Exploring Substrata Flexibility and Peat Reduction with Wood Fiber in Stratified Substrates

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KEYWORDS. coconut coir, growing media, HydraFiber, peatmoss, petunia, pine bark

ABSTRACT. Considerable research has investigated solutions for alternative substrates in reducing horticulture peat applications. Among many options, soilless substrate stratification has been shown to reduce peat inputs by upwards of 50%, and coconut coir and wood fiber are two popular alternatives to peat in many soilless substrates. Most stratified studies have used a pine bark–based substrata; however, scant research has explored substrata variations to promote more flexibility in stratified substrate management decisions. Therefore, the objective of our study was to explore different variations of the top-strata and substrata materials to identify the potential of reduced-peat and no-peat production of greenhouse-grown petunias. A commercial peatlite or coirlite (7:3 blend of peat/coir:perlite by volume) was layered over pine bark or wood fiber (HydraFiber) at a 50/50-by-volume ratio, as well as an unstratified peatlite or coirlite control. Results show that a petunia plant can be produced successfully with equal quality growth using 50% less peat-based media when pine bark or wood fiber is layered below. Moreover, greenhouse petunias can still be grown to salable and marketable quality (with slightly less shoot, root, and flower development) using systems with 100% peat elimination in coir-based unstratified and stratified (coirlite layered over pine bark or wood fiber) profiles. This work provides more options for growers seeking flexible solutions.

Floriculture production is responsible for ∼40% of all annual horticultural specialty crop sales in the United States (US Department of Agriculture, National Agricultural Statistics Service 2020), in which the substrate in practice serves as a fundamental pillar in nearly all production management decisions. The substrate determines the efficient and continual supply of moisture (controlling irrigation efficiency), mineral nutrients (optimizing fertilizer retention), and oxygen to the root zone, ultimately governing both the sustainability of greenhouse crop production and overall health of the plant. Floriculture production has relied predominantly on peatmoss substrates to ensure optimal growing conditions. However, the peatmoss industry has come under scrutiny in recent years as a result of environmental (wetland habitats and carbon storage) and economic (costs, demands, and deficits in the peat supply chain) issues (Barrett et al. 2016; Blok et al. 2021; Raviv et al. 2019). As a result, research regarding alternatives for peat applications has increased considerably.

Globally, coconut coir substrates have expanded in use as a popular peat alternative (Barrett et al. 2016; Schmilewski 2008). Coconut coir is derived from the mesocarp as a byproduct of coconut (*Cocos nucifera*) harvests. The physiochemical characteristics of coir are similar to that of peat (Schmilewski 2008), with additional benefits. Coconut coir is considered a hydrophilic material, in that its rewettability is improved when compared with hydrophobic peat materials (Raviv et al. 2019). Plus, coconut coir fibers improve significantly plant performance and substrate hydraulic transfer under dry conditions (Fields et al. 2017). Wood fiber substrates have also been introduced. Wood fiber substrates have increased in popularity and availability, with several physiochemically unique materials available to growers across the country (Dickson et al. 2022). Most of these materials have desirable physiochemical properties for substrata material, in that they contain high porosity (e.g., air-filled porosity). They have been used to reduce peat inputs without decreases in yield or plant quality (Thiessen et al. 2023).

Moving beyond using alternative materials to extend peat reserves, substrate stratification is a relatively new form of substrate engineering that has been developed recently to reduce peat applications by upward of 50%. Originally developed for nursery substrates, substrate stratification involves layering unique substrates within a container to modify spatially the physiochemical storage capacities (Fields et al. 2021). Among many potential benefits, layering a high-performance and expensive peat-based substrate atop an inexpensive bark material has been shown to reduce costly substrate applications by as much as of 50% while augmenting container root growth (Criscione et al. 2025; Fields and Criscione 2023). Fields et al. (2024b) further refined the stratified substrate practice by exploring various stratified ratios (e.g., depth of layering) to investigate additional options for interested growers. However, a limited number of studies have assessed different media pairings in stratified systems, especially regarding lower strata materials. Most stratified studies have used a pine bark (either unprocessed or screened, coarse particles) substrate in the bottom layer and have focused on the upper strata, where most of the water and nutrient exchange occurs (Criscione et al. 2022; Fields et al. 2021, 2022). Thiessen and Fields (2025) used wood fiber as a substrata in young plant production, although these were with small container volumes (∼59 cm^3). Thus, more research is needed because the lower stratum is where readily available, low-cost materials can have the greatest economic or environmental impact in the industry.

Considering sufficient horticultural research has examined different soilless substrates to serve as a peat alternative

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or as entire substitutes (Barrett et al. 2016), including considerable attention to coconut coir (Evans et al. 1996; Machado et al. 2021) and wood fiber (Eveleens, et al. 2021; Jackson et al. 2008), the objective of our study was to explore different variations of the top and substrata materials to identify the potential of reduced-peat and no-peat production of greenhouse-grown petunias. These substrate materials are viable options in reducing horticultural peat applications; however, producers may need to go beyond traditionally blending alternate materials to extend peat supplies further, and so growers are less reliant on certain manufacturers and specific products. Thus, our study explored stratifying a peat-based substrate over bark and a commercially available wood fiber product. Furthermore, we explored the same stratified systems using a coir-based upper substrate to reduce peat applications by 100%. It was hypothesized that plants grown in the wood fiber substrata or in coir-based systems would perform equally to those in standard and bark substrata systems.

Materials and methods

Substrate materials. Sphagnum peatmoss (fertilome ®; The Gold Canadian Sphagnum Peat Moss; Riviere-Ouelle, Canada) was hydrated and 0.11 m^3 of expanded peat was placed in a ribbon soil mixer with 0.05 m^3 horticultural grade perlite (Aero-Soil Horticultural Perlite; Dicalite Management Group, Inc.; West Conshohocken, PA, U.S.A.) to make a 7:3 ratio (by volume) peat–perlite blend (peatlite). Thereafter, the ribbon mixer was cleaned, and coconut coir (FibreDust LLC, Glastonbury, CT, USA) was hydrated and 0.11 m^3 of expanded coir was placed in the ribbon soil mixer for 10 min with 0.05 m^3 perlite (Dicalite Management Group), micronutrients, and lime to make a 7:3 ratio (by volume) coir–perlite (coirlite). Approximately 0.06 m^3 of aged pine bark (*Pinus taeda*; Phillips Bark Processing Co., Brookhaven, MS, USA) was collected and mixed with dolomitic lime (Lime-Rite Pelletized Dolomitic Lime, Roswell, GA, USA) by piling materials together then passing a pile back and forth three times with a shovel. The limestone application rate for peatlite, coirlite, and pine bark was 4.8, 2.4, and 3.6 $kg \cdot m^{-3}$, respectively, to target a final pH of ~6.0. Approximately 0.06 m^3 of commercial wood fiber product (HydraFiber EZ-Blend; Buffalo Grove, IL, USA) was lightly hydrated and expanded to break compaction post-packaging. This product is a fiber created from expanded wood and bark mixtures, and is pH adjusted.

Substrate physical properties of each individual substrate used in this experiment were assessed via porometer analysis as described by Fontenot and Bilderback (1993). They included air space, container capacity, total porosity, and bulk density. Particle size distribution of all substrate materials was analyzed by passing 100 g of dried particles through a nest of sieves (mesh aperture, 6.3, 2.0, 0.7, 0.5, 0.25, and 0.01 cm) via agitation for 5 min with a Ro-Tap shaker (Rx-29; W.S. Tyler, Mentor, OH, USA). Four particle-diameter classifications were created: extra-large (> 6.3 mm), large (6.3–2.0 mm), medium (2.0–0.7 mm) and fine (< 0.7 mm).

These four substrate materials were then used to make the six experimental substrate systems examined in our study, the first two of which were peatlite and coirlite, along with four stratified profiles each consisting of a 50:50 depth layering. These four additional treatments included peatlite layered atop pine bark (PB), peatlite layered atop wood fiber (PW), coirlite layered atop pine bark (CB), and coirlite layered atop wood fiber (CW).

Growth trial. A *Petunia* hybrid 'Supertunia Vista Bubblegum' plug was transplanted into 2.4 L containers (C300S; Nursery Supplies, Kissimmee FL, USA) filled with one of six substrate treatments (n = 7). For the conventional profiles (i.e., peatlite or coirlite), substrates were filled uniformly in the container, tapped lightly three times, then filled to the inner container lip to mimic standard industry container-filling practices. The stratified substrate treatments were filled to 50% of the container height (8.3 cm) with their substrata (either aged pine bark or wood fiber) using a spacer bracket to ensure uniformity and then were tapped lightly to settle the particles. Thereafter, the rest of the container was filled with either peatlite or coirlite to the inner container lip and tapped lightly again three times to ensure proper filling. All containers were hand-watered three times to hydrate completely. Containers were then placed randomly on two greenhouse benches connected to one solenoid and installed with a 1.8 $L \cdot h^{-1}$ spray stake (plum; Netafim, Fresno, CA, USA). Each container received 240 mL irrigation every other day for 14 d. After 14 d of growth, plants received 240 mL irrigation daily. In place of an irrigation application, all plants were hand-fertigated every week (250 mL) with 200 ppm N liquid fertilizer ($20N–20P_2O_5–20K_2O$; Peters Professional Fertilizer, Summerville, SC, USA) by pouring the fertilizer solution evenly across the surface of each substrate.

Plant growth indices [(Plant height + Plant width + Perpendicular width)/3] were measured weekly for all replicates. In addition, plant greenness (as a proxy for chlorophyll development) was measured with a soil plant analysis development (SPAD) meter (SPAD 502 Plus; Spectrum Technologies, Inc., Aurora, IL, USA), and plant flower count was measured weekly on all replicates. The plants were allowed to grow for 45 d, until they were considered fully salable. At this time, photographs were taken of representative replicates and all plants were harvested destructively. The aerial portion of the plants (shoots) was severed at the substrate surface and then substrate particles were washed from the roots. The shoot and root material was dried in a forced-air drying oven at 70 °C for 7 d to measure dry mass.

Data analysis. All data were analyzed using JMP Pro version 18.0.0 (SAS Institute, Inc., Raleigh, NC, USA) with analysis of variance to identify any significant statistical differences across the means of the responses described previously. If significant, post hoc Tukey's honestly significant difference test ($\alpha = 0.05$) was used to separate means across substrate treatments.

Results and discussion

Substrate physical properties. There were differences across the individual stratified composite layers (Table 1). Pine bark stored the least amount of water ($P < 0.0001$) and contained the greatest air-filled porosity ($P < 0.0001$) across substrate treatments (Table 1). Coirlite stored more water than peatlite ($+0.08\ cm^3 \cdot cm^{-3}$) and had significantly lower bulk density values ($-0.05\ g \cdot cm^{-3}$; $P < 0.0001$), although both substrates contained similar air-filled porosity values and were

Table 1. Static physical properties[i] of four individual substrates including a peatlite blend (7:3, peat:perlite by volume), a coirlite blend (7:3, coir:perlite by volume), unscreened pine bark, and wood fiber materials.

Substrate	Container capacity ($cm^3 \cdot cm^{-3}$)	Air-filled porosity ($cm^3 \cdot cm^{-3}$)	Total porosity ($cm^3 \cdot cm^{-3}$)[ii]	Bulk density ($g \cdot cm^{-3}$)	Extralarge (g)	Large (g)	Medium (g)	Fine (g)
Peatlite	0.54 b[iii]	0.22 c	0.76 c	0.14 b	2.72 c	35.12 b	27.91 b	31.25 a
Coirlite	0.62 a	0.22 c	0.85 b	0.09 c	0.23 c	28.88 c	37.78 a	33.93 a
Pine bark	0.44 c	0.42 a	0.86 b	0.18 a	24.30 b	42.73 a	19.93 c	12.97 b
Wood fiber[iv]	0.59 a	0.36 b	0.96 a	0.09 c	92.55 a	0.25 d	1.01 d	6.12 c
P value[v]	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[i] Physical properties were measured via porometer analysis.

[ii] Total porosity = Minimum air space (minimum air-filled porosity after free drainage) + Maximum water holding capacity (water storage maximum water holding capacity after free drainage).

[iii] Lowercase letters denote detected differences among means using Tukey's honestly significant difference test ($\alpha = 0.05$).

[iv] Hydrafiber EZ Blend, a commercially available wood product comprised of wood and bark.

[v] Measures of overall treatment effects using analysis of variance, with $\alpha = 0.05$.

within recommended substrate storage capacity ranges (Bilderback et al. 2013) (Table 1). The finer texture in coirlite materials, or lack of larger particle proportions relative to peatlite, is likely what resulted in the increased water storage characteristics in the coirlite (Durand et al. 2024) (Table 1). Coir is often considered a 1:1 replacement for peat; however, research has indicated that these relative proportions should be slightly skewed, with the wide range of particle sizes found in different coir samples being a primary driver of the difference (Abad et al. 2005). Londra et al. (2018) made similar observations, with coir-based substrates having greater total porosity than peat-based substrates at similar blend ratios. Nevertheless, fibrous coir materials can be applied easily to match the physical properties of peat. Fields et al. (2018) used a 40% (by volume) coir to match the water storage characteristics of a 35% (by volume) peat.

Wood fiber substrates had the greatest total porosity across substrate treatments ($P < 0.0001$) and > 90% of its particle proportions were characterized as extralarge (Table 1). Despite traditional particle characterization (i.e., particle sieving) being useful for classifying most soilless substrates (Bartley et al. 2022), as a result of the "clumping" nature of the specific wood fiber particles in our study, most particles are aggregated and remained on larger sieve apertures, representing particle size distribution inaccurately (Mizell 2024). As a result, the particle size distribution of the wood fiber used in our research was reported as aggregated clumps instead of individual particles. We felt this "effective particle size" was a fair assessment, as this is the nature of the materials in the substrate. More important, the wood-based product was used as an unamended component in the bottom strata in our research, as opposed to blending into a substrate. The complex and interwoven nature of fibers delivers unique hydraulic characteristics with regard to particle size and structure to porosity storage values.

Fields et al. (2024a) evaluated the storage capacity of different stratified substrate systems—specifically, fine bark (< 6.3 mm) layered over coarse bark particles (≥ 6.3 mm) and peatlite layered over unprocessed pine bark. They concluded that the storage capacities of coarser textured substrates can be estimated accurately using the average of the two individual stratified composite layers, although finer textured substrates cannot be estimated accurately. Nevertheless, it was reported that when placing a coarser textured substrate below finer textured particles (e.g., PB), there was a significant decrease in water storage and an increase in air-filled porosity throughout the entire system (Fields et al. 2024a). From these reports, it can be ascertained that regardless of the stratified system (e.g., PB, PW, CB, CW), stratified profiles overall contained greater air-filled porosity and less water storage than conventionally filled finer textured substrates.

GROWTH TRIAL. Our study examined petunia growth when produced in different variations of stratified substrate systems, continuing with either 50% peat reduction through alternative substrata options or 100% reduction in peat applications through a combination of alternative upper and substrata variations.

At study initiation, regardless of substrate treatment, all plants were of a similar size ($P > 0.05$; Fig. 1). With exception at 31 d after initiation (DAI), when plants produced in 100% peatlite were significantly larger ($P = 0.0478$), plants produced in peat-based systems also had a similar size for the entire study (Fig. 1). Moreover, there were no differences in final flower production in plants grown in peat-based profiles ($P = 0.4408$; Fig. 2). Some differences were found regarding dried biomass values, when plants grown in PB contained significantly greater root mass ($P < 0.0001$; Fig. 3). Despite these differences, plants were qualitatively similar and marketable (Fig. 4). This validates previous stratified studies that produced equal- or better quality herbaceous ornamental plants in peat-based media layered over pine bark (Criscione et al. 2025; Fields and Criscione 2023; Fields et al. 2024b). Furthermore, these results highlight the feasibility of using a wood fiber substrata as an alternative material to conventionally used pine bark. Placing wood fiber below a high-performing peat-based material does not decrease plant quality or yield (Thiessen and Fields 2025).

Similar to the peat-based substrates, there were no differences in plant growth (Figs. 1 and 3) and final flower production ($P = 0.7173$; Fig. 2) among coir-based substrate treatments. Plants grown in CW had lower root development when compared with its stratified counterpart ($P < 0.0427$; Fig. 3); however, this did not affect the quality of the plants. All plants were still considered salable (Fig. 4).

After ∼23 d, plant growth in peat- and coir-based substrates began to diverge, with a faster growth rate

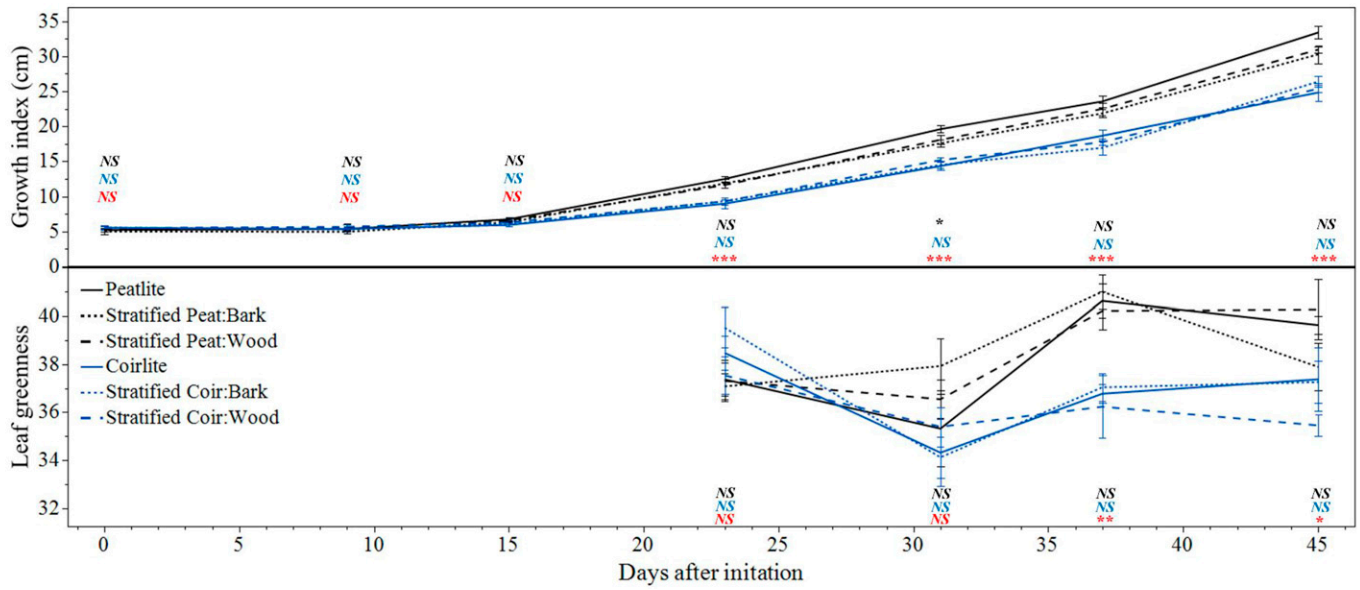

Fig. 1. Growth indices (top) and leaf greenness [soil plant analysis development (SPAD); bottom] of petunia plants grown in one of six substrate treatments. The first two treatments were 100% peatlite (7:3 peat:perlite by volume) and 100% coirlite (7:3 coir:perlite by volume). The remaining four stratified profiles each consist of a 50:50 depth layering as follows: peatlite layered atop pine bark or wood fiber and coirlite layered atop pine bark or wood fiber. Plants were constrained to an analysis of variance, with $\alpha = 0.05$ within substrate treatments [peat-based profile (black text) or coir-based profile (blue text)] or across substrate treatments (red text). NS, *, **, * Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.**

seen in plants grown in peat-based substrates that remained slightly larger than plants grown in coir-based systems for the remainder of the study (Fig. 2). That being said, these growth differences were minor (Fig. 4). Similar observations were made in leaf greenness (SPAD), where 37- and 45-DAI plants grown in peat-based substrates had greater chlorophyll development ($P < 0.05$; Fig. 1). There were some differences detected across flower production at study culmination. Plants grown in peatlite-based systems had greater flower counts than plants grown in coir-based substrates ($P < 0.0001$; Fig. 2). Moreover, plants grown in peat-based substrates had greater shoot biomass values in every case when compared with coir-based-grown plants ($P < 0.0001$; Fig. 3). Other previous reports have identified reduced growth and flowering of petunia plants with increasing coir percentages (Hongpakdee

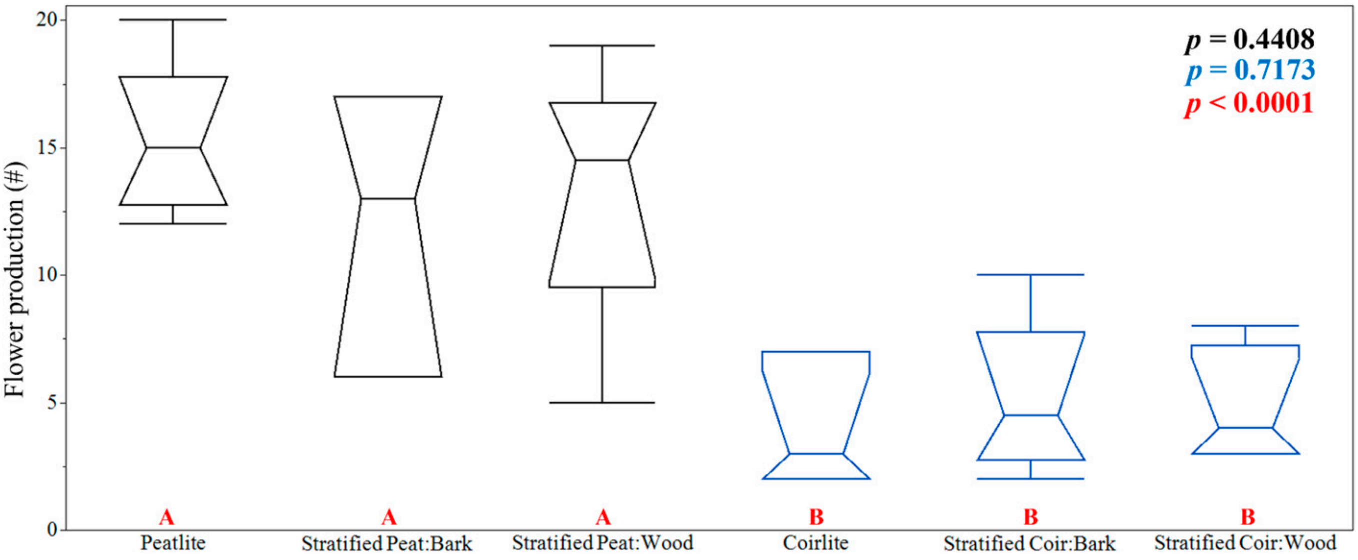

Fig. 2. Final flower production at study culmination (45 d after study initiation) of petunia plants grown in one of six substrate treatments, the first two of which include 100% peatlite (7:3 peat:perlite by volume) and 100% coirlite (7:3 coir:perlite by volume). The remaining four stratified profiles each consist of a 50:50 depth layering of peatlite layered atop pine bark or wood fiber and coirlite layered atop pine bark or wood fiber. Plants were constrained to an analysis of variance, with α = 0.05 within substrate treatments [peat-based profile (black text or boxplots) or coir-based profile (blue text or boxplots)] or across substrate treatments (red text). If significant at α = 0.05, a Tukey' post hoc honestly significant difference test was conducted.

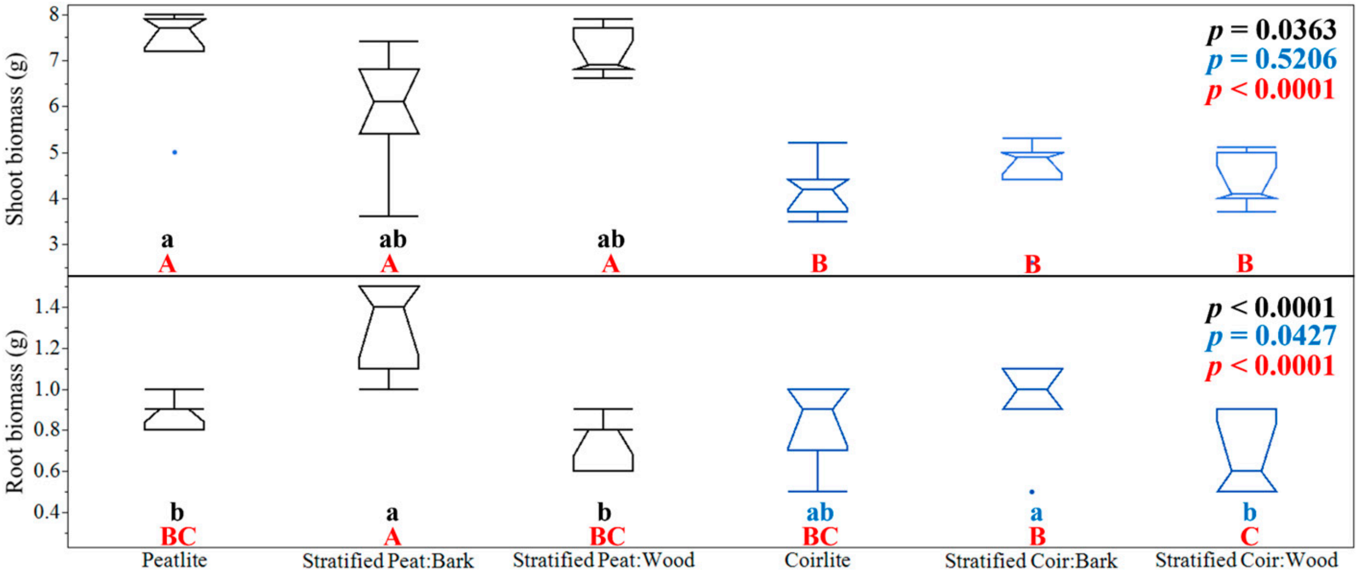

Fig. 3. Dried petunia plant shoot (top) and root (bottom) biomass values of petunia plants grown in one of six substrate treatments, the first two of which include 100% peatlite (7:3 peat:perlite by volume) and 100% coirlite (7:3 coir:perlite by volume). The remaining four stratified profiles each consist of a 50:50 depth layering of peatlite layered atop pine bark or wood fiber and coirlite layered atop pine bark or wood fiber. Plants were constrained to an analysis of variance, with α = 0.05 within substrate treatments [peat-based profile (black text or boxplots) or coir-based profile (blue text or boxplots)] or across substrate treatments (red text). If significant at α = 0.05, a Tukey' post hoc honestly significant difference test was conducted.

and Ruamrungsri 2017). Quantitatively, plants grown in peat-based substrates are larger than coir-grown plants, although, qualitatively, plants grown in any of the substrate treatments are salable crops with sufficient root development (Fig. 4).

Conclusion

Our research explored various production tactics to reduce peat use in greenhouse bedding plant production. With the identification and development of different variations for successful stratification in the substrata (e.g., pine bark vs wood fiber) or top strata (e.g., peatlite vs coirlite), we are effectively creating a more robust system for growers that lessens reliance on any single material. Producers can tailor stratified systems with substrates that are more available and cost-effective for a particular crop. The results in our study demonstrate flexibility for producers to change substrata materials as needed if costs or availability are strict limiting factors in production decisions. Moreover, if growers want to continue using peat-based materials, they can confidently reduce inputs by 50%. When supply chain availability is limited or if associated substrate material costs increase, growers can produce popular ornamental plants at 100% peat elimination using coir-based substrates with no adjustments to production practices and little loss in productivity. Further refinement of cultural practices would likely mitigate any associated production differences.

Fig. 4. Representative photographs of shoots (top) and roots (bottom) of petunia plants grown in one of six substrate treatments, the first two of which include 100% peatlite (7:3 peat:perlite by volume) and 100% coirlite (7:3 coir:perlite by volume). The remaining four stratified profiles each consist of a 50:50 depth layering of peatlite layered atop pine bark or wood fiber and coirlite layered atop pine bark or wood fiber.

In addition, stratification within peat- and coir-based substrates provides additional options for growers seeking to reduce reliance on any specific materials and potentially contributes to increased material circularity, in the event onsite waste or excess materials may be available.

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