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Sugarcane and Pine Biochar as Amendments for Greenhouse Growing Media for the Production of Bean (*Phaseolus vulgaris* L.) Seedlings

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Abstract

Louisiana sugarcane farmers in 2016 harvested 11.7 million Mg of millable sugarcane from 163,000 ha, producing 1.47 million Mg of raw sugar and an estimated 3.5 million Mg of bagasse. Even though Louisiana sugar mills use 80% to 90% of the bagasse for fuel production, another 350,000 to 700,000 Mg of bagasse accumulates each year. The conversion of the excess bagasse into biochar is one solution to reduce the excess supply. Research was conducted to determine the impact of sugarcane biochar as an amendment to soilless planting media for the production of green bean (*Phaseolus vulgaris* L.) seedlings. Sugarcane bagasse biochar (SBB) and pine biochar (PB) were each combined by volume with a commercial certified organic soilless growing media into 5 combinations (0%:100%, 25%:75%, 50%:50%, 75%:25%, and 100%:0%, biochars and growing media, respectively). Green bean variety 'Bowie' seeds were planted in each of the different planting mixtures. The particle size distribution for the two biochars are in stark contrast to each other with the PB particle median, mean, geometric mean, and mode much greater than those of the SBB. As amendments to the soilless greenhouse growing media, the biochars (SBB and PB) functioned very well, especially at the 25% and 75% levels. The 100% SBB performed as well as the 100% commercial soilless growing media and slightly better than the 100% PB when comparing seedling fresh and dry weights. The 100% PB is not recommended as a soilless growing media even with the supplemental fertilizer used in these experiments. These results indicate that the volume of a standard soilless greenhouse growing media can be successfully extended by adding 25% to 75% SBB and PB without reducing bean seedling growth. Future research is needed to evaluate these biochars for the production of additional plant species.

Keywords: agricultural by-products, bagasse, certified organic, pine, soilless growing media, sugarcane

1. Introduction

Louisiana sugarcane farmers in 2016 harvested 11.7 million Mg of millable sugarcane from 163,000 ha, producing 1.47 million Mg of raw sugar and an estimated 3.5 million Mg of bagasse (American Sugar Cane League, 2017). Global sugar production in 2016 was over 170 million Mg of raw sugar, which resulted in the production of over 300 million Mg of bagasse at milling facilities (United States Department of Agriculture, 2017). Bagasse is the fibrous plant by-product remaining after removing the sucrose, water, and other extraneous material impurities (*e.g.* sediment) from the sugarcane brought to the mill. Bagasse, on a dry weight basis, is composed of 40-50% cellulose, 30-35% hemicellulose, 20-30% lignin, and a small percentage of other materials (Cardona et al., 2010; A. R. F. Drummond & I. W. Drummond, 1996; Martin et al., 2007; Pandey et al., 2000; Sales & Lima, 2010;). Sugarcane bagasse has been used for paper and fiber board production (Amin, 2011; Xin et al., 2002), cattle feed (Nigam, 1990; Pandey et al., 2000), potting media (Jhurree-Dussoruth et al., 2011; Trochoulias et al., 1990), a mulch for crop production (Webber et al., 2017a), a source for value added products (*i.e.* pigments, enzymes, amino acids, and drugs) (Pandey et al., 2000), and energy production (thermal conversion and ethanol) (Badger, 2002; Kilicaslan et al., 1999; Martin et al., 2007; Peng et al., 2009; Sun & Cheng, 2002).

Louisiana sugarcane mills burn sugarcane bagasse to generate steam power to run equipment within the mill and/or as a boiler fuel for the clarification, evaporation, and crystallization processes. Although the composition of ash produced is dependent on the source of the sugarcane, bagasse ash content is predominately (60-81%) silica dioxide (SiO_2) and is low in essential plant nutrients (Payá et al., 2002; Zandersons et al., 1999). Research investigating the use of sugarcane bagasse ash as an amendment to soilless greenhouse growing media determined that the amended media functioned well in many respects for the seedling production of squash, cantaloupe, bean (*Phaseolus vulgaris* L.), and Chinese kale (*Brassica alboglabra*). However, Webber et al. 2016; 2017b reported that high ratios of bagasse ash (100%) increased bulk density (0.12 to 71 g cm^{-3}), resulting in a decrease in the physical growing media properties.

Even after Louisiana sugar mills use 80% to 90% of the bagasse for fuel production (Hass & Lima, 2017; Pandey et al., 2000) 350,000 to 700,000 Mg of bagasse accumulates annually. The conversion of the excess bagasse into biochar is an excellent option to reduce excess material and develop additional income streams. Biochar is the result of incomplete carbonization of organic material under limited oxygen (pyrolysis). Substantial research has been conducted concerning the impact of biochars and "slash and burn" practices on mineral soils with a much smaller quantity directed towards biochars as an amendment to soilless growing media (Barrett et al., 2016; Vaughn et al., 2013). In a research review of environmentally sustainable amendments for soilless growing media, twenty seven different organic materials were listed, including four amendments related to sugarcane waste (Barrett et al., 2016). The sugarcane waste materials included as amendments for soilless growing media were filtercake compost (Stoffella et al., 1996), sugarcane trash/sewage sludge compost (Jayasinghe et al., 2010), sugarcane bagasse ash (Webber et al., 2016), and sugarcane bagasse/manure vermicompost (Khomami & Moharam, 2013). The three primary criteria for selecting amendments used in soilless growing media are performance, economics, and the increasing emphasis on the environmental impact (Barrett et al., 2016). The primary environmental concern is the identification of suitable alternatives to replace peat in soilless growing media due to several negative environmental impacts of peat harvesting (Alexander et al., 2008; Schmilewski, 2014). Vaughn et al. (2013) investigated the use of biochars from pelletized wood and wheat straw as a replacement (5% to 15%) for peat in soilless growing media and determined that both biochars would be suitable replacements for peat at 5% to 15% rates.

The reported advantages of adding biochars to soils and soilless growing media include a greater ability to retain plant nutrients by reducing nutrient leaching, the addition of nutrients to the soil system, and decreasing the existing bulk densities, which increases aeration and root penetration (Laird, 2008; Vaughn et al., 2013; White et al., 2015). In contrast to sugarcane bagasse ash, adding biochar to a soilless growing media should provide a more ideal physical environment (Laird, 2008; Webber et al., 2016, 2017b). Guo et al. (2018) reported that as PB was combined with soilless growing media from 0 to 100% biochar in 20% increments, pore space and bulk densities increased from 21.5% to 35.7% volume, and 0.10 to 0.18 g cm^{-3}, respectively. Gu et al. (2018) documented that when 5 to 30% pine biochar was added to a commercial soilless growing media, the production of globe amaranth (*Gomphrena globosa* L.) var. 'Fireworks' was not adversely affected, although 30% pine biochar was the highest level investigated. Although in general, biochars have many characteristics in common, the plant material source and the preparation methods employed can greatly influence the properties and effectiveness when used as an amendment in soilless growing media (Vaughn et al., 2013). Greenhouse research was conducted to determine the impact of sugarcane bagasse biochar and pine biochar as an amendment to soilless planting media for the production of green bean (*Phaseolus vulgaris* L.) seedlings.

2. Material and Methods

2.1 Experimental Design

The SBB used in the greenhouse experiments was produced and provided by American Biocarbon LLC (White Castle, LA) using proprietary methods. American Biocarbon's torrefaction unit was used to convert the bagasse from the adjacent sugarcane mill (Cora Texas Manufacturing Co., White Castle, LA) into biochar at approximately 340 °C. The SBB was produced from sugarcane harvested in 2015 and transported in large tote bags to the USDA, ARS, Sugarcane Research Unit (Houma, LA) and stored inside until used. Cora Texas sugar mill is one of 11 sugarcane mills that together processed approximately 163,000 ha and 11.7 million Mg of Louisiana sugarcane in 2016 (American Sugar Cane League, 2017). The PB used in this experiment was produced by Proton Power Inc. (Lenouir City, TN, USA) and provided by Texas A&M AgriLife Extension (College Station, TX, USA) and is the byproduct of the fast pyrolysis of pinewood at 450 °C (Gu et al., 2013; Guo et al., 2018; Ingram et al., 2008).

The SBB and PB were combined each by volume with a commercial growing media (Sunshine, Natural and Organic Professional Growing Mix, Sun Gro Horticulture Canada Ltd, Seba Beach, Canada) into five combinations [0%:100%, 25%:75%, 50%:50%, 75%:25%, and 100%:0%, biochars (SBB or PB) and commercial growing media, respectively] which served as experimental treatments. Each of the soilless media treatments were thoroughly mixed prior to placing the mixtures in Speedling© (Speedling Inc., Ruskin, FL) trays (128 cells, 67.6 cm × 34.6 cm trays, cells: 3.1 cm square × 6.35 cm deep). The mixtures were moistened to facilitate the complete and consistent filling of each of the Speedling trays. The Speedling trays were then planted with green bean var. 'Bowie' (Harris Seed Co., 355 Paul Road Rochester, NY 14624).

The greenhouse experiments (USDA, ARS, Sugarcane Research Unit, Houma, LA) were repeated twice in the spring of 2017 and were RCBD. The first bean experiment was planted on March 28, 2017 and harvested 21 days after planting (DAP), April 18, 2017. The second experiment was planted on April 6, 2017 and harvested 21 DAP (April 27, 2017). Each experiment included the 2 types of biochar (SBB and PB) and five soilless media mixtures (0%:100%, 25%:75%, 50%:50%, 75%:25%, and 100%:0%, biochar and growing media, respectively) and four replications/experiment.

2.2 Biochar Laboratory Analysis

Proximate analyses for all samples were performed in triplicate by following the American Society for Testing and Materials (ASTM) method D5142-09 using a thermo-gravimetric analyzer (TGA701, LECO, St. Joseph, MI). Moisture was determined as the weight loss after heating the sample under N_2 atmosphere in open crucibles to 107 °C to stable sample weight. Volatile matter was determined as weight loss after heating sample under N_2 atmosphere in covered crucibles to 950 °C for 7 min. Ash was calculated from remaining mass after heating sample under O_2 atmosphere in open crucibles to 750 °C and holding to stable weight. Fixed carbon was calculated by difference.

Surface area measurements (duplicate samples) were obtained from nitrogen adsorption isotherms at 77 °K using a Nova 2200e Surface Area Analyzer (Quantachrome Corp., Boynton Beach, FL). Specific surface areas (BET, Brunner-Emmett-Teller) were taken from adsorption isotherms using the BET equation. The micro pore size distributions were calculated using t-plots derived from the Nova 2200 software. A Thermo Orion pH meter (Beverly, MA) was used to measure pH, where 1.0 g of sample was placed in 100 mL of deionized water, covered with Parafilm, and allowed to equilibrate by stirring at 300 rpm for 48 h (duplicate samples).

2.3 Physical Analysis of Biochar Amendment Combinations

Each soilless media mixture was analyzed for bulk density (g cm^{-3}), porosity (%), water saturation (%), and water at field capacity (%). Each physical test on the soil media mixtures was repeated four times. The measuring chamber was a cylinder with a 40 mm inner diameter and an interior height of 64.5 mm with a measured volume of 81 cm^3.

2.4 Plant Growth and Analysis

Five bean seedlings from the center of each tray were randomly harvested 21 DAP. Each seedling was divided into above and below ground plant portions. Plant height was determined by measuring the distance from the media surface to the apical meristem. The upper portion of the plant was further divided into leaves and stalks. The plant roots were weighted after removing all planting media from root system. Fresh weight of the leaves, stalks, and roots was recorded. The plant portions were then oven-dried for 2 days at 60 °C and then subsequently reweighed to determine dry weights. Plant establishment was determined at harvest by calculating the percentage of Speedling® planting cells containing viable seedlings. All data were subjected to ANOVA and mean separation using LSD with P = 0.05 (SAS Inc., SAS, Ver. 9.0, Cary, NC).

3. Results and Discussion

3.1 Laboratory Analysis of Biochars

The laboratory analysis determined that the PB moisture content (MC), fixed carbon (FixC), higher heating value (HHV), lower heating value, and pH were greater than the SBB by 1.7% (MC), 44% (FixC), 10.7 MJ kg^{-1} (HHV), 9.5 MJ kg^{-1} (LHV), and 2.25 pH, respectively (Table 1). The SBB also had 31.7% greater volatile matter (VOL) and 12.4% greater ash (ash) than PB (Table 1). An increase in ash content typically will increase the biochar's bulk density and potential nutrient availability for seedling production (Webber et al., 2017b). The greater fixed carbon percentage increases the energy value (HHV and LHV) of the PB compared to the SBB, and may influence the potential income streams for the two biochars (Table 1).

Table 1. Laboratory analysis of sugarcane bagasse biochar (SBB) and pine biochar (PB) for moisture content (MC), volatile matter (VOL), fixed carbon (FixC), ash (ASH), higher heating value (HHV), lower heating value (LHV), and pH

Biochar	MC	VOL	FixC	Ash	HHV	LHV	pH
	%	%	%	%	MJ kg^{-1}	MJ kg^{-1}	
SBB[Z]	6.9±0.41	44.0±1.00	38.8±0.43	17.2±1.13	20.5±0.24	19.0±0.23	5.80±0.05
PB[Y]	8.55±0.33	12.3±0.23	82.9±0.83	4.79±0.62	31.2±0.27	28.5±0.26	8.05±0.01

Note. [Z]SBB = Sugarcane Bagasse Biochar produced by American Biocarbon LLC.[Y]PB = Pine Biochar. Volatiles, fixed carbon, and ash in percent dry basis.

The particle size distribution for the two biochar are in stark contrast to each other with the laser analysis revealing that the PB particle median, mean, geometric mean, and mode were much greater than those of the SBB (Table 2). The PB particle size distribution were 3.8x (median), 4.3x (mean), 2.9x (geometric mean), and 5.1x (mode) greater than the SBB sizes (Table 2). And, unlike the unimodal particle size distribution that produced a single peak at near 110 µm for SBB, the PB particle distribution produced a bimodal curve with the first and smaller peak at 10 µm and the second and larger peak at 1000 µm.

Table 2. Laser scattering particle size distribution analysis (LA-950) of sugarcane bagasse biochar (SBB) and pine biochar (PB) used as amendments to the greenhouse soilless growing media

Biochar	Median	Mean	Geometric Mean	Mode
	µm	µm	µm	µm
SBB[Z]	142.03	166.53	111.19	213.84
PB[Y]	537.54	707.61	326.16	1091.87

Note. [Z]SBB = Sugarcane Bagasse Biochar produced by American Biocarbon LLC.[Y]PB = Pine Biochar produced by Proton Power, Inc.

3.2 Physical Analysis of Amendment Concentrations: Bulk Density and Porosity

The bulk densities of the media mixtures increased from 0.11 g cm^{-3} (the commercial medium: 0% SSB and 0% PB) to 0.14 g cm^{-3} for the 25% SBB and 0.17 g cm^{-3} for the 100% PB (Table 3). The bulk densities for SBB decreased from its high at 25% biochar down to 0.11 g cm^{-3} for the 100% SBB, while the bulk densities for PB media increased as the percentage of PB increased (Table 3). These results are in contrast to similar research using the same mixture combinations with sugarcane bagasse ash instead of sugarcane biochar (Webber et al., 2017b). The bulk densities remained in an ideal range when the biochars were added, unlike earlier research where the addition of sugarcane bagasse ash increased bulk densities from 0.12 to 0.71 g cm^{-3} (Webber et al., 2017b). In contrast to Vaughn et al. (2013) who used biochar wood (0.62 g cm^{-3}) and straw pellets (0.24 g cm^{-3}) as a suitable replacement for peat at substitution rates of 5 to 15%, the SBB and PB bulk densities for SBB and PB were suitable at all percentages (Table 3). The SBB bulk densities were not different from the commercial soilless growing media used in the research except for 25% SB media (0.14 g cm^{-3}) and all SBB and PB combinations were comparable to the bulk density of peat, 0.16 g cm^{-3}, measured by Vaughn et al. (2013). The lower bulk density values of the SBB maintained bulk densities in a suitable range as the biochar content increased from 0 to 100% of the growing media (Table 3), while the slightly greater PB bulk density also kept the media bulk densities in an acceptable range (Table 3). These results were consistent with Guo et al. (2018) who reported bulk densities from 0.10 to 0.18 g cm^{-3} when pine biochar was added to a soilless growing media for the production of poinsettia (*Euphorbia pulcherrima*).

As the biochar percentage increased in the SBB media mixtures, the pore space, water saturation, and water at field capacity percentages remained fairly constant, in contrast to the PB media mixtures which peaked at 0% PB and decreased as the percentage of PB increased (Table 3). The pore space, water saturation, and water field capacity values for all mixture combinations for both biochars were at adequate levels to provide sufficient water availability to young seedlings. This is in contrast to research with sugarcane bagasse ash where the water saturation and water at field capacity decreased significantly as the percentage of ash increased in the greenhouse growing mixtures (Webber et al., 2017b).

Table 3. Impact of sugarcane biochar and pine-char percentage as an amendment to greenhouse growing media on bulk density (g cm^{-3}), percent total pore space, percent water saturation, and percent water at field capacity

Composition^{Z}	Bulk Density	Pore Space	Water Saturation	Water at Field Capacity
	g cm^{-3}	%	%	%
SBB^{Y}				
0%	0.11 e^{W}	71.18 b	86.49 a	84.35 a
25%	0.14 cd	76.79 a	84.92 a	79.64 b
50%	0.13 de	71.47 b	84.96 a	83.48 a
75%	0.12 e	73.13 ab	86.28 a	84.34 a
100%	0.11 e	73.80 ab	86.92 a	85.28 a
PB^{X}				
0%	0.11 e	71.18 b	86.49 a	84.35 a
25%	0.13 cd	57.09 c	80.98 b	77.16 c
50%	0.15 bc	60.91 c	80.59 b	76.10 c
75%	0.15 ab	60.57 c	79.60 b	72.98 d
100%	0.17 a	58.37 c	77.47 c	67.12 e

Note. ^{Z}Percentage of Sugarcane Bagasse Biochar (SBB) in the growth medium based on volume; ^{Y}SBB = Sugarcane Bagasse Biochar produced by American Biocarbon LLC. ^{X}PB = Pine Biochar provided by Texas A&M and produced by Proton Power, Inc. ^{W}Means in a column followed by the same lower case letter are not significantly different at P = 0.05, ANOVA.

3.3 Seedling Analysis

3.3.1 Bean Seedling Fresh and Dry Weights

There were no significant experiment × treatment interactions for the bean seedling fresh and dry weights (Table 4), therefore the bean seedling data will be discussed across experiments (Tables 5 and 6).

Table 4. Analysis of variance (ANOVA) for bean fresh and dry weights for source factors experiments, treatments, and experiment × treatment

Source	Bean Seedling Fresh Weights				
	Stalk	Leaves	Tops	Roots	Total
	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Experiment	<.0001	<.0001	<.0001	0.6521^{Z}	<.0001
Treatment	0.67859^{Z}	0.0637^{Z}	0.1787^{Z}	0.0065	0.0978^{Z}
Experiment × Treatment	0.2171^{Z}	0.2256^{Z}	0.2576^{Z}	0.1642^{Z}	0.2959^{Z}
Source	Bean Seedling Dry Weights				
	Stalk	Leaves	Tops	Roots	Total
	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
Experiment	0.0035	<.0001	<.0001	0.0201	<.0001
Treatment	0.6396^{Z}	0.0705^{Z}	0.2008^{Z}	0.9973^{Z}	0.3940^{Z}
Experiment × Treatment	0.1509^{Z}	0.1949^{Z}	0.1869^{Z}	0.1312^{Z}	0.2341^{Z}

Note. ^{Z}Not Significantly Different at P = 0.05, PROC ANOVA.

Except for the 100% PB media, all the SBB and PB planting mixtures performed well compared to the commercial greenhouse growing media (0% SBB and 0% PB) for bean seedling development in respect to the fresh and dry weights (Tables 5 and 6). Earlier research (Guo et al., 2018) reported a similar pattern when PB was added to a commercial soilless growing media for the production of poinsettia in a greenhouse production setting. Poinsettia growth and development was not adversely affected by 80% PB content, but 100% PB was not recommended. The 100% PB exception was seen with the weight of the dry bean leaves, where the average experimental dry weighs were significantly less for the 100% PB (1.42 g) compared to the standard greenhouse media (1.68 g) (Table 6). Same was true for the tops dry weight with 2.03 g with 100% PB versus 2.39 g for the standard greenhouse media (Table 6). The 100% SBB actually produced more roots on the fresh weight basis (3.85 g) than the commercial greenhouse mixture (2.74 g) and all other mixture combinations (Table 5). The 100% SBB also produced greater total seedling fresh weight (24.83 g) than all of the media mixtures containing PB (25%, 50%, 75%, and 100% PB) and significantly more fresh leaves (15.19 g) than the 100% PB mixture (12.78 g) (Table 5). The 50% SBB produced greater leaf (16.25 g) and top seedling (22 g) weights than all of the mixtures containing PB (25%, 50%, 75%, and 100% PB) (Table 5).

In the same manner, select bean seedling dry weights of the SBB mixtures were often greater than those of certain PB mixtures (Table 6). For example, SBB 50% leaf dry weigh production (1.80 g) was greater than any growing media containing PB (25%, 50%, 75%, and 100%) and the 100% SBB dry leaf weight (1.71 g) was greater than the corresponding 100% PB mixture (1.42 g). The bean seedling tops dry weights for 50% SBB (2.51 g) were greater than 25% and 100% PB mixtures, 2.14 and 1.42 g, respectively (Table 6). The 100% SBB also had a greater seedling top weight (2.42 g) than the corresponding 100% PB mixture (2.03 g) (Table 6). Lastly, largest seedling dry weight (2.99 g) was observed for the 50% SBB mixture while the lowest was obtained with 100% PB (at 2.48 g) (Table 6).

Table 5. Impact of sugarcane bagasse biochar and pine biochar soilless media percentages on bean seedling stalk, leaves, tops, and total fresh weights (g) averaged across two experiments, four replications per experiment, and five seedlings per replication

Biochar[Z]	Bean Seedling Fresh Weights (g)									
	Stalk		Leaves		Tops		Roots		Total	
SBB[Y]										
0%	5.65	a[W]	14.88	abc	20.53	ab	2.74	b	23.26	abc
25%	5.16	a	14.24	abc	19.40	ab	2.33	b	21.74	abc
50%	5.74	a	16.27	a	22.00	a	2.69	b	24.69	ab
75%	5.58	a	14.49	abc	20.07	ab	2.56	b	22.63	abc
100%	5.79	a	15.19	ab	20.98	ab	3.85	a	24.83	a
PB[X]										
0%	5.65	a	14.88	abc	20.53	ab	2.74	b	23.26	abc
25%	5.27	a	13.13	bc	18.40	b	2.81	b	21.21	bc
50%	5.35	a	13.27	bc	18.61	b	2.53	b	21.14	bc
75%	5.40	a	12.88	bc	18.28	b	2.58	b	20.85	c
100%	5.04	a	12.78	c	17.82	b	2.29	b	20.11	c

Note. [Z]Percentage of sugarcane biochar in the growth medium based on volume; [Y]SBB = Sugarcane Bagasse Biochar produced by American Biocarbon LLC. [X]PB = Pine Biochar provided by Texas A&M. [W]Means in a column followed by the same lower case letter are not significantly different at P = 0.05, ANOVA.

Table 6. Impact of sugarcane bagasse biochar and pine biochar soilless media percentages on bean seedling stalk, leaves, tops, and total dry weights (g) averaged across two experiments, four replications per experiment, and five seedlings per replication

Biochar[Z]	Bean Seedling Dry Weights (g)									
	Stalk		Leaves		Tops		Roots		Total	
SBB[Y]										
0%	0.72	a[W]	1.68	ab	2.39	ab	0.45	a	2.84	ab
25%	0.61	a	1.59	abc	2.19	abc	0.45	a	2.64	ab
50%	0.71	a	1.80	a	2.51	a	0.48	a	2.99	a
75%	0.65	a	1.59	abc	2.24	abc	0.44	a	2.68	ab
100%	0.70	a	1.71	ab	2.42	ab	0.48	a	2.89	ab
PB[X]										
0%	0.72	a	1.68	ab	2.39	ab	0.45	a	2.84	ab
25%	0.66	a	1.48	bc	2.14	bc	0.44	a	2.58	ab
50%	0.69	a	1.54	bc	2.23	abc	0.47	a	2.70	ab
75%	0.67	a	1.52	bc	2.20	abc	0.46	a	2.66	ab
100%	0.62	a	1.42	c	2.03	c	0.44	a	2.48	b

Note. [z]Percentage of sugarcane biochar in the growth medium based on volume; [Y]SBB = Sugarcane Bagasse Biochar produced by American Biocarbon LLC. [X]PB = Pine Biochar provided by Texas A&M and produced by Proton Power, Inc. [W]Means in a column followed by the same lower case letter are not significantly different at P = 0.05, ANOVA.

3.3.2 Bean Seedling Height, Establishment, Deformed, and Marketable

There were no significant experiment × treatment interactions (P = 0.05) for the bean seedling height or percent marketable bean seedlings (Table 7), therefore this data will be discussed across experiments (Table 8), while the percentage seedling establishment and deformed will be discussed by experiments (Table 8).

Table 7. Analysis of variance (ANOVA) for bean plant height, percent plant establishment, percent deformed plants, and percent marketable plants for source factors experiments, treatments, and experiment × treatment

Source	Height	Establishment	Deformed	Marketable
	Pr > F	Pr > F	Pr > F	Pr > F
Experiment	<.0001	<.0001	<.0001	<.0001
Treatment	0.6966[Z]	0.0068	<.0001	<.0001
Experiment × Treatment	0.1717[Z]	0.0346	0.0483	0.0658

Note. [Z]Not Significantly Different at P = 0.05, PROC ANOVA.

Sugarcane bagasse biochar plant media percentages did not influence plant height when averaged across the 2 experiments (Table 8). Bean seedling establishment was excellent for ‘Experiment 1’, ranging from 92.6% (100% PB) to 99.6% (75% SBB & 25% PB) with only a significant decrease at the 100% PB (92.6%) treatment (Table 8). In ‘Experiment 2’ bean seedling establishment was typically less than Experiment 1, ranging from 91.8% (50% PB) to 97.7% (25% PB) with significantly less plants at 25% SBB (90.2%) and PB 50% (91.8%) (Table 8). In seedling deformity in Experiment 1 was fairly low (0.39% to 3.5%) for all planting media combination except for 100% PB, which produced an increase in deformed seedlings (8.6%) (Table 8). Seedling deformity was much greater in all planting media combinations in Experiment 2 compared to Experiment 1, ranging from 6.3% (75% PB) to 17.6% (100% PB). Yet, it must be noted that in both Experiments 1 and 2 it was only the 100% PB media that produced significantly greater deformed seedlings than the commercial greenhouse media (0% SBB and PB 0%) and in several treatments (100% SBB, 25% PB, 50% PB and 75% PB) the percent of seedling deformity was actually less than the commercial greenhouse media (0% SBB and PB 0%) (Table 8). The seedling establishment and deformity data were used to determine the percentage of seedlings suitable for marketing. The PB media combinations exhibited the greatest differences for percent marketable bean seedlings, 80.9% (100% PB) to 93.6% (25% PB), compared to the SBB range of 86.1% (25% SBB) to 92.6% (100% SBB) (Table 8). The 100% PB (80.9% marketable seedlings) was the only mixture combination averaged across both experiments that reduced marketable seedlings compared to the standard greenhouse media mixture (90.4%

marketable seedlings) (Table 8). Based on seedling deformity and the resulting marketable seedling data, the authors suggest that the producer do not use a 100% PB growing media for the production of bean seedlings. The 100% PB produced the lowest seedling establishment (Experiment 1), the greatest deformities (Experiments 1 and 2), and the lowest percentage of marketable seedlings (averaged across Experiments 1 and 2) (Table 8). Perhaps the establishment and deformity issues were related to the larger particle size distribution of the PB compared to the SBB or perhaps the PB is naturally more abrasive to plant tissues than the SBB. When observing the deformed bean seedlings, the seedling's epicotyl and cotyledons were scared as if the biochars abrasiveness was damaging the seedlings as the seedlings were emerging and establishment.

Table 8. Impact of sugarcane bagasse biochar and pine biochar on bean seedling height (cm), seedling establishment (%), deformed seedlings (%), and marketable seedlings

Biochar^Z	Seedling Height		Seedling Establishment				Deformed Seedlings				Marketable Seedlings	
			Expt. #1		Expt. #2		Expt. #1		Expt. #2			
SBB^Y	cm		%		%		%		%		%	
0%	14.33	a^W	98.05	a	96.49	ab	0.78	b	12.89	bc	90.43	ab
25%	12.78	a	97.27	a	90.24	c	1.56	b	13.67	b	86.13	b
50%	13.32	a	96.88	a	92.19	bc	3.52	b	11.33	bcd	87.11	b
75%	13.94	a	99.61	a	95.70	ab	1.17	b	9.38	cdf	92.38	a
100%	14.50	a	97.66	a	96.49	ab	0.39	b	8.60	de	92.58	a
PB^X												
0%	14.33	a	98.05	a	96.49	ab	0.78	b	12.89	bc	90.43	ab
25%	14.31	a	99.61	a	97.66	a	3.13	b	7.03	e	93.56	a
50%	13.88	a	98.83	a	91.80	bc	1.56	b	8.21	de	90.43	ab
75%	13.96	a	98.83	a	95.31	ab	1.17	b	6.25	e	92.38	a
100%	12.35	a	92.58	b	95.13	ab	8.60	a	17.58	a	80.86	c

Note. ^{Z}Percentage of sugarcane biochar in the growth medium based on volume; ^{Y}SBB = Sugarcane Bagasse Biochar produced by American Biocarbon LLC. ^{X}PB = Pine Biochar provided by Texas A&M and produced by Proton Power, Inc. ^{W}Means in a column followed by the same lower case letter are not significantly different at P = 0.05, ANOVA.

4. Conclusions

When using a biochar as an amendment for growing medium, it is important to evaluate its various physico-chemical properties. Biochars herein utilized were sourced from different plant species (sugarcane *vs.* pine) and converted to biochars through different processes, resulting in different physical and chemical compositions. Although these differences may not be critical to all biochar uses, the information may be critical in understanding the potential applications of the biochars. The greater fixed carbon percentage increases the energy value (HHV and LHV) of the PB compared to the SBB, and may influence the potential income streams for the two biochars. The particle size distribution for the two biochars are in stark contrast to each other with the PB particle median, mean, geometric mean, and mode being much greater than those of the SBB. These differences in particle size and distribution significantly increased the bulk density and decreased the pore space (%), water saturation (%), and water at field capacity (%) of the PB in contrast to the SBB, although these parameters remain in suitable ranges for soilless growing media. The 100% SBB was not significantly different in any of these parameters to the standard soilless growing media. As amendments to the soilless greenhouse growing media, the biochars (SBB and PB) functioned very well especially at the 25 and 75% levels for bean seedling production. The 100% SBB preform as well as the 100% commercial soilless growing media and slightly better than the 100% PB when comparing seedling fresh and dry weights. The 100% PB is not recommended as a soilless growing media even with the supplemental fertilizer used in these experiments. These results indicate that the volume of a standard soilless greenhouse growing media can be successfully extended by adding 25% to 75% of either sugarcane bagasse or pine biochars without reducing bean seedling production quality. Future research is needed to evaluate these biochar sources for seedling production for additional plant species.

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