Development of Bio-functional Materials from Agricultural/Forestry Processed Wastes using a Concept of Multi-utilization with Pyrolysis

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Abstract Pyrolysis of agricultural/forestry processed wastes (AFPW) is one approach that has been investigated to develop materials into products of higher value. This paper describes a concept of multi-utilization with pyrolysis under various conditions which has been extensively prepared for related bio-functional materials like biochar, charcoal and activated carbon (AC). The prepared materials were developed into products such as biochar as part of cultural media for agricultural production; charcoal or AC as a potential moisture-proof adsorbent for food use; and the AC as a kind of liquid absorption for water purification. The biochar was prepared from AFPW as a cultural media substrate. Cultural media with biochar can be applied to vegetable plug seedlings with functions including preserving moisture and fertility, offering oxygen to expand the roots. For a food moisture-proof adsorbent, bamboo and wood charcoals were refined into various ACs using physical activations. The hygroscopicity of the resulting AC was better than that of charcoals, and the water activity of the AC was from 0.45 to 0.46. In addition, water purifying AC used sorghum distillery residue with the method of physics activation with steam-activation, which meets the quality standard for drinking water in Taiwan. The above products are concerned with multi-utilization under various pyrolysis conditions which can be used as a reference for resource reutilization from AFPW and also as examples of bio-functional materials' ability to be implemented in a sustainable reuse of resources.

Keywords Pyrolysis, Multi-utilization, Agricultural/Forestry Processed Wastes, Bio-functional Materials

1. Introduction

In the last 100 years many problems have come to threaten the environment, such as vanishing forests, acid rain, the

burning of fossil-fuels and global warming. Since 2000, anthropogenic carbon dioxide (CO₂) emissions, unprecedented high levels of greenhouse gases in the atmosphere, have risen by more than 3% annually, putting earth's ecosystems on a trajectory toward rapid climate change that is both dangerous and irreversible [1, 2]. Currently, researchers are focusing on so-called "bio-materials" and/or "eco-materials" that make effective and environmentally friendly use of natural resources, such as the reuse of natural wastes, the recycling of industrial wastes, the development of new environmentally friendly materials, etc.

Pyrolysis, one thermochemical process, is generally used for the conversion of biomass into fuels, char (biochar, charcoal and carbon), and by-products in this conversion process [3]. It has been estimated that by the year 2050 about 80% of all crops and forestry residue may be converted into biochar and energy according to the International Biochar Initiative Organization [4]. Agricultural/forestry processed wastes (AFPW) could be rich resources in the earth [5] and as a precursor for preparing biochar and activated carbon (AC) with various preparation conditions [6].

The advantages of AFPW as the precursor for biochar, charcoal and AC include solving the problem of wastes, converting it to environment functional materials, decreasing the amount of AFPW and increasing it with a higher value-added. The different preparations of AFPW can be adapted to the production of different bio-functional materials, such as biochar with a low pyrolysis temperature, refined charcoal with a high pyrolysis temperature and AC with various carbonization and activation temperatures. According to the difference in porosity, specific surface areas and adsorption characteristics, multi-utilization for the application of biochar, charcoal and AC was considered from AFPW.

Figure 1 depicts a flow chart of this paper. The bio-functional materials prepared from AFPW are illustrated under three subjects: (1) the prepared biochar as a substrate

in a portion of cultural media with C-rich residues, organic substances and mineral elements; (2) the refined charcoal as a food moisture-proof adsorbent with the ability for absorption and high specific surface areas and (3) the prepared AC with better characteristics of adsorption/desorption as a water purification material. These hopefully increase the value-added, resource-utilized and/or ability-evaluated for AFPW, when they are applied to the safety of human health, the function of life and the sustainable use of the ecosystem. Furthermore, for the product life cycle assessment, these bio-functional materials are needed to evaluate their carbon footprint, carbon sequestration and carbon cycle in the future.

Figure 1. A flow chart of bio-functional materials preparing from agricultural/forestry processed wastes (AFPW)

The advantage of the addition of biochar to the soil is that it has the ability to retain nutrients, high stability against decay and the ability to remove carbon dioxide from the atmosphere and revitalize degraded ground [7]. This is because biochar is a carbon rich, about 65-90%, and porous substance with oxygen functional groups and/or aromatic surfaces [8, 9]. Using biochar as a portion of cultural media, such as vegetable plug seedlings, assists in many ways including preservation of moisture and fertility, availability of oxygen to expand the roots, etc. [7, 10-12].

The first section of this paper describes biochar that was prepared from AFPW, including sorghum distillery residue (SDR), cultivation bag waste (CBW), Japanese cedar sawdust (JCS) and pulp sludge (PS), to be used as a cultural media substrate. Digital images of SDR, CBW, JSC and PS, as well as each prepared biochar are shown in Figure 2. Huang [6] reported that the carbonization temperature had a strong influence on both physical and chemical characteristics of various biochars. The yield and C, N and H contents of biochar specimens were 31.02-89.02%, 18.94-85.79%, 0.80-5.95% and 0.06-4.66%. The C and H contents of JCS biochar were the highest followed by SDR biochar, but the N content of SDR biochar was higher than the others. The pH value, iodine value and electrical conductivity of 4 types of biochar were 6.46-11.73, 42.29-341.42 mg/g and 0.07-3.44 ds/m. The water absorption in the SDR and JCS biochars were increased with the increase in carbonization temperature. The average pore diameter ranged from 3.88 to 28.96 nm belonging mostly to mesoporous structures. These prepared biochars, therefore, represent a potential material for cultural media substrate.

2. Biochar as Part of Cultural Media

Notes SDR: sorghum distillery residue; CBW: cultivation bag waste; JSC: Japanese cedar sawdust (JSC); PS: pulp sludge

Figure 2. Digital images of SDR, CBW, JSC and PS, and resulting products – biochar

Table 1 shows the physical properties of cultural media, including perlite and prepared biochar, with different carbonization temperatures mixed with a peat medium. The air-filled porosity (AFP) of the commercial perlite + peat (control group) was 9.03% and those for 200 to 450 + peat (test groups) were from 11.11 to 12.75%, which was significantly different from Duncan's multiple range tests. The container capacity (CC) of the control group was 65.88% and capacities for the test groups were from 61.87 to 73.44%. The CC of the peat containing biochar carbonized at six different temperatures was higher than that of the control group. The total porosity (TP) of the control group was 72.74% and those of the test groups were from 71.08 to 73.44%. It was observed that the TP of the six types of test groups was about the same as that of the control group (Table 1). The above results indicate that the cultural media are close to the ideal media in service [13-15]. In addition, the bulk density (BD) of the control group was 0.13 g/cm³ and those of all test groups were from 0.12 to 0.14 g/cm³. Therefore, the BD of the cultural media was lower than the ideal range of BD (0.3 to 0.7 g/cm³) [16]. Both of them are classified as lightweight media. The results suggest that the physical properties of the six types of test groups are close to those of the control group.

The following results are not shown in this paper. The cucumber (*Cucumis sativus* L.) plug seedlings indicated that for the 28th day the dry weight and fresh weight with perlite

in the media were 4.510 g and 0.467 g; the SDR biochar values at 450°C carbonization temperature were 4.203 g and 0.484 g; the CWB biochar values at 450°C were 4.023 g and 0.421 g; the JCS biochar values were 4.361 g and 0.462 g and the PS biochar values were 4.311 g and 0.480 g. Table 2 illustrates the seedling index for cucumbers in various cultural media during the 7 to 28-day nursery growth period. The seedling indexes of the control group and test groups all increased as time went by. According to Duncan's multiple range tests, on the 7th, 14th, 21st and 28th day, the seedling index of the cultural medium with perlite was smaller than that of the SDR biochar at 450°C carbonization temperature. The seedling index of the SDR biochar at 450°C was the highest one with significant differences to perlite in the media and the other test groups. Moreover, Huang [6] reported that during the plug seedling period, the cation exchange capacity (CEC) of the media with biochar at 450°C was higher than that of the media with perlite.

The above results suggest that AFPW biochar as the cultural media substrate was able to contribute to quality growth of the vegetable plug seedlings. Among all, the seedling index for cultural media with SDR biochar at 450°C carbonization temperature as the substrate at a 15% volume was better than the media with perlite and the others that could obtain better quality growth of vegetable plug seedlings.

Table 1. Physical property of cultural media with SDR biochar ¹⁾

Cultural media ²⁾	AFP ³⁾ (%)	CC (%)	TP (%)	BD (g/cm ³)
Perlite + peat ⁴⁾	9.03 (2.03) ^{a5}	65.88 (3.55) ^c	72.74 (1.33) ^b	0.13 (0.01) ^{bc}
200 ⁶⁾ + peat	11.11 (0.14) ^b	61.87 (2.13) ^a	71.08 (1.55) ^a	0.12 (0.01) ^b
250 + peat	12.14 (2.40) ^c	62.94 (3.64) ^b	72.09 (1.37) ^b	0.12 (0.01) ^b
300 + peat	12.30 (3.26) ^c	62.86 (1.71) ^b	72.66 (1.54) ^b	0.13 (0.01) ^{bc}
350 + peat	12.21 (1.42) ^c	62.54 (3.70) ^b	72.84 (1.65) ^b	0.13 (0.01) ^{bc}
400 + peat	12.75 (0.68) ^c	62.23 (5.10) ^b	73.44 (2.09) ^c	0.14 (0.01) ^c
450 + peat	12.19 (0.54) ^c	62.74 (4.31) ^b	73.12 (2.10) ^c	0.14 (0.01) ^c

¹⁾ SDR biochar: sorghum distillery residue biochar;

²⁾ Cultural media: substrate: peat = 15: 85 (v/v %);

³⁾ AFP: air-filled porosity; CC: container capacity; TP: total porosity; BD: bulk density;

⁴⁾ control group;

⁵⁾ Mean (standard deviation) with the different superscripts are significantly different ($p < 0.05$) by Duncan's multiple range tests. Alphabets express the different substrate at the same peat to control group;

⁶⁾ SDR biochar prepared with the carbonization temperature to as cultural media substrate.

Table 2. Seedling index of cucumber for cultural media with perlite and SDR biochar during 28 nursery growth period

Cultural media ¹⁾	Days of seedling growth (in days)			
	7	14	21	28
Perlite + peat ²⁾	0.022 (0.003) ^{aA3)}	0.099 (0.013) ^{aA}	0.213 (0.038) ^{abA}	0.279 (0.041) ^{aA}
200 ⁴⁾ + peat	0.038 (0.004) ^{cd}	0.110 (0.013) ^a	0.189 (0.058) ^a	0.267 (0.079) ^a
250 + peat	0.032 (0.004) ^b	0.097 (0.017) ^a	0.204 (0.013) ^{ab}	0.286 (0.052) ^a
300 + peat	0.035 (0.004) ^{bc}	0.108 (0.015) ^a	0.202 (0.024) ^{ab}	0.351 (0.035) ^a
350 + peat	0.034 (0.003) ^{bc}	0.107 (0.014) ^a	0.225 (0.012) ^{ab}	0.295 (0.048) ^a
400 + peat	0.038 (0.003) ^{cd}	0.118 (0.020) ^{ab}	0.231 (0.029) ^{ab}	0.347 (0.087) ^a
450 + peat	0.040 (0.007) ^{db}	0.134 (0.014) ^{bb}	0.244 (0.019) ^{bb}	0.338 (0.094) ^{ab}

^{1), 2)} and ⁴⁾ are the same as Table 1 ^{2), 4)} and ⁶⁾;

³⁾ Mean (standard deviation) with the different superscripts are significantly different ($p < 0.05$) by Duncan's multiple range tests. The lower alphabets express the different substrate at the same peat to control group. The upper alphabets express SDR biochar at 450 °C of carbonization temperature with peat to control group.

3. Refined Charcoal as Food Moisture-proof Adsorbent

Charcoal is a porous material with a high specific surface area that has many functions, such as indoor deodorization, humidity control, water quality improvement and air purification [17], and can be added as a pigment in food [18, 19]. After being refined by activation, charcoal becomes AC that still retains the charcoal's characteristics [20]. The high specific surface area and total pore volume of AC are greater than those of charcoal [21] and can be applied for gaseous and liquid adsorption [22]. However, the charcoal and AC raise a profound question as to whether or not residue *in vivo* causes any harm by inducing cell lesions or carcinogens, when they are considered as a food moisture-proof absorbent or pigment ingredients. The second section of this paper addresses the moisture absorption and preliminary safety of AC refined from Makino bamboo, Moso bamboo and Japanese cedar charcoals with CO₂ at different activation temperatures and times [20].

The hygroscopicity for charcoal and AC at both relative humidities (RH) of 40 and 90% is shown in Table 3. No

matter what the RH was, the maximum weight percent of the AC was better than that of charcoal. According to Duncan's analysis, at 40 and 90% RH the maximum weight percent of AC and charcoal is obviously different. The maximum weight percents of Makino bamboo, Moso bamboo and Japanese cedar AC at 40% RH were 12.1-30.6%, 11.6-23.8% and 10.1-16.8%, higher than that of silica gel at 11.07%. For a 90% RH, the maximum weight percent of AC was 15.2-45.1%, higher than that (9.9-13.3%) of all charcoals. The highest maximum weight percent (45.1%) was found to be for Makino bamboo AC with CO₂ at 900°C activation temperature for 150 min which was higher than for silica gel (37.2%); the lowest (15.2%) was Makino bamboo AC with CO₂ at 800°C for 90 min. This indicates that the increase in the moisture adsorption is based on the increase of both activation temperature and time. Moreover, no matter what kind of AC is used, the higher hygroscopic ability is affected by the activation temperature and time, and the influence of the activation temperature is greater than that of the activation time [23, 24].

Table 3. Maximum percent weight of charcoals, activated carbons and silica gel in high/low relative humidity conditions at either 90 or 40 % with a constant temperature at 25 °C

Precursor	Activation		Maximum percent weight (%)	
	Temperature (°C)	Time (min)	40 % RH	90 % RH
Makino bamboo charcoal	Control	- ¹⁾	9.2 (0.48) ^{aA 2)}	11.3 (0.63) ^{aA}
	800	90	12.1 (0.24) ^b	15.2 (0.93) ^b
		120	13.0 (0.24) ^c	17.1 (0.78) ^c
		150	13.8 (0.51) ^d	18.2 (0.75) ^c
	900	90	21.3 (0.78) ^B	28.5 (0.65) ^B
		120	24.3 (0.94) ^C	34.6 (1.06) ^C
		150	30.6 (2.96) ^D	45.1 (0.97) ^D
	Control	-	6.7 (0.31) ^{aA}	9.9 (0.26) ^{aA}
Moso bamboo charcoal	800	90	11.6 (0.28) ^b	15.6 (0.49) ^b
		120	12.5 (0.25) ^c	17.3 (0.94) ^c
		150	13.1 (0.29) ^d	17.6 (0.41) ^c
		Control	6.7 (0.31) ^{aA}	9.9 (0.26) ^{aA}
	900	90	20.0 (1.25) ^B	29.1 (0.71) ^B
		120	22.1 (1.34) ^C	29.9 (1.10) ^B
		150	23.8 (1.09) ^D	40.3 (0.75) ^C
	Control	-	6.7 (0.31) ^{aA}	9.9 (0.26) ^{aA}
Japanese cedar charcoal	800	90	10.1 (0.64) ^b	17.4 (1.03) ^b
		120	10.5 (1.61) ^c	17.9 (2.28) ^b
		150	10.7 (0.57) ^d	18.7 (1.02) ^b
		Control	9.5 (0.52) ^{aA}	13.3 (0.45) ^{aA}
	900	90	15.1 (1.08) ^B	32.7 (1.82) ^B
		120	16.1 (1.02) ^C	35.7 (3.37) ^B
		150	16.8 (1.40) ^D	33.4 (2.10) ^B
	Control	-	9.5 (0.52) ^{aA}	13.3 (0.45) ^{aA}
Silica gel	-	-	11.7 (0.10)	37.2 (0.17)

¹⁾ — : Non condition;

²⁾ Mean (standard deviation) separation within columns to control group (Control) by Duncan's multiple range tests at 5 % significant level. Alphabets express the different activation time at the same activation temperature to Control.

The water activity (A_w) indicates the amount of water in the total water content available to micro-organisms. Each of the species of micro-organisms has its own minimum A_w . The growth of micro-organisms is no longer possible when the A_w is below 0.65-0.95 [25]. After the charcoals were refined by using physical activation, the A_w of the AC decreased and was lower than the A_w for micro-organism growth. The A_w values of charcoals and AC were 0.56-0.58 and 0.45-0.46, respectively (results not shown in this paper). The heavy metal content (as Pb ppm base) of charcoal and AC were below 40 ppm (results not shown in this paper) and met the Sanitation Standard for Edible Natural Colorants, Food Sanitation Standards. For the Ames test, none of the charcoal or prepared AC had toxicity or mutagenicity toward *Salmonella typhimurium* TA98 and TA100 with or without S9 (results not shown in this paper). It is suggested that since the preliminary safety evaluation shows no toxicity and mutagenicity, charcoal and AC can not only be considered to be safe pigment materials for food, but also can be used as natural moisture-proof materials due to their low A_w and good adsorption.

4. Activated Carbon as Water Purification Material

AC is a porous adsorbing material with a nonpolar surface and is effective in adsorbing organic matter from water solution [26-28]. It has stable chemical properties and is resistant to acid, alkali, high temperatures and high pressure, and is extensively applicable to the drinking water

purification process [29]. SDR, one residual product brewed from sorghum liquor, generally is part of fermentation wastes in the food industry. According to the Environmental Protection Administration, Executive Yuan in Taiwan [30], the annual output for SDR is about 131 000 MT, which is in accordance with the statistics reported for industrial waste. For example, the daily output of SDR is about 300 tons in Kinmen County, one important production area for sorghum liquor in Taiwan, and this increases year by year [31]. SDR has not been developed nor has it become a highly value-added product, even though it has been researched in areas such as soil improvement and crop nutrition [32, 33], compost materials [34, 35], biotransformation using fungus [36], extraction of antioxidants [37, 38], functional application of extracts [39, 40], production of ethanol biomass [31] and feed improvement [41-44]. SDR is also a fibrous material and/or carbonaceous matter, which can become an AC by the use of a suitable pyrolysis and/or activation method. SDR can be prepared into SDRAC with multiple mesopores [45]. The following study reports on sorghum distillery residue activated carbon (SDRAC) being prepared by physical activation to evaluate its application to water purification, as well as the preliminary safety of water quality before and after purification [46]. The photos and microscope observations for the SDR and the SDRAC specimens are shown in Fig. 3. The 500 times SEM micrograph of SDR indicated that there was no pore with a rugged surface, and the image of SDRAC showed the presence of uneven honeycomb-like groups of pores on the surface.

Note: SDRAC: sorghum distillery residue activated carbon

Figure 3. Photos and SEM (x 500) of SDR and SDRAC

The two types of water purification methods were as follows: (1) standing method: the SDRAC and the water specimen were mixed at a weight ratio of 1:10 (wt%) and kept still for 30 and 60 min [47]; (2) filtration method: the SDRAC was placed in a glass funnel. The water specimen flowed from the top to the bottom under gravity and was controlled by a valve. The flow velocities were 10 ± 2 mL/min and 5 ± 2 mL/min [48], and the weight ratio of SDRAC to the water specimen was 1:10 (wt%) as well. The turbidity of the water specimen was determined by the ratio of the reference standard turbidity suspension of the water specimen to the intensity of the specific scattered light, and the unit used was Nephelometric Turbidity Unit (NTU) [49]. Table 4 shows the turbidity of the raw water and slow filter water purified by the filtration method with SDRAC. The raw water turbidity was 20.6 NTU, and the slow filter water was 1.34 NTU. The turbidity of the raw water was reduced to 2.80-1.73 NTU after filtration. The water turbidity was able to be removed by 86.4-91.6%; the turbidity of slow filter water was removed by 7.4-58.9%, i.e. 1.24-0.55 NTU. It was indicated that the SDRAC was influenced by them when purifying water, and the water turbidity decreased as the flow velocity decreased. The water quality standard for drinking water specifies the turbidity as 2 NTU. It is suggested that the raw water specimen processed by SDRAC at a flow velocity

of 5 ± 2 mL/min can reach the water quality standard for drinking water.

The following results are not shown in this paper. The pH value of water was increased by the SDRAC filtration or standing in the solution, and the pH value, after processing, was increased by 13.4-61.6%. The total hardness of the raw water and slow filter water specimens processed by SDRAC was removed by 23.2-52.3%, and the value was 55.6-88.6 mg/L. The nitrite nitrogen concentration could be reduced after processing by SDRAC. Table 5 shows the total bacterial count of raw water and slow filter water specimens, as filtered by the standing method with SDRAC. The total bacterial count for raw water was 1539 CFU/mL. The total bacterial count decreased significantly after standing, and the total bacterial count in water was reduced by 99.5-99.9% after 30 and 60 min SDRAC standing, i.e. 1-5 CFU/mL. The total bacterial count was able to be reduced by more than 99%, thus, conforming to the water quality standard for drinking water (100 CFU/mL). Uraki *et al.* [50] reported that the AC filtration and standing processes are effective methods to reduce the total bacterial count in water. The active mechanism operates when the strong alkaline solution condition is presented in AC to cause bacterial death and the bacteria are adsorbed in the AC.

Table 4. Turbidity¹⁾ of water specimen for raw water and slow filter water after processing by standing method with SDRAC²⁾ Unit: NTU

Water specimen ³⁾	Raw water ⁴⁾	Percent removal (%) ⁵⁾	Slow filter water ⁴⁾	Percent removal (%)
Blank ⁶⁾	20.60 (1.84) ^{b7)}	-	1.34 (0.39) ^b	-
T850-60- 90-10 mL/min ⁸⁾	2.50 (0.26) ^a	87.8	1.11 (0.24) ^b	17.1
T850-60- 90- 5 mL/min	1.73 (0.16) ^a	91.6	0.60 (0.06) ^a	55.2
T800-60- 90-10 mL/min	2.80 (0.29) ^a	86.4	1.24 (0.26) ^b	7.4
T800-60- 90- 5 mL/min	1.96 (0.03) ^a	90.4	0.59 (0.15) ^a	55.9
T800-60-120-10 mL/min	2.36 (0.36) ^a	88.5	0.99 (0.24) ^{ab}	26.1
T800-60-120- 5 mL/min	1.90 (0.14) ^a	90.7	0.61 (0.14) ^a	54.4
T800-60-150-10 mL/min	2.36 (0.28) ^a	88.5	0.94 (0.15) ^{ab}	29.8
T800-60-150- 5 mL/min	1.84 (0.06) ^a	91.0	0.55 (0.04) ^a	58.9

¹⁾ Turbidity of water quality standard for drinking water source is no standard; Turbidity of water quality standard for drinking water is 2 NTU [49];

²⁾ SDRAC: see the Figure 3;

³⁾ Water specimen was processed by method of water purification with different prepared SDRAC;

⁴⁾ The raw water and the slow filter water were obtained on May 27, 2014;

⁵⁾ Percent removal (%) = [(turbidity of blank - turbidity of water specimen after processing with SDRAC) / turbidity of blank] * 100;

⁶⁾ Blank: water specimen is raw water or slow filter water that unprocessed with any SDRAC;

⁷⁾ Mean (standard deviation) with the different superscripts are significantly different ($p < 0.05$) by Duncan's multiple range tests;

⁸⁾ T (Activation temperature) - Activation duration - Flow rate - Time of flow velocity

Table 5. Total bacterial count¹⁾ of water specimen for raw water and slow filter water after processing by standing method with SDRAC²⁾ Unit: mg/L

Water specimen ³⁾	Raw water ⁴⁾	Percent removal (%) ⁵⁾	slow filter water ⁴⁾	Percent removal (%)
Blank ⁶⁾	1539 (66.00) ^{b7)}	-	1025 (104.00) ^b	-
T850-60- 90- 30min ⁸⁾	3 (0.82) ^a	99.8	1 (0.00) ^a	99.9
T850-60- 90- 60min	4 (1.70) ^a	99.7	5 (1.63) ^a	99.5
T800-60- 90- 30min	1 (0.00) ^a	99.9	1 (0.47) ^a	99.9
T800-60- 90- 60min	4 (2.16) ^a	99.7	2 (0.82) ^a	99.8
T800-60-120- 30min	2 (0.47) ^a	99.8	1 (0.47) ^a	99.9
T800-60-120- 60min	4 (1.63) ^a	99.7	5 (1.63) ^a	99.5
T800-60-150- 30min	1 (0.00) ^a	99.9	1 (0.47) ^a	99.9
T800-60-150- 60min	2 (0.88) ^a	99.8	3 (2.16) ^a	99.7

¹⁾ Total bacterial count of water quality standard for drinking water source is no standard; Total bacterial count of water quality standard for drinking water is 100 mg/L [49];

²⁾ see the Figure 3; ³⁾, ⁴⁾, ⁶⁾, ⁷⁾ and ⁸⁾ see Table 4;

⁵⁾ Percent removal (%) = [(total bacterial count of blank - total bacterial count of water specimen after processing with SDRAC) / total bacterial count of blank] * 100

The accepted concentration of coliform according to the water quality standard for drinking water sources is 20 CFU/mL, and the accepted concentration for drinking water is 0.06 CFU/mL [49, 51]. The filtrate of raw water, slow filter water filtered by SDRAC, and both standing and filtration methods were all below 1 CFU/mL (results not shown in this paper) in Taiwan. Besides, the bacterial survival rate of cytotoxicity testing for water specimens before and after purification was higher than 80% of the control specimen (Blank) and test groups; meaning there was no cytotoxicity. The mutagenicity results show that spontaneous revertants did not occur more than twice; thus, there was no mutagenicity (results not shown in this paper). The water processed by SDRAC meets water quality standards for drinking water, and the preliminary safety of SDRAC can be guaranteed by the Ames Tests. Therefore, SDR may be used to prepare AC, which can be prepared into SDRAC, and can be as the functional material for water purification.

5. Conclusions

AFPW was used for preparing biochar as the substrate of functional cultural media in plug seedling growth. It was feasible to apply biochar in quality growth of vegetable plug seedlings. Among all those tested, the seedling index for the cultural media with SDR biochar with a 450°C carbonization temperature substrate at 15% volume was better than those of the media with the perlite and the others demonstrated by better quality growth of the vegetable plug seedlings. The study also used one of AFPWs - SDR as the precursor to prepare SDRAC, using the method of physics activation with steam, to as the purification materials for evaluating the preliminary safety of water quality before and after purification. The water treated by SDRAC had no cytotoxicity or mutagenicity. Turbidity, total hardness, nitrite nitrogen, total bacterial count and coliform of the water purified prepared with SDRAC met the quality standards for drinking water in Taiwan. Besides, refined charcoal with better absorption and higher specific surface area is expected to be similar to the materials of edible natural colorants and/or natural moisture-proof adsorbents, because its Aw ranges from 0.45 to 0.46. The heavy metal content in the Pb ppm base of refined charcoal was below 40 ppm. This meets the Sanitation Standard of Edible Natural Colorants from the announcement by the Department of Health's Executive Yuan, in Taiwan. The preliminary safety evaluation, using the Ames test for refined charcoal, had no cytotoxicity and mutagenicity as well. Therefore, the above biochar, refined charcoal and AC from AFPW concerned with the concept of multi-utilization with pyrolysis can be a reference for the use of bio-functional materials to attain the sustainable reuse of resources.

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