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Linking biochar properties to biomass of basil, lettuce and pansy cultivated in growing media

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Abstract

The use of biochar as an additive for growing media for the production of potted plants requires a sound knowledge of how its properties impact plant biomass production. This study aims at linking physical and chemical properties of biochar with horticultural crop biomass. For this purpose, we incorporated six different biochars into growing medium and grew basil (*Ocimum basilicum* L.), lettuce *(Lactuca sativa* L. var. crispa) and pansy (*Viola wittrockiana* Gams.) for one month in greenhouse conditions. We found that physical and chemical properties of biochars had a significant impact on plant growth. Biochars with low density and high porosity promoted the biomass of basil and lettuce. While nutrient concentration in biochars had no impact on plant growth, lettuce and pansy biomasses decreased with increasing biochar pH and basil biomass decreased with increasing biochar electrical conductivity. By identifying which biochar properties influence plant biomass, our study allows selection of the biochars which are the best suited for incorporation into growing media.

Keywords: compost; sustainability; peat; pot experiment; waste management

1. Introduction

Over the last decade, biochar has attracted increasing attention for addressing environmental and agronomical issues. Owing to its beneficial properties, such as rich carbon (C) content, generally high cation exchange capacity (CEC) and large surface area, biochar has been extensively used to improve soil fertility, remediate soil and treat wastewater (Ahmad *et al*., 2014; Biederman and Harpole, 2013; Houben *et al*., 2017; Pourret and Houben, 2018).

More recently, biochar has also been considered as an appropriate additive or even a substitute for conventional growing media (Banitalebi *et al*., 2019). Growing media are soilless substrates that provide plants with nutrients, air and water, and physical support (Kaudal *et al*., 2016). Important properties for the use of materials for growing media include pH and electrical conductivity (EC) because too high or too low pH and/or high EC can mitigate plant growth and quality (Bunt, 1988). According to Abad (2001), an “ideal substrate” should have a pH ranging from 5.3 to 6.5 and EC ≤ 0.5 dS m^{-1}. Plant growth also depends highly on physical properties of the growing medium, especially porosity and density, which is related to their effects on available water content (Bilderback *et al*., 2005). Another important parameter for the production of potted plants is the stability of the growing medium as it is generally desired that physical and chemical properties remain stable over the crop growth period (Dalias *et al*., 2018).

Growing media are commonly made from peat and aggregates (perlite and vermiculite) but the negative impact on the environment and the high cost of their production warrant the use of alternative products (Barrett *et al*., 2016). For a few years, it has been suggested that addition of biochar to growing media could reduce the use of these eco-unfriendly materials while improving their properties such as nutrient availability, water retention, alkalinity and biological activity

(Lévesque *et al*., 2018; Nemati *et al*., 2015). However, the benefit of incorporating biochar into growing media is still controversial because, although several studies reported a positive effect on plant growth (Graber *et al*., 2010; Méndez *et al*., 2015; Tian *et al*., 2012), others showed no or even a negative effect (Steiner and Harttung, 2014; Vaughn *et al*., 2013). These discrepancies might be explained by the wide variety of biochars used by researchers. Feedstock and pyrolysis conditions drive biochar properties, which can in turn mediate their effects on plant growth (Li *et al*., 2019).

In order to select and design biochars which are the best suited for incorporation into growing media, it is essential to identify which physical and chemical properties of the biochars play the major roles on plant growth. The objective of the present study was therefore: (i) to determine the response of horticultural crop biomass grown in growing media to the presence of contrasted biochars and (ii) to identify the physical and chemical properties of the biochars responsible for their effects on plant biomass.

2. Materials and Methods

2.1. Biochars

Commercial grade biochars were obtained from VTGreen (Allier, France) using an industrial pyrolysis reactor (Biogreen® Technology, ETIA, Oise, France). The principle employing continuous thermal treatment without oxygen with a set residence time of 10 min. Feedstocks available in large quantities in France, ensuring a high supply and having a low initial value, were selected for biochar production: coffee residues, resulting from coffee liqueur extraction and provided by Compomar (Essone, France); wood granules (<8 mm) from resinous trees provided by a wood storage center (LCE, Maine-et-Loire, France); maize cobs cultivated, dried and crushed by Agrivalor (Alsace, France); rapeseed straws cultivated, dried and crushed by Agriopale (Pas-de-Calais, France); and green wastes compost rejects composed of poplar and conifers branches and provided by Fertivert (Seine-

Maritime, France). The temperature of pyrolysis was 550°C for wood granules (hereafter referred as Wood BC), 450°C for maize cobs and green compost rejects (hereafter referred as Maize BC and Compost BC, respectively), 650°C for rapeseed straws (hereafter referred as Rapeseed BC) and 450°C and 650°C for coffee residues (hereafter referred as Coffee450 BC and Coffee650 BC, respectively). The different pyrolysis temperatures were selected to obtain biochars with contrasting chemical and physical properties.

Biochars were analyzed for pH (AFNOR, 2012a), EC (AFNOR, 2012b), CEC (AFNOR, 1999), density, porosity (AFNOR, 2012c), organic C content (AFNOR, 2011), total nitrogen (N) content (AFNOR, 2002a)), C:N ratio, ash content at 815°C (ISO, 2016), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) contents (AFNOR, 2002b).

2.2. Growing medium-biochar mixtures

Each biochar was incorporated at 10 % (v/v) into a growing medium made of 60% of sphagnum blond peat (Gamm Vert, France), 15% of green waste compost (Fertivert, Seine-Maritime, France), 10% of composted manure and grape pomace (BioFumur®, Terre et Nature, France), and 5% of 0-4 mm build sand (Cantillana, Gamm Vert, France).

2.3. Greenhouse pot experiment

Horticultural plants largely cultivated in growing media and belonging to different families, thus having potential different responses to biochar addition were tested: basil, lettuce*,* and pansy. Basil, lettuce and pansy seeds were individually sown in 80 mL pots filled with commercial seed substrate (Gamm Vert, France), kept under controlled greenhouse conditions (temperature 24/16°C; day/night, 16 h photoperiod) and watered by adding demineralized water two times a week. Three-week old seedlings of basil and lettuce, and four-week old seedlings of pansy were then transplanted separately in the six biochar-enriched media. Basil seedlings were transplanted in 0.5 L pots containing 80 g dry weight (DW) equivalent of medium, while lettuce and pansy were transplanted in 1.6 L pots containing 180 g DW equivalent of medium. The trials were conducted under the same controlled greenhouse conditions in four replicates. Throughout the experiment, the moisture content of each growing medium was kept at 80% water holding capacity (WHC) by adding demineralized water and weighing the pots four times a week. After one month, aboveground parts of plants were harvested, dried at 60°C for 48 h and weighed.

2.4. Statistical analyses

Data analysis was performed using Rstudio (Version 0.99.903). Correlations between physical and chemical biochar properties and biomass of basil, lettuce or pansy were analyzed using the Pearson correlation coefficient. The significance of the medium effect on basil, lettuce and pansy biomass was tested by one-way ANOVA and Tukey's HSD test was used to identify the differences between media. All tests of significance were conducted at $P<0.05$.

3. Results

3.1. Biochar properties

The six biochars tested in this study showed contrasting physical and chemical properties (Table 1). Although all the biochars were alkaline, their pH ranged from 7.90 (Wood BC) to 11.40 (Compost BC). The pH of growing media after biochar application was positively correlated to biochar pH (Fig. 1a). The EC was the lowest for the two coffee-derived biochars and the highest for Compost BC. A weak positive correlation between growing media EC and biochar EC was found (Fig. 1b). This relationship was, however, mainly driven by the biochar, with the highest biochar EC value (Compost BC) increasing markedly the growing medium EC. The CEC differed greatly among the biochars, ranging from 2.90 $\text{cmol}_c\ \text{kg}^{-1}$ (Rapeseed BC) to 32.4 $\text{cmol}_c\ \text{kg}^{-1}$ (Coffee650 BC). Rapeseed BC had the highest porosity and the lowest density, while Wood BC and Compost BC had the lowest porosity and the highest density. Organic carbon (C) content was high for all the biochars, ranging from

31.55% (Compost BC) to 48.75% (Wood BC). Total nitrogen (N) content was lower than 1%, except for the two coffee biochars with 4.21% (Coffee450 BC) and 3.92% (Coffee650 BC). Consequently the C:N ratio was the lowest for the coffee biochars and the highest for Wood BC. Biochars showed also very different concentrations in nutrients. Irrespective of the nutrient, Wood BC and Rapeseed BC had low and high nutrient concentrations, respectively. The highest concentration of K was recorded for Coffee650 BC and Compost BC exhibited the higher concentration of Mg.

Table 1. Biochar properties

		Wood BC	Rapeseed BC	Maize BC	Compost BC	Coffee450 BC	Coffee650 BC
pH		7.90	11.20	9.60	11.40	9.60	10.50
EC	dS m^{-1}	2.40	1.22	1.14	3.54	0.23	0.56
CEC	$cmol_c$ kg^{-1}	12.30	2.90	27.30	8.50	15.20	32.40
Porosity	%	87.30	95.90	88.50	86.30	93.00	92.60
Density	g L^{-1}	281.00	73.00	171.00	291.00	110.00	108.00
Organic C	%	48.75	35.30	45.35	31.55	42.65	46.00
Total N	%	0.18	0.81	0.68	0.84	4.21	3.92
C:N		270.83	43.58	66.69	37.56	10.13	11.73
Ash 815°C	%	2.10	16.80	7.00	26.30	4.20	6.20
P	mg kg^{-1}	611	3753	1353	3709	2662	2357
K	mg kg^{-1}	2739	18179	16519	17847	11538	18926
Ca	mg kg^{-1}	1787	66172	2358	34015	2001	1072
Mg	mg kg^{-1}	482	4161	1025	5066	2171	1267

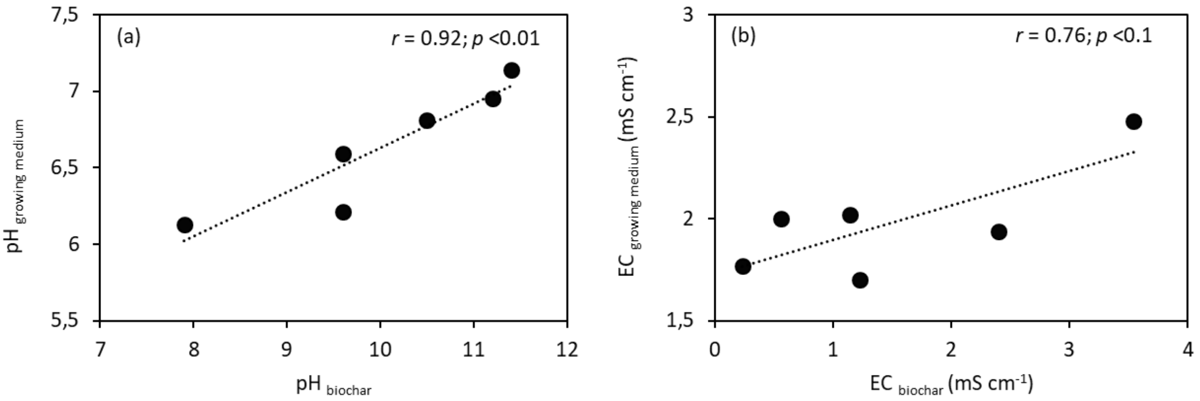

Figure 1. Relationships between biochar pH and growing medium pH (a) and biochar electrical conductivity (EC) and growing medium EC (b).

3.2. Basil

The nature of biochar incorporated into the medium significantly impacted the biomass of basil (Fig. 2a). Basil grown in media containing Coffee450 BC (2.2 ± 0.16 g) or Rapeseed BC (2.1 ± 0.12 g) had significantly greater biomass than those grown in media containing other biochars. The four other biochars induced similar basil biomasses, with a minimum obtained with the compost BC (1.0 ± 0.24 g). Correlations between basil biomass and biochars physical and chemical properties showed that biomass was significantly and positively correlated with the porosity of the biochars (r = 0.65), and significantly and negatively correlated with the EC (r = - 0.45), the CEC (r = - 0.44) and the bulk density (r = - 0.54) of the biochars (Table 2).

3.3. Lettuce

Biochars leading to the highest lettuce biomasses were Wood BC (5.1 ± 0.51 g), Rapeseed BC (4.8 ± 0.48 g), and Coffee450 BC (4.0 ± 0.38 g) (Fig. 2b). The lowest lettuce biomass was obtained with Compost BC (1.7 ± 0.24 g), and was significantly lower than with all other biochars. Biomass was significantly and positively correlated with the porosity (r = 0.49) of the biochars and significantly and negatively correlated with the pH (r = - 0.44) and the ash content (r = - 0.51) (Table 2).

3.4. Pansy

The highest pansy biomass was obtained with Wood BC (5.9 ± 1.16 g), but was significantly higher than the biomass obtained with Compost BC (1.8 ± 0.36 g) only (Fig. 2c). Biomass was significantly and positively correlated with the organic C (r = 0.55) content and the C:N ratio (r = 0.5) of the biochars, and significantly and negatively correlated with pH (r = - 0.59), P content (r = - 0.57), and ash content (r = - 0.53) (Table 2).

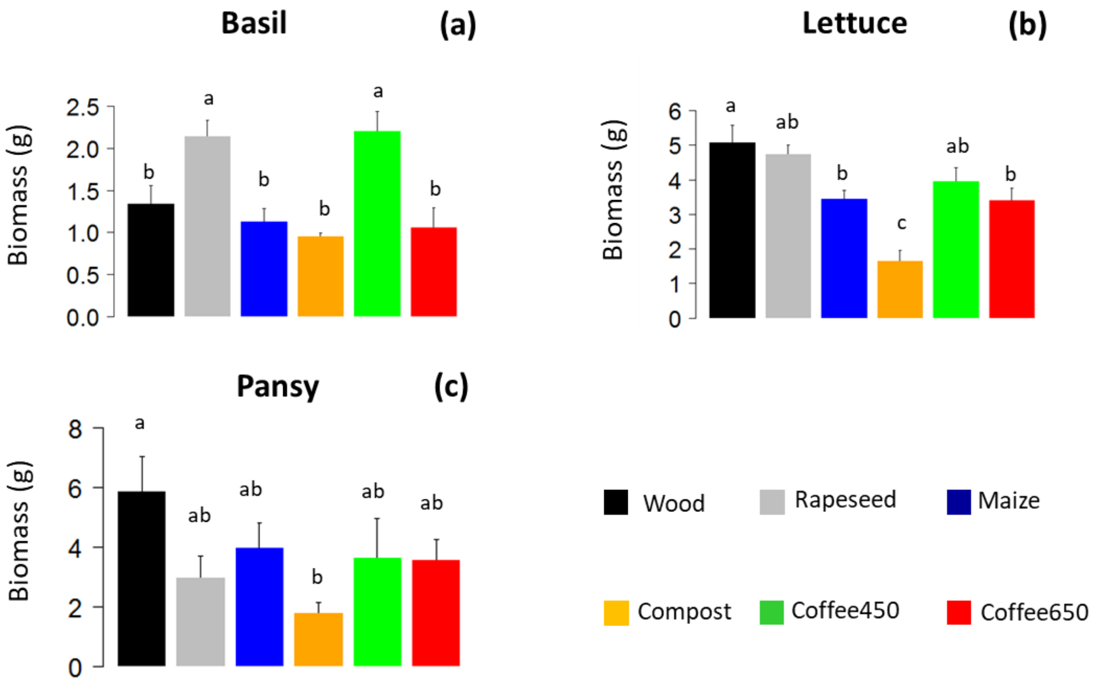

Figure 2. Average biomass of basil (a), lettuce (b) and pansy (c) in the presence of biochar. Data are presented as mean ± standard deviation. Columns with same letter do not differ significantly at the 5% level according to the Tukey's multiple comparison test.

Table 2. Pearson's correlation coefficients between basil, lettuce and pansy biomass and physical and chemical properties of biochars. Correlation coefficients are significant at $p < 0.05$; ns means non-significant.

	Basil	Lettuce	Pansy
pH	ns	-0.44	-0.59
EC	-0.45	ns	ns
CEC	-0.44	ns	ns
Porosity	0.65	0.49	ns
Density	-0.54	ns	ns
Organic C	ns	ns	0.55
Total N	ns	ns	ns
C:N	ns	ns	0.5
Ash 815°C	ns	-0.51	-0.53
P	ns	ns	-0.57
K	ns	ns	ns
Ca	ns	ns	ns

Mg	ns	ns	ns

4. Discussion

The six biochars used in this study comprised a wide array of physical and chemical properties. Overall, properties of the present biochars compared well with the values reported by other researchers for similar feedstock materials and pyrolysis conditions (Houben *et al*., 2014; Sun *et al*., 2014; Zhao *et al*., 2013) and followed similar trends, e.g. ash content of wood-derived biochars was lower than that of non-wood-derived biochars (Mukome *et al*., 2013). Our data highlight the role of pyrolysis temperature on biochar properties since, for instance, Coffee biochar produced at 650°C had a higher pH than Coffee biochar produced at 450°C, which is consistent with the literature and can be explained by the concomitant increase in ash content (Table 1) and decrease in acidic functional groups (Enders *et al*., 2012). Similarly to pH, EC of biochars was affected by pyrolysis temperature (EC of Coffee650 BC is 2.4 times higher than EC of Coffee450 BC), which was due to the release of soluble salts from organic compounds during pyrolysis (Banitalebi *et al*., 2019). However, our data also evidenced the role played by feedstock materials since, for instance, Wood BC had a much lower pH than Maize BC, Compost BC and Coffee450 BC. Like pH, feedstock materials played also a significant role on biochar EC since, for instance, biochars produced at the same temperature displayed a wide range of EC. Consistently with the literature (Li *et al*., 2019), final properties of biochar resulted thus from the combined effect of their different feedstock materials and pyrolysis conditions.

As expected, the incorporation of the six dissimilar biochars into growing media yielded dissimilar plant biomass responses. Increasing porosity usually improves water and air exchanges in the growing media. As shown by Liu *et al*. (2017), the impact of biochar on soil water retention is strongly dependent on its porosity. Consistently with Roehrdanz *et al*. (2019), our results indicated that incorporating biochar with low density and high porosity led to higher biomass production for basil and lettuce, respectively, which is most likely related to their beneficial effects on water availability. This is in line with Méndez *et al*. (2015) showing that biomasses of lettuce grown on pea-based growing media amended with biochar were positively related to the improvement of hydrophysical growing media properties.

In the present study, lettuce and pansy biomasses were significantly negatively correlated with biochar pH, which reflects the high sensitivity of these crops to elevated pH, as already reported by previous studies (Kuehny and Morales, 1998; Logan and Lindsay, 1996; Roosta, 2011). By increasing pH of growing media, alkaline amendments such as biochar can decrease nutrient availability, mainly for P, Fe and Mn, resulting in lower yield (Belda *et al*., 2013). It must be noted that the negative correlations between lettuce and pansy biomasses and ash content most likely result from the strong relationship between ash content and basicity of biochars (Mukome *et al*., 2013).

High EC reflects high levels of soluble salts that, through decreasing osmotic potential, may limit the availability of water to plants, thereby limiting germination and plant growth (Nieto *et al*., 2016). Previous studies have evidenced that biochar might impair the growth of plants due to osmotic stress induced by high biochar EC (Rajkovich *et al*., 2012; Revell *et al*., 2012). In the present study, the significant negative correlation between basil biomass and biochar EC suggests that the growth of this crop was negatively impacted by the incorporation of biochar with high EC. These results are in line with other researchers reporting a decreasing basil biomass, as well as lower transpiration and chlorophyll content, with increasing levels of salinity (Bekhradi *et al*., 2015). Oppositely, the lack of significant correlation between EC and biomass of lettuce and pansy might indicate a lower EC sensitivity, as shown for instance by van Iersel (1999) for pansy.

Since addition of biochar with high organic C content and elevated C:N ratio usually improves substrate stability because it decreases its decomposition, the positive correlation between pansy biomass and these two biochar properties might be due to a higher growing media stability, a parameter which was previously found to strongly affect the growth of pansy (Burnett *et al*., 2016; Purman and Gouin, 1992). However, this should be further investigated by, among others, characterizing the changes of properties of growing media over time.

Finally, except for the unexpected negative correlation between pansy biomass and P concentration in biochar, crop biomasses were not correlated with nutrient concentrations of biochar. This suggests that the effects of biochar incorporation into growing media on plant growth do not primarily rely on their nutrient composition but rather on other properties, including their pH, EC, porosity and density. It must, however, be noted that the present study only focused on the relationship between biochar properties and plant biomass. Further study on other physiological traits should be carried out because they could be more sensitive to changes in biochar properties than plant biomass. For instance, since pansy flowering is dependent on nutrient availability in the substrate (Zawadzińska and Janicka, 2007), it is important to determine whether nutrient concentration in biochar impacts flowering abundance and time. In addition, since the aim of this study was to examine how the biochar properties mediated the plant response, we did not consider the influence of the initial properties of the growing medium in which we incorporated each of the six biochars. Because biochar properties may be themselves mediated by the surrounding environment, e.g. soil properties (Hardy *et al*., 2016), biological activity (Houben and Sonnet, 2015; Lehmann *et al*., 2011), the next challenge will be to elucidate how the composition of the growing medium drives the plant response to biochar application. In a more general context, it will be essential that, besides having the properties suitable for plant production as identified in this study and others (Nemati *et al*., 2015; Singh *et al*., 2010), biochars selected for plant production meet quality standards (Meyer *et al*., 2017).

5. Conclusions

Our results have confirmed that the efficacy of biochar incorporation into growing media to improve plant biomass is not only dependent on the properties of the biochar itself but also on the crop species. However, general patterns can be drawn. First, increasing biochar pH and EC had generally a detrimental effect on plant biomass while biochars with low density and/or high porosity were beneficial for plant growth. Second, irrespective of the plant species, nutrient concentrations were not related to plant biomass. By linking physical and chemical properties of biochar with plant biomass, this study provides insights to engineer and better select biochar for incorporation into growing media for potted plants production.

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