{Bc}
SDRMPP–40–300	6.26(0.17)^{ABa}	0.49(0.10)^{Bb}
SBMPP–0–450	6.25(0.01)^{Ab}	0.23(0.01)^{Bb}
SDRMPP–20–450	6.10(0.02)^{Ba}	0.35(0.01)^{Db}
SDRMPP–40–450	6.40(0.04)^{Bab}	0.20(0.00)^{Aa}
SBMPP–0–600	6.34(0.03)^{Ab}	0.18(0.01)^{Aa}
SDRMPP–20–600	6.53(0.03)^{Bc}	0.20(0.01)^{Aa}
SDRMPP–40–600	6.53(0.01)^{Bb}	0.18(0.01)^{Aa}
JCSCPPS–20–300	6.34(0.01)^{Bb}	0.36(0.02)^{Ac}
JCSCPPS–40–300	6.31(0.13)^{Ba}	0.34(0.01)^{Ac}
JCSCPPS–20–450	6.18(0.01)^{Ba}	0.28(0.01)^{Cb}
JCSCPPS–40–450	6.36(0.03)^{Ba}	0.19(0.01)^{Aa}
JCSCPPS–20–600	6.44(0.04)^{Bc}	0.21(0.01)^{Aa}
JCSCPPS–40–600	6.51(0.03)^{Ba}	0.17(0.00)^{Aa}

[1)] See Table 2 [1)]
[2)] See Table 1 [2)]
[3)] See Table 2 [3)]

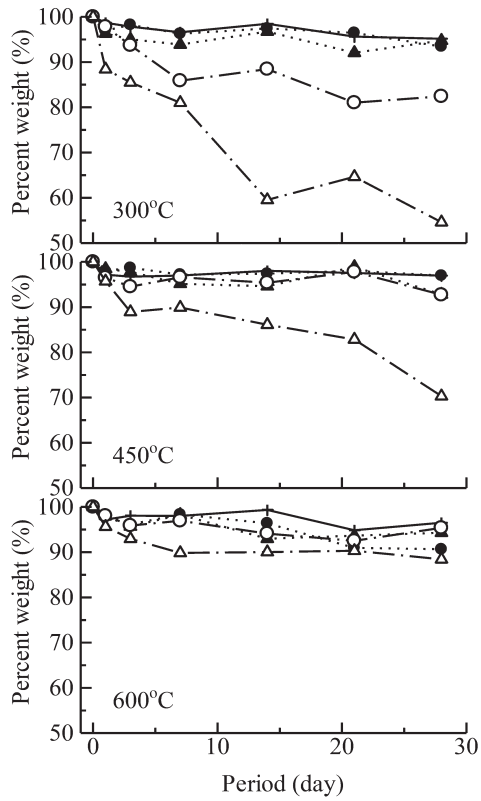

Fig. 3. Degradablity of various sludge biochar medium pellets with peat.
Legends: —+—: SBMPP-0,
···●···: SDRMPP-20, ···▲··· : SDRMPP-40,
—○—: JCSMPP-20, ···△··· : JCSMPP-40
Notes: Legends see Table 2[3)]

This is because the SBMPs have a higher pellet density than peat. In the same volume, the mixed SBMP can increase the BD of a culture medium, so as to further approximate 0.30–0.75 g/cm^3 of a lightweight medium (Chen, 1996).

Chemical properties

Joseph *et al.* (2010) indicates that the pH of a suitable soil environment for the growth of plants is 6.5–7.5. Table 3 showed that the pH of peat 5.51; when SDRMP and JCSMP were mixed with peat, the pH value increased to 6.05–6.53, and slightly approximating the suitable growing environment for plants. According to Table 1, the pH value of SDRMP and JCSMP was 6.81–9.63, and the pH value increased with the carbonization temperature, meaning the mixing of them could increase the pH value of culture medium, further approximating the suitable soil environment for plant growth. The EC value of a general plug culture medium has better be lower than 1.00 ds/m (Koranski, 1993). If the EC value is too high, then the concentration of soluble salts is very high, the osmotic pressure is high, and it is difficult for the plant to absorb moisture and nutrient (Delfine, 2001). The EC value of peat was 0.15 ds/m, and that of SDRMPP and JCSMPP was lower than 1.00 ds/m (Table 3), meeting the range of an ideal culture medium and meaning that the EC value of the culture medium might be increased under the effect of the EC value of various SBMPs.

Degradability

During degradation of SBMP, the average temperature was about 24°C, and the average relative humidity was about 78%. As shown in the right portion of Figure 3, the maximum percent weight of SDRMP was about 10%, and there was no obvious change. This is because the carbonization results in densification; the compressive strength is increased (Yuan *et al.*, 2015). From the JCSMP degradation result, on Day 7 of the JCSMP–20–300 and JCSMP–40–300 degradation test, the percent weight decreased 14.12 and 18.98%, and higher than 3.41% of SBMP–0–300. It was decreased 45.4% on Day 28 of degradation, which might because JCSMP–40–300 was mixed with a high content of JCS, more pores and JCS were left after carbonization, the SBMP disintegrated after a period of degradation, and the percent weight was increased significantly. On Day 14 of degradation of JCSMP–40–450, the percent weight decreased about 10.09%, and higher than 3.02% of SBMP–0–450 and 3.41% of JCSMP–20–450. On Day 28, the percent weight of JCSMP–40–450 decreased 29.68 %, and that of SBMP–0–450 and JCSMP–20–450 decreased 4.83 and 7.28%, respectively. This is related to different proportions of JCS and the pyrolysis degree of compositions. According to the same figure, on Day 28 of degradation of JCSMP–40–600, the percent weight decreased about 11.57%, or obviously lower than that of JCSMP–40–300 and JCSMP–40–450. It may because when the carbonization temperature is 600°C (Raveendran *et al.*, 1996), the lignin of JCS is burnt completely, relating to the porosity of JCSMP.

CONCLUSION

In this study, different proportions of SDR and JCS were blended in WS to develop SBMP at different carbonization temperature. The pH, EC and CEC value of the properties presented insignificant difference to various SBMP, and the pH of SBMP increased with carbonization temperature. The higher the different proportion was, the higher was the CEC value. SBMP had higher water absorption for higher carbonization temperature and proportions. Moreover, the water desorption decreased as the carbonization temperature increased, which was related to the pore size of SBMP due to carbonization temperature and was different from the proportions and type of blend material, matching the result that JCSMP had a higher iodine value than SDRMP. SBMP and peat had the same trend of AFP, CC and TP of physical properties, but there was no difference to the carbonization temperature and the different proportions of SDR and JCS. The chemical properties of pH and EC value were significantly different from the peat (the control group). After one month's degradation, the percent weight of SDRMP was lower than that of JCSMP, and it increased with carbonization temperature. It is suggested that blending SDR and JCS in WS to develop various SBMPs preparing at different carbonization temperature offers great potential for the portion of agricultural culture media.

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AUTHOR CONTRIBUTION

The students, J. H. Yeh, K. Y. Tsai, J. Y. Lian, M. H. Chen and W. C. Huang, performed the experiments, analyzed the data and the statistical analysis. 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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