HORTSCIENCE 59(2):248–254. 2024. https://doi.org/10.21273/HORTSCI17621-23

Peat Substrates Amended with Wood-based Biochar Do Not Influence the Efficacy of Paclobutrazol Drenches

Patrick Veazie
Department of Horticultural Sciences, North Carolina State University, 2721 Founders Drive, Raleigh, NC 27695, USA

Ka Yeon Jeong
Sun Gro Horticulture, Distribution Inc., 770 Silver Street, Agawam, MA 01001, USA

Brian Jackson
Department of Horticultural Sciences, North Carolina State University, 2721 Founders Drive, Raleigh, NC 27695, USA

David Suchoff
Department of Crop and Soil Sciences, North Carolina State University, 101 Derieux Place, Raleigh, NC 27695, USA

Brian E. Whipker
Department of Horticultural Sciences, North Carolina State University, 2721 Founders Drive, Raleigh, NC 27695, USA

Keywords. begonia, pansy, plant growth regulators, poinsettia, soilless substrate

Abstract. **Various soilless substrate components have been evaluated for many years to identify sustainable resources that do not negatively impact plant growth. Biochar is a carbon-based material that has been evaluated for use as an alternative aggregate in peat-based soilless substrates. In addition, the use of carbon adsorption for compound removal is widely used in groundwater remediation, municipal water filtration, and volatile organic compounds. Experiment one aimed to determine the impact of coarse biochar (<6 mm) on paclobutrazol efficacy when incorporated at 15% or 30% by volume in a peat-based substrate when compared with a perlite-amended substrate at the same incorporation volumes. In Expt. 1, a single paclobutrazol drench application of 0, 0.5, 1.0, 2.0, and 4.0 mg·L^{-1} was applied to 'Princettia Red' and 'Princettia White' poinsettias (*Euphorbia pulcherrima* × *Euphorbia cornastra*). In Expt. 2, two different biochar particle sizes of coarse (<6 mm) and extra coarse (>6 mm) were examined at the same incorporation volumes as Expt. 1 and compared with a perlite-amended substrate at the same incorporation volumes. However, during Expt. 2, continual drench applications at times of irrigation of 0.0, 6.25, 12.5, 25.0, 50, and 100 μg·L^{-1} (ppb) paclobutrazol were applied to pansy (*Viola* ×*wittrockiana*) 'Matrix Blue Blotch' and begonia (*Begonia* ×*hybrida*) 'Big Red Bronze Leaf'. The efficacy of paclobutrazol drenches for controlling growth in all species was unaffected by the substrate composition regarding aggregate type or aggregate incorporation rate. Thus, even though biochar is often used for bioremediation and wastewater treatment, it did not negatively impact the efficacy of paclobutrazol drenches at the concentrations used. This research suggests that when biochar is used as an amendment to peatmoss it will not influence paclobutrazol drench efficacy when incorporated up to 30% by volume for the examined species.**

Horticultural soilless substrates used in floriculture crop production are often composed of a wide variety of materials ranging from peatmoss, bark, and aggregates, such as perlite and vermiculite (Nemati et al. 2015). A wide range of alternative aggregates including wood chips, rice hulls, and biochar have been evaluated as alternative aggregates for horticultural substrates (Evans and Gachukia 2004; Guo et al. 2018; Jackson et al. 2008; Owen 2013; Woldetsadik et al. 2018). In most cases, a 10% to 30% incorporation rate of alternative aggregates such as biochar, wood chips, or rice hulls, into a peat-based substrate resulted in similar growth when compared with perlite (Northup 2013; Owen 2013).

Biochar is a charcoal-like material that is produced from organic feedstocks by using pyrolysis, gasification, or hydrothermal carbonization (Huang and Gu 2019). Pyrolysis is the thermal decomposition of biomass by heating the feedstocks to 400 °C to 600 °C in the absence of oxygen (Gvero et al. 2016). The product of the pyrolysis process can have a wide array of physical properties and can have significant impacts on substrate pH, electrical conductivity (EC), and porosity, and is primarily associated with the properties of the feedstock (Huang and Gu 2019). The pH of biochar is generally considered to be basic (pH ≥ 7.0); however, pH has been reported ranging from 3.5 to 10.3 (Fornes et al. 2015; Khodadad et al. 2011; Nemati et al. 2015; Spokas et al. 2012). The basic properties of biochar may be useful to neutralize the acidity caused by peat in most blends leading to a decrease in the amount of liming material required to achieve an optimal growing pH (Bedussi et al. 2015). Guo et al. (2018) examined the impact of pinewood biochar incorporation rate into a commercially available substrate and fertility rates on poinsettia (*Euphorbia pulcherrima*) growth and reported that biochar incorporation rates of up to 80% can yield acceptable results when amended into a peat-based substrate. In addition, Yu et al. (2023) reported when poinsettias were inoculated with root rot (*Pythium aphanidermatum*) plants grown in hardwood biochar, 20% by volume, exhibited significantly higher shoot dry weight and lower disease severity when compared with perlite aggregate substrates at the same percentage. However, although most published research focuses on the impact of biochar on plant growth, limited research has been conducted to determine how production practices would need to be modified for implementation in a commercial setting.

Plant growth regulators (PGRs) allow the production of uniform compact plants that can be tightly spaced in a growing area (Smith 2019). Additional benefits associated with the use of PGRs, such as ancymidol, daminozide, chlormequat chloride, flurprimidol, paclobutrazol, and uniconizole, include increased chlorophyll concentrations resulting in greener leaves, reduced water stress, and disease suppression (Whipker 2023). Controlling stem elongation of poinsettias is crucial to producing desired market size and shaped plants, controlling stem elongation is commonly done using PGRs to retard plant growth (Faust et al. 2001; Niu et al. 2002). Paclobutrazol is a triazole PGR that is effective on poinsettias when applied as either a spray or drench (Newman and Tant 1995). The triazole class of PGRs is not readily transported through phloem, so increased efficacy occurs when they can be transported by the xylem stream when applied as a drench (Barret and Bartuska 1982; Desta and Amare 2021). Although there are many common methods of PGR applications, drenches offer precision of application, application uniformity, and reduction of potential drift that is associated with foliar sprays (Owen et al. 2016).

Although drench applications provide an effective method for plant uptake through the roots, substrate composition has been reported to affect the application rate. Quarrels and Newman (1994) reported a significant reduction of paclobutrazol drench efficacy on

Received for publication 20 Nov 2023. Accepted for publication 7 Dec 2023.
Published online 19 Jan 2024.
P.V. is the corresponding author. E-mail: Phveazie@ncsu.edu.

poinsettias when applied to pine bark substrates; however, Owen et al. (2016) reported no significant differences in paclobutrazol drench rate efficacy when amending peat-based substrates with wood chip aggregates as a perlite replacement. The use of carbon adsorption for compound removal is widely used in groundwater remediation, municipal water filtration, and volatile organic compounds (Ioannidou et al. 2010). Granular activated carbon has been shown to reliably remove pesticides and herbicides from water (Brooks et al. 2000). In addition, a 50 $\mu g \cdot L^{-1}$ paclobutrazol solution that was in contact with granular activated carbon for 59 seconds resulted in a 36% greater begonia dry weight when compared with plants irrigated with a 50 $\mu g \cdot L^{-1}$ paclobutrazol solution that did not pass through granular activated carbon filter (Grant et al. 2018). Although paclobutrazol is routinely used on many vigorous floriculture crops such as poinsettias, other crops such as vinca (*Vinca minor*), begonia (*Begonia ×hybrida)*, and pansy (*Viola ×wittrockiana*) are considered to be highly sensitive to paclobutrazol (Million et al. 1999). In one study, researchers reported 30% less growth when begonias were exposed to 5 $\mu g \cdot L^{-1}$ paclobutrazol by constant feed sub-irrigation (Million et al. 2002).

Past research has highlighted uses of biochar filters for remediation of low concentrations of paclobutrazol, and biochar incorporation rates affect the growth of floriculture crops (Grant et al. 2018). Currently, there is no published research examining paclobutrazol efficacy on biochar incorporated substrates. The goal of these experiments was to evaluate the impact of two different grades of biochar at two incorporation rates on the efficacy of paclobutrazol drench applications for low- and high-sensitive greenhouse species.

Materials and Methods

Expt. 1

Cuttings of two rooted poinsettia hybrids 'Princettia Red' and 'Princettia White' (*Euphorbia pulcherrima × Euphorbia cornastra)* (Suntory Flowers, Tokyo, Japan) were transplanted on 25 Aug 2022. Cuttings were rooted and shipped in 10 cell liners [3 × 3 × 4.41 cm (length × width × height)] and were transplanted into 14-cm-diameter azalea plastic pots (1.4 L) (ITML Horticulture Products, Middlefield, OH, USA). A 2 × 2 × 5 factorial design (aggregate type × aggregate rate × PGR rate) was created where cultivars were sampled independently of one another.

Substrate treatments. Rooted cuttings were transplanted into one of four substrate treatments. These treatments were composed of an 85:15 or 70:30 (v:v) mix of Canadian sphagnum peatmoss (Sun Gro Horticulture Company, Agawam, MA, USA) fluffed from compressed bales and either horticultural coarse perlite (Sun Gro Horticulture Company) or coarse wood biochar (<6 mm) (Sun Gro Horticulture Company) with fine particles removed (<2 mm) with an initial pH of ~9.0. A wetting agent (AquaGro 2000 G; Aquatrols, Cherry Hill, NJ, USA) at 600 $g \cdot m^{-3}$, starter charge 15N–2.2P–12.6K (J.R. Peters, Allentown, PA, USA) at 1186.6 $g \cdot m^{-3}$, and dolomitic limestone (Sun Gro Horticulture Company) at 3.56 $kg \cdot m^{-3}$ to achieve a target pH of 6.0 were incorporated (Table 1).

The plants were grown in a glasshouse in Raleigh, NC, with 23 °C day/17 °C night air temperature settings. Plants were irrigated as necessary with a water-soluble fertilizer (Ultrasol 20N–4.4P–16.4K; SQM, Atlanta, GA, USA) to provide the following ($mg \cdot L^{-1}$): 150 N, 32.7 P, 125 K, 0 Ca, 3.75 Mg, 11.5 S, 0.128 B, 0.15 Cu, 0.75 Fe, 0.75 Mn, 0.0075 Mo, and 0.225 Zn for 2 weeks and then irrigated with Ultrasol 13N–0.87P–10.79K (SQM) to provide the following ($mg \cdot L^{-1}$): 150 N, 10.1 P, 125 K, 69.2 Ca, 34.6 Mg, 0 S, 0.196 B, 0.231 Cu, 1.15 Fe, 1.15 Mn, 0.0115 Mo, and 0.346 Zn for the remainder of the trial. Plants were pinched after the first 2 weeks of vegetative growth on 9 Sep. Supplemental lighting was used between 20:00 and 2:00 nightly for the first 4 weeks of growth and was turned off the day of PGR treatment. On 27 Sep, 87 mL of the solution containing 0.0, 0.5, 1.0, 2.0, or 4.0 $mg \cdot L^{-1}$ paclobutrazol (Piccolo 10 XC; Fine Americas, Walnut Creek, CA, USA) was applied per 1.4-L container.

Data collection. The experiment was a completely randomized design with 10 single plant replicates (n = 10). On 20 Nov, six plants were sampled for plant height, diameter (measured at the greatest width, turned 90°, and averaged), and bract diameter (measured at the greatest width, turned 90°, and averaged).

Expt. 2

Pansy (*Viola ×wittrockiana*) 'Matrix Blue Blotch' seeds (Syngenta Flower, Gilroy, CA, USA) were sown 21 Dec 2022 into 288 cell trays [2.05 × 2.05 × 2.87 cm individual cells (length × width × height)] containing Sunshine #4 mix (Sun Gro Horticulture Company). Seeds were germinated under full-spectrum fluorescent lights (AgroBrite T5 Full Spectrum, Hydrofarm, Petaluma, CA, USA) with an intensity of 200.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ with no additional light sources using a light meter (MQ-610 ePar Meter; Apogee Instruments, Logan, UT, USA) providing 11.52 $mol \cdot m^{-2} \cdot d^{-1}$ based on a 16-hour photoperiod (out of 24 h). On 17 Jan 2023, plugs were transplanted into 0.67-L containers filled with each substrate (Table 2) and watered in with tap water. On 17 Feb, begonia 'Big Red Bronze Leaf' (*Begonia ×hybrida*) (Ball Horticultural Company, West Chicago, IL, USA) seedlings were received in 162 cell trays [2.54 × 2.54 × 4.06 cm individual cells (length × width × height)] and were transplanted the same day. Plants were grown in a glass greenhouse in Raleigh, NC, with a 23 °C day/17 °C night air temperature setting. All containers had emitters on a ring drip system and were watered as needed depending on weather conditions. Plants were fertilized at each irrigation with Ultrasol 13N–0.87P–10.79K (SQM, Atlanta, GA, USA) mixed with respective PGR treatment from 100-L barrels and applied through drip irrigation as needed at every irrigation with an estimated 10% leaching fraction. The solution was delivered via pumps (model 1A; Little Giant Pump Co., Oklahoma City, OK, USA) connected to 1.9-cm-diameter irrigation tubing fitted with circular drip emitters (Dramm USA, Manitowoc, WI, USA). A 3 × 2 × 6 factorial design (aggregate type × aggregate rate × PGR rate) was created where species were sampled independently of one another.

Table 1. Summary of substrate treatments used during Expt. 1 for evaluating biochar as an alternative aggregate for high concentration of paclobutrazol applications to poinsettias.

Aggregate type	Peat %	Biochar %	Perlite %	Lime rate ($kg \cdot m^{-3}$)
Perlite	85	0	15	3.56
Perlite	70	0	30	3.56
Biochar	85	15	0	3.56
Biochar	70	30	0	3.56

Substrate treatments. Plugs were transplanted into one of six substrate treatments. Treatments were composed of an 85:15 or 70:30 (v:v) mix of Canadian sphagnum peatmoss with either horticultural coarse perlite, or coarse (<6 mm) or extra coarse (>6 mm) wood biochar with fines removed (<2 mm) (SunGro Horticulture Company). Wetting agent (AquaGro 2000 G; Aquatrols) at 600 $g \cdot m^{-3}$, starter charge 15N–2.2P–12.6K (J.R. Peters) at 1186.6 $g \cdot m^{-3}$, varying rates of dolomitic limestone (Sun Gro Horticulture Company) to achieve a substrate pH of 6.0 (Table 2) were also incorporated.

Plant growth regulator treatments. Plants received one of six paclobutrazol treatments of 0, 6.25, 12.5, 25, 50, or 100 $\mu g \cdot L^{-1}$ at each irrigation in the fertilizer solution. The experiment was a completely randomized design with 10 single plant replicates.

Data collection. On 10 Mar 2023, six single plant replicates (n = 6) were sampled for plant height (measured from the substrate line to the highest leaf), and plant diameters (measured width at widest point, turned 90°, and averaged) were recorded for each plant. Shoots were cut at the substrate surface, dried at 70 °C for 96 h, and weighed.

Statistical analysis. Statistical analysis for both experiments was conducted using the GLIMMIX procedure in SAS (version 9.4; SAS Institute, Cary, NC, USA). Substrate treatment (discrete), PGR rate (continuous), and their interactions were treated as fixed effects. Higher order polynomial regression models were fit and models with the highest order significant polynomial were selected. For all analyses, a $P \leq 0.05$ was used to determine significant effects.

Results and Discussion

Expt. 1

Plant height. Plant heights of 'Princettia Red' and 'Princettia White' were not significantly different when examining the interaction

Table 2. Summary of substrate treatments used during Expt. 2 for evaluating two grades of biochar as alternative aggregates for low concentration of paclobutrazol applications to begonias and pansies.

Aggregate type	Peat %	Biochar %	Perlite %	Lime rate ($kg\cdot m^{-3}$)
Perlite	85	0	15	3.56
Perlite	70	0	30	3.56
Coarse Biochar[i]	85	15	0	3.56
Coarse Biochar	70	30	0	3.56
Extra-coarse Biochar[i]	85	15	0	2.97
Extra-coarse Biochar	70	30	0	2.97

[i] Coarse and extra-coarse biochar aggregates are smaller than 6 mm and larger than 6 mm in size, respectively.

between the three-way interaction of aggregate type × aggregate incorporation rate × paclobutrazol concentration. However, for 'Princettia Red' the interaction of aggregate type × aggregate rate was significant ($P = 0.028$), but the greatest range difference was 1.3 cm and would not be considered commercially significant (data not shown). In addition, 'Princettia White' exhibited a significant difference when examining the simple effect of aggregate type ($P = 0.008$); however, the difference between aggregate types was 0.8 cm and was not commercially significant (data not shown). The efficacy of paclobutrazol drench on plant height was not significantly different among substrates incorporated with biochar and perlite at two aggregate incorporation rates of 15% and 30%. Thus, the plant height data for each cultivar were pooled from all substrates before determining the impact of paclobutrazol concentration on plant height. There was a significant quadratic relationship between paclobutrazol concentration and 'Princettia Red' plant height (Fig. 1A). Plant height was 23.4%, 30.3%, 39.9%, and 46.1% shorter than the untreated control for 0.5, 1.0, 2.0, and 4.0 $mg\cdot L^{-1}$ concentrations, respectively. Also, a significant quadratic relationship between plant height and paclobutrazol concentrations for 'Princettia White' (Fig. 2A) occurred. Plant height was 20.0%, 29.5%, 36.9%, and 43.0% shorter, respectively, than the untreated control for 0.5, 1.0, 2.0, and 4.0 $mg\cdot L^{-1}$.

Plant diameter. Plant diameter followed a similar trend as plant height in which 'Princettia Red' and 'Princettia White' were not significantly different when examining the three-way interaction of aggregate type × aggregate incorporation rate × paclobutrazol concentration. However, for 'Princettia Red' the simple effect of aggregate rate was significant ($P = 0.011$), but the greatest range difference was 0.8 cm and would not be considered commercially significant (data not shown). In addition, 'Princettia White' exhibited significant differences when examining the simple effects of aggregate type and aggregate rate ($P < 0.001$ and $P = 0.033$, respectively); however, the values ranged 1.1 cm and 0.8 cm, respectively, and were not commercially significant (data not shown). Thus the data were pooled to examine the effect of paclobutrazol concentration on plant diameter. There was a significant quadratic relationship between paclobutrazol concentration and 'Princettia Red' plant diameter (Fig. 1B). Plant diameter was 16.3%, 24.8%, 32.2%, and 39.2% smaller than the untreated control for 0.5, 1.0, 2.0, and 4.0 $mg\cdot L^{-1}$, respectively. Also, a significant quadratic relationship between plant diameter and paclobutrazol concentration for 'Princettia White' (Fig. 2B) was observed. Plant

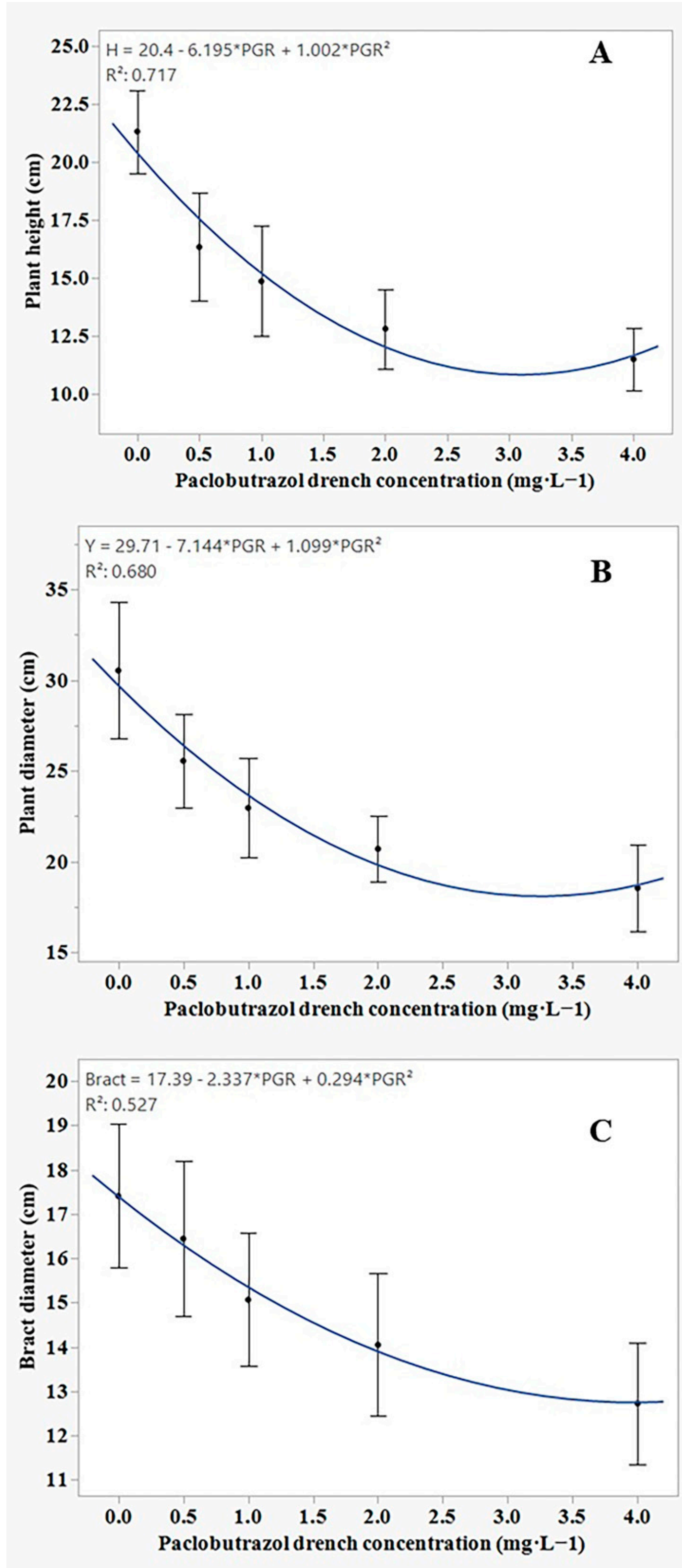

Fig. 1. Impact of paclobutrazol drench concentrations on 'Princettia Red' plant height (**A**), diameter (**B**), and bract diameter (**C**).

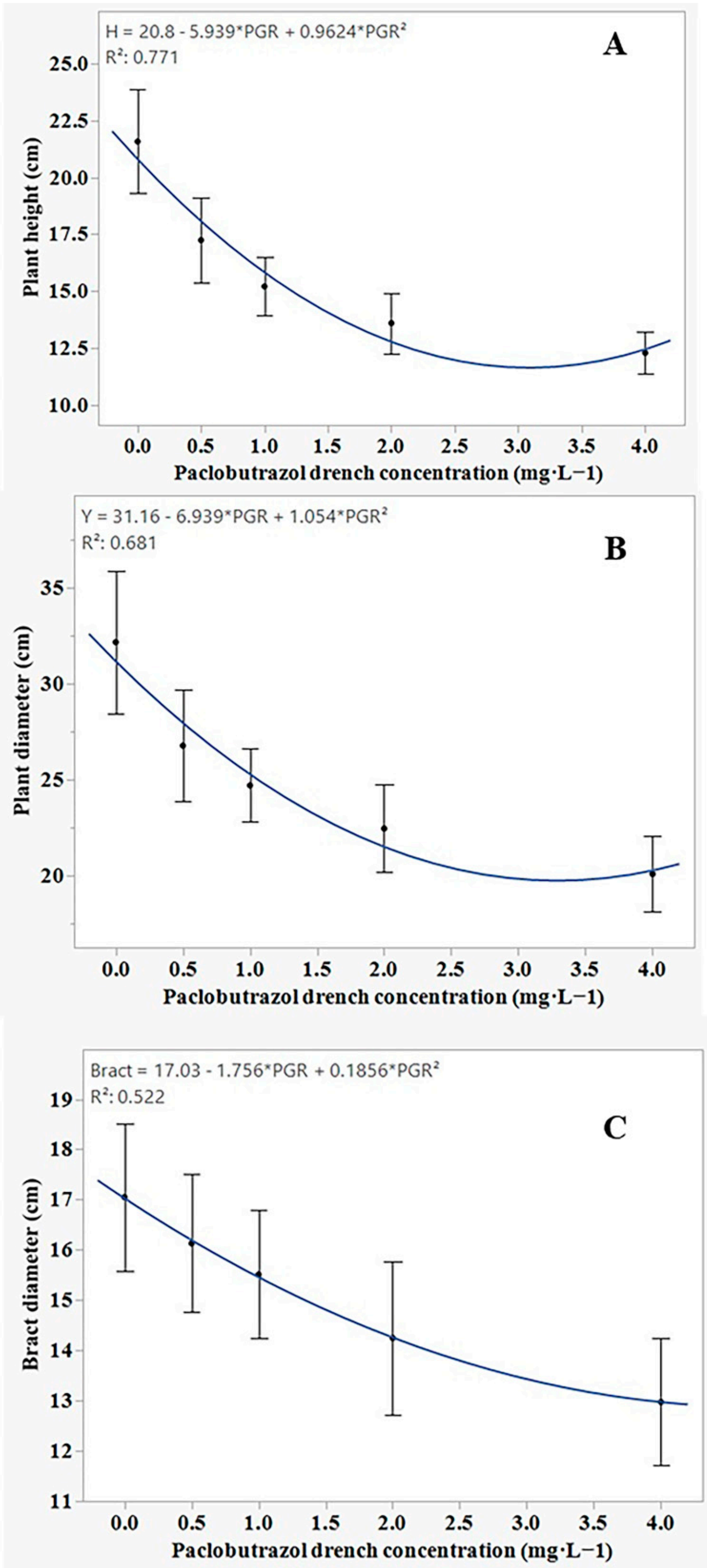

Fig. 2. Impact of paclobutrazol drench concentration on 'Princettia White' plant height (**A**), diameter (**B**), and bract diameter (**C**).

diameter was 16.8%, 23.2%, 30.2%, and 37.5% smaller than the untreated control for 0.5, 1.0, 2.0, and 4.0 mg·L^{-1}, respectively.

Bract diameter. Significant differences in bract diameter were not observed when examining the three-way interaction of aggregate type × aggregate rate × paclobutrazol concentrations for either cultivar. 'Princettia Red' exhibited significant differences when examining the simple effects of aggregate type and aggregate rate ($P < 0.001$ and $P = 0.001$, respectively); however, the values ranged 0.9 cm and 0.5 cm, respectively, and were not commercially significant (data not shown).

In addition, 'Princettia White' exhibited significant differences when examining the simple effects of aggregate type × aggregate rate ($P < 0.001$ and $P = 0.0014$, respectively); however, the values ranged 0.9 cm and 0.5 cm, respectively, and were not commercially significant (data not shown). Thus, the bract diameter data for each cultivar were pooled from all substrates before determining the impact of paclobutrazol concentration efficacy on bract diameter. There was a significant quadratic relationship between paclobutrazol concentration and 'Princettia Red' bract diameter (Fig. 1C). Bract diameter was 5.6%, 13.4%, 19.4%, and 26.9% smaller than the untreated control for 0.5, 1.0, 2.0, and 4.0 mg·L^{-1}, respectively. Also, a significant quadratic relationship between bract diameter and paclobutrazol concentration for 'Princettia White' (Fig. 2C) occurred. Bract diameter was 5.4%, 9.0%, 16.4%, and 23.9% smaller than the untreated control for 0.5, 1.0, 2.0, and 4.0 mg·L^{-1}, respectively.

This research suggests that wood biochar is suitable as a substrate component up to 30% by volume for peat-based substrates for poinsettia production while still achieving similar performance compared with traditional peat-perlite–based substrates. In addition, when wood biochar was incorporated with sphagnum peat up to 30% by volume, paclobutrazol efficacy was not negatively affected when compared with a 15% perlite-amended substrate. These results were similar to those observed by Owen (2013), in which wood-based alternative aggregates generally did not decrease the efficacy of paclobutrazol for species that are not labeled as highly sensitive. However, additional research is needed to determine if paclobutrazol efficacy is affected when biochar incorporation rates increase >30% or if the feedstock is not wood based.

Expt. 2

Plant height. Significant differences in plant height were not observed when examining the three-way interaction of aggregate type × aggregate rate × paclobutrazol concentrations for either species. Begonias did exhibit a significant difference regarding the simple effect of aggregate ($P = 0.012$); however, the range of values was 0.8 cm and was not considered commercially significant (data not shown). Therefore, based on these results, the incorporation of biochar, either at coarse or extra-coarse grade and when using either a 15% or 30% incorporation rate did not impact the efficacy of low-dose paclobutrazol drench applications. Thus, the plant height data for each species were pooled from all substrates before determining the impact of paclobutrazol concentration on plant height. There was a significant quadratic relationship between paclobutrazol concentration and begonia plant height (Fig. 3A). Plant height was 22.8%, 31.0%, 46.3%, 58.5%, and 63.29% shorter than the untreated control for 6.25, 12.5, 25, 50, and 100 μg·L^{-1}, respectively. Also, a significant quadratic relationship

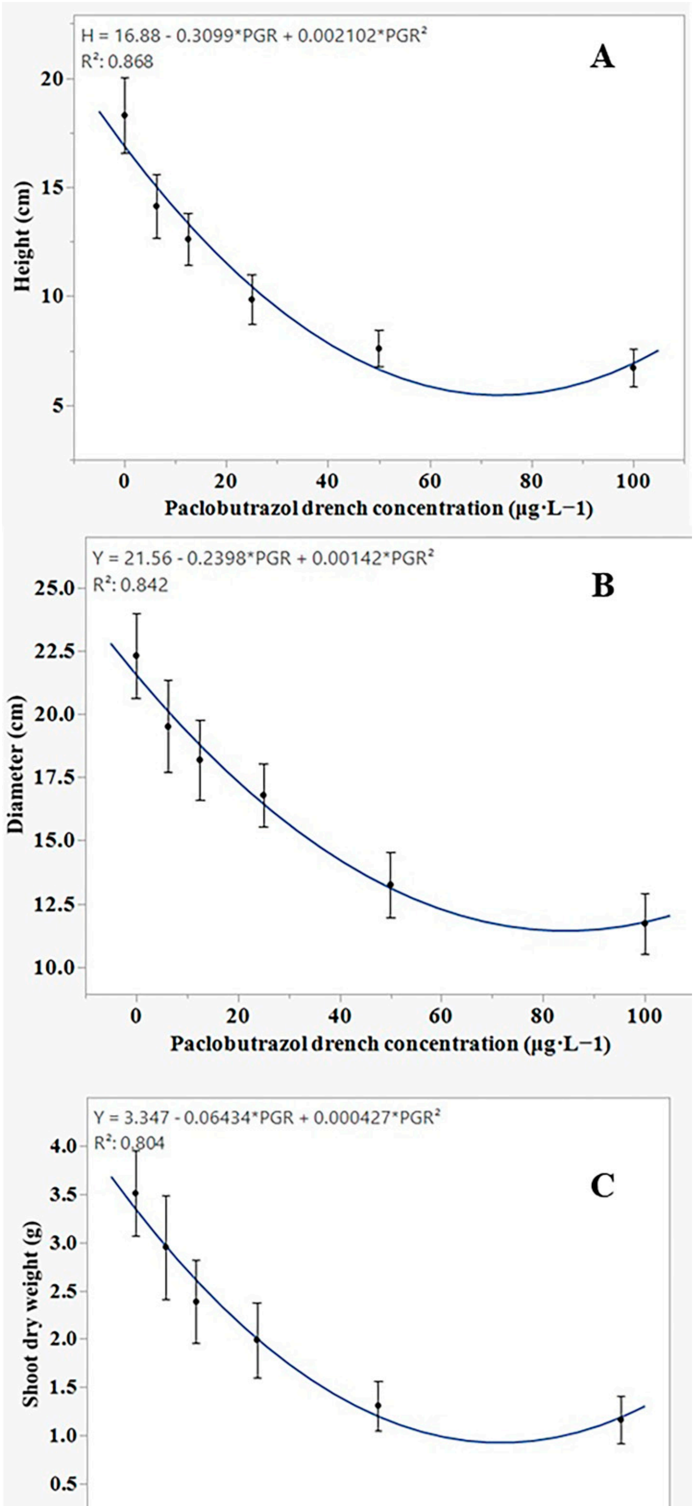

Fig. 3. Impact of paclobutrazol drench concentrations on *Begonia ×hybrida* 'Big Red Bronze Leaf' plant height (**A**), diameter (**B**), and shoot dry weight (**C**).

between plant height and paclobutrazol rate occurred with pansies (Fig. 4A). Plant height was 38.1%, 53.0%, 61.4%, 70.1%, and 75.8% shorter than the untreated control for 6.25, 12.5, 25, 50, and 100 $\mu g \cdot L^{-1}$, respectively.

Plant diameter. Plant diameter followed a trend similar to plant height in which neither begonia nor pansies were significantly different when examining the three-way interaction of aggregate type × aggregate incorporation rate × paclobutrazol concentration. The simple effects of aggregate and aggregate rate for begonias were significant ($P = 0.0057$ and $P = 0.015$, respectively); however, the values were 0.7 cm and 0.5 cm, respectively, and were not commercially significant (data not shown). Thus, the data were pooled to examine the effect of paclobutrazol concentration on plant diameter. There was a significant quadratic relationship between paclobutrazol concentration and begonia plant diameter (Fig. 3B). Plant diameter was 12.6%, 18.5%, 24.7%, 40.6%, and 47.4% smaller than the untreated control for 6.25, 12.5, 25, 50, and 100 $\mu g \cdot L^{-1}$, respectively. Also, a significant quadratic relationship between plant diameter and paclobutrazol concentration occurred for pansy (Fig. 4B). Plant diameter was 38.3%, 54.5%, 63.4%, 70.1%, and 72.2% smaller than the untreated control for 0.5, 1.0, 2.0, 6.25, 12.5, 25, 50, and 100 $\mu g \cdot L^{-1}$, respectively.

Shoot dry weight. Significant differences in shoot dry weight were not observed when examining the three-way interaction of aggregate type × aggregate rate × paclobutrazol concentrations for either species. For begonia the interaction of aggregate × aggregate rate was significant ($P = 0.0058$); however, the difference was 0.46 g and would not be considered biologically different (data not shown). Thus, the shoot dry weight data for each cultivar were pooled from all substrates before determining the impact of paclobutrazol rate on shoot dry weight. There was a significant quadratic relationship between paclobutrazol concentration and begonia shoot dry weight (Fig. 3C). Shoot dry weight was 14.8%, 32.0%, 43.3%, 62.7%, and 66.8% less than the untreated control for 0.5, 1.0, 2.0, 6.25, 12.5, 25, 50, and 100 $\mu g \cdot L^{-1}$, respectively. Also, a significant quadratic relationship between shoot dry weight and paclobutrazol concentration for pansy occurred (Fig. 4C). Shoot dry weight was 54.4%, 70.8%, 79.8%, 86.1%, and 89.6% less than the untreated control for 0.5, 1.0, 2.0, 6.25, 12.5, 25, 50, and 100 $\mu g \cdot L^{-1}$, respectively.

This research suggests that wood biochar is a suitable aggregate material to incorporate it with sphagnum peatmoss up to 30% by volume in horticultural substrates for greenhouse begonia and pansy production while still achieving similar growth compared with traditional peat-perlite substrates. The comparison of an alternative aggregate up to 30% by volume is considered to be the upper end of commercial aggregate usage for most peat-based substrates in greenhouse crops (Owen et al. 2016). In previous research, paclobutrazol was successfully filtered out when exposed to a small-scale granular activated carbon system for 59 seconds, resulting in begonias yielding similar dry weight when exposed to a 50 $\mu g \cdot L^{-1}$ paclobutrazol filtered solution compared with those that were exposed to a 0 $\mu g \cdot L^{-1}$ paclobutrazol solution (Grant et al. 2018). In addition, Million et al. (1998) reported that increased percentages of pine bark, up to 60% pine bark, would decrease the efficacy of paclobutrazol drenches. Although the incorporation of two different

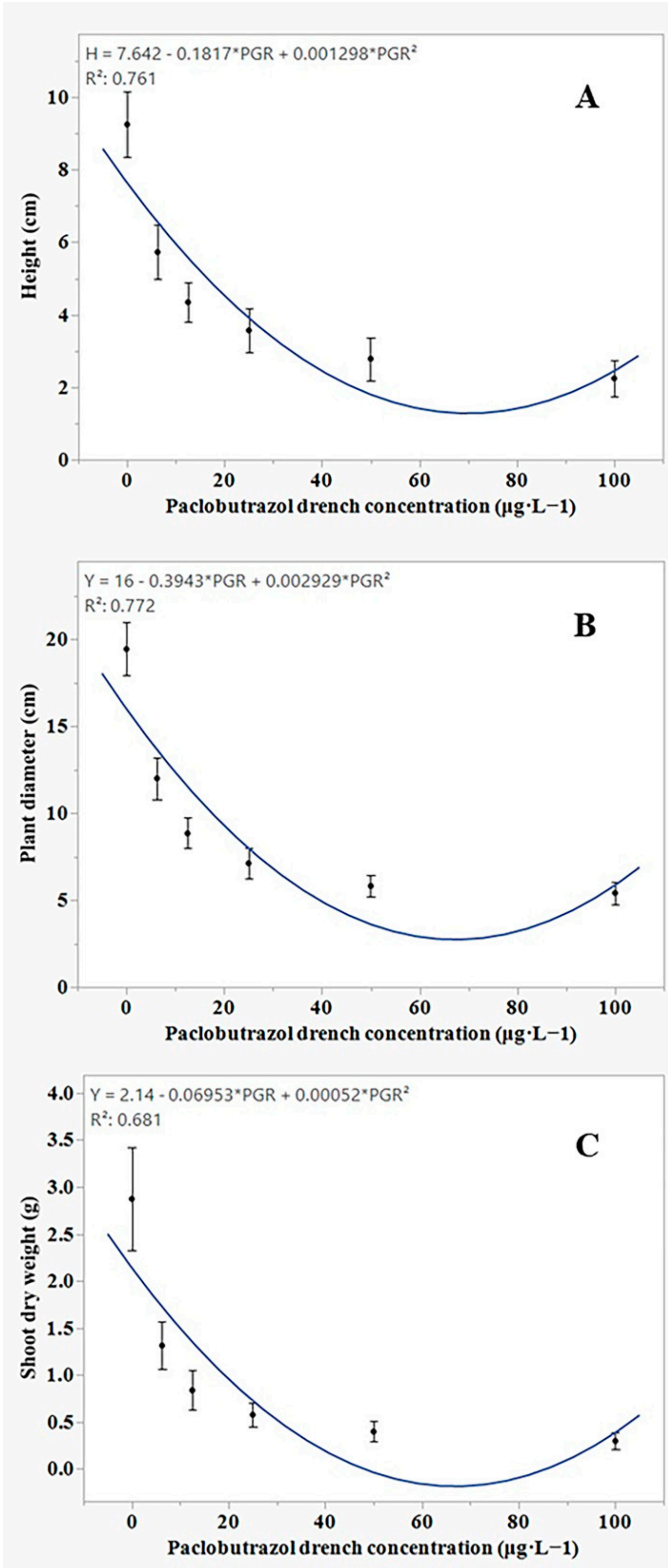

Fig. 4. Impact of paclobutrazol drench concentrations on *Viola ×wittrockiana* 'Pansy Matrix Blue Blotch' height (**A**), diameter (**B**), and dry weight (**C**).

particle size biochars up to 30% did not result in reduced efficacy of paclobutrazol, this is likely due to not a high enough percentage to yield enough contact with the biochar for paclobutrazol to bind to the biochar particles or preventing binding to the peat. Another potential reason that paclobutrazol efficacy was not negatively impacted by biochar incorporation up to 30% in a growing media is that the particle sizes examined may not have resulted in enough particle surface area to contact the paclobutrazol. Additional research examining various biochar particle sizes and incorporation rates is needed to determine the effect of surface area of paclobutrazol binding to biochar.

Conclusion

The biochar-amended substrates evaluated in this study were all adequate for growing low- and high-sensitive species, poinsettia, pansy, and begonia without any negative impact on plant growth when compared with plant grown in peat-perlite substrates. In both experiments, substrate composition did not decrease the paclobutrazol efficacy when comparing the response curves to perlite-amended substrates. This suggests that biochar can be used as an alternative aggregate preforming comparable to a peat-perlite substrate for horticultural crop production.

References Cited

Barrett JE, Bartuska CA. 1982. PP333 Effects on stem elongation dependent on site of application. HortScience. 17(5):737–738. https://doi.org/10.21273/HORTSCI.17.5.737.

Bedussi F, Zaccheo P, Crippa L. 2015. Pattern of pore water nutrients in planted and non-planted soilless substrates as affected by the addition of biochars from wood gasification. Biol Fertil Soils. 51(5):625–635. https://doi.org/10.1007/s00374-015-1011-6.

Brooks D, Roll RR, Naylow W. 2000. Wastewater technology factsheet. Granular activated carbon adsorption and regeneration. EPA 832-F-00-017. US Environmental Protection Agency.

Desta B, Amare G. 2021. Paclobutrazol as a plant growth regulator. Chem Biol Tech Ag. 8(1): 1–15. https://doi.org/10.1186/s40538-020-00199-z.

Evans MR, Gachukia M. 2004. Fresh parboiled rice hulls serve as an alternative to perlite in greenhouse crop substrates. HortScience. 39(2): 232–235. https://doi.org/10.21273/HORTSCI.39.2.232.

Faust JE, Korczynski PC, Klein R. 2001. Effects of paclobutrazol drench application date on poinsettia height and flowering. HortTechnology. 11(4):557–560. https://doi.org/10.21273/HORTTECH.11.4.557.

Fornes F, Belda RM, Lidón A. 2015. Analysis of two biochars and one hydrochar from different feedstock: Focus set on environmental, nutritional and horticultural considerations. J Clean Prod. 86:40–48. https://doi.org/10.1016/j.jclepro.2014.08.057.

Grant GA, Fisher PR, Barrett JE, Wilson PC. 2018. Removal of paclobutrazol from irrigation water using granular-activated carbon. Irrig Sci. 36:159–166. https://doi.org/10.1007/s00271-018-0572-1.

Guo Y, Niu G, Starman T, Volder A, Gu M. 2018. Poinsettia growth and development response to container root substrate with biochar. Horticulturae. 4(1):1. https://doi.org/10.3390/horticulturae4010001.

Gvero PM, Papuga S, Mujanic I, Vaskovic S. 2016. Pyrolysis as a key process in biomass combustion and thermochemical conversion. Therm Sci. 20(4):1209–1222.

Huang L, Gu M. 2019. Effects of biochar on container substrate properties and growth of plants—A review. Horticulturae. 5(1):14. https://doi.org/10.3390/horticulturae5010014.

Ioannidou OA, Zabaniotou AA, Stavropoulos GG, Islam MA, Albanis TA. 2010. Preparation of activated carbons from agricultural residues for pesticide adsorption. Chemosphere. 80(11): 1328–1336. https://doi.org/10.1016/j.chemosphere.2010.06.044.

Jackson BE, Wright RD, Barnes MC. 2008. Pine tree substrate, nitrogen rate, particle size, and peat amendment affect poinsettia growth and substrate physical properties. HortScience. 43(7): 2155–2161. https://doi.org/10.21273/HORTSCI.43.7.2155.

Khodadad CL, Zimmerman AR, Green SJ, Uthandi S, Foster JS. 2011. Taxa-specific changes in soil microbial community composition induced by pyrogenic carbon amendments. Soil Biol Biochem. 43(2):385–392. https://doi.org/10.1016/j.soilbio.2010.11.005.

Million JB, Barrett JE, Nell TA, Clark DG. 1998. Influence of media components on efficacy of paclobutrazol in inhibiting growth of broccoli and petunia. HortScience. 33(852):852. https://doi.org/10.21273/HORTSCI.33.5.852.

Million JB, Barrett JE, Nell TA, Clark DG. 1999. Inhibiting growth of flowering crops with ancymidol and paclobutrazol in subirrigation water. HortScience. 34(6):1103–1105. https://doi.org/10.21273/HORTSCI.34.6.1103.

Million JB, Barrett JE, Nell TA, Clark DG. 2002. One-time vs. continuous application of paclobutrazol in subirrigation water for the production of bedding plants. HortScience. 37(2):345–347. https://doi.org/10.21273/HORTSCI.37.2.345.

Nemati MR, Simard F, Fortin J, Beaudoin J. 2015. Potential use of biochar in growing media. Vadose Zone J. 14(6):1–8. https://doi.org/10.2136/vzj2014.06.0074.

Newman SE, Tant JS. 1995. Root-zone medium influences growth of poinsettias treated with paclobutrazol-impregnated spikes and drenches. HortScience. 30(7):1403–1405. https://doi.org/10.21273/HORTSCI.30.7.1403.

Niu G, Heins R, Carlson W. 2002. Using paclobutrazol to control height of poinsettia ‘Freedom’. HortTechnology. 12(2):232–236. https://doi.org/10.21273/HORTTECH.12.2.232.

Northup J. 2013. Biochar as a replacement for perlite in greenhouse soilless substrates (MS Thesis). Iowa State University, Ames, IA, USA.

Owen W. 2013. Pine wood chips as an alternative to perlite in greenhouse substrates: Critical parameters to consider (MS Thesis). North Carolina State University, Raleigh, NC, USA.

Owen WG, Jackson BE, Whipker BE, Fonteno WC. 2016. Paclobutrazol drench activity not affected in sphagnum peat-based substrates amended with pine wood chip aggregates. HortTechnology. 26(2):156–163. https://doi.org/10.21273/HORTTECH.26.2.156.

Quarrels JR, Newman SE. 1994. Pine bark levels and particle size influence the activity of paclobutrazol and uniconazole on ‘Freedom’ and ‘Gutbier V-14 Glory’ poinsettias. HortScience. 29(7):737. https://doi.org/10.21273.

Smith JT. 2019. Paclobutrazol drench efficacy in soilless substrates containing wood and pine bark, and vegetative hemp growth in peat and coir-based substrates (MS Thesis). North Carolina State University, Raleigh, NC, USA.

Spokas KA, Cantrell KB, Novak JM, Archer DW, Ippolito JA, Collins HP, Boateng AA, Lima IM, Lamb MC, McAloon AJ. 2012. Biochar: A synthesis of its agronomic impact beyond carbon sequestration. J Environ Qual. 41(4):973–989. https://doi-org.prox.lib.ncsu.edu/10.2134/jeq2011.0069.

Whipker BE. 2023. Plant growth regulator guide. Ball Publishing, West Chicago, IL, USA.

Woldetsadik D, Drechsel P, Marschner B, Itanna F, Gebrekidan H. 2018. Effect of biochar derived from fecal matter on yield and nutrient content of lettuce (*Lactuca sativa*) in two contrasting soils. Environ Syst Res. 6(1):1–12. https://doi.org/10.1186/s40068-017-0082-9.

Yu P, Ong K, Ueckert J, Gu M. 2023. Biochar and trichoderma reduce containerized poinsettia root rot caused by *Pythium aphanidermatum.* HortScience. 58(8):846–854. https://doi.org/10.21273/HORTSCI17203-23.