Research Reports

Greenhouse and Landscape Performance of Bedding Plants in Biocontainers

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ADDITIONAL INDEX WORDS. **pots, sustainability, biodegradable**

SUMMARY. **Biodegradable and plastic containers were evaluated for greenhouse and landscape production of 'Score Red' geranium (*Pelargonium ×hortorum*), 'Grape Cooler' vinca (*Catharanthus roseus*), or 'Dazzler Lilac Splash' impatiens (*Impatiens wallerana*) at Louisiana State University (LSU), Baton Rouge, LA; Longwood Gardens (LWG), Kennett Square, PA; and University of Arkansas (UA), Fayetteville, AR. Of the 5-inch containers, the highest geranium and vinca shoot growth occurred in plastic containers compared with bioplastic and rice straw containers. Of the 4-inch containers, paper containers produced the greatest geranium shoot growth compared with the peat containers at LSU and LWG. Shoot growth in impatiens was similar for all container types at all three locations. When all container types were considered, there was no difference in the root growth of geranium or impatiens at all three locations. However, vinca had the highest root growth in paper containers compared with that in peat and coconut fiber. The root:shoot (R:S) ratio of geranium were mixed for all pot sizes, types, and locations. Vinca R:S ratio was highest in both the 4- and 5-inch plastic control containers at LSU and lowest in both plastic containers at LWG. Direct plant containers generally performed well in the landscape as the plants grown in plastic containers at LWG. Plants grown in all tested containers produced marketable plants for both the retail and landscape markets. However, growers and landscapers should be aware of growth differences that may occur when using biodegradable containers and align production practices accordingly.**

Bedding plants are one of the primary products of the floriculture industry. In the United States, the wholesale value for bedding and garden plants in 2007 was ≈$6.5 billion, which was 58% of total gross sales for floriculture crops [U.S. Department of Agriculture (USDA), 2009]. These crops are commonly grown in plastic containers, which present a significant disposal issue for consumers and the horticulture industry (Hall et al., 2009). Producers of bedding plants may encounter disposal issues of these plastic containers, particularly if plant materials are not sold during a season, and consumers and landscapers must also dispose of plastic containers once the plants are removed (Evans and Karcher, 2004). An estimated 1.7 billion pounds of plastic were used in agriculture in 2002 (Levitan and Barros, 2003).

There are numerous types of alternative, biodegradable containers that can be composted or planted directly into the soil, which eliminate the need for plastic containers (Rodda, 2008). The most common non-plastic biodegradable container has been the peat container. Although referred to as "peat" containers, they are typically made from a combination of peat and waste wood pulp or paper. Peat containers were reported to have advantages over plastic containers by reducing transplant shock and transplanting time, air pruning roots, quicker establishment of finished plants, and their ability to biodegrade (Khan et al., 2000). However, peat containers may have significant disadvantages compared with plastic containers; they are more expensive, they have been shown to have lower dry and wet strength than the plastic containers, and algae can grow on their outer walls (Evans et al., 2010; Evans and Karcher, 2004). Additionally, plants grown in peat containers required more water than plants grown in plastic containers (Evans and Karcher, 2004). When transplanting Jiffy® peat pots (Jiffy Products of America, Batavia, IL), it is recommended to remove or bury the rim of the peat pots so that the rim does not act as a wick to dry out the substrate (Grower's

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The mention of trade names implies no endorsement of the products mentioned, nor criticism of similar products mentioned.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
16.3871	inch^3	mL	0.0610
0.4536	lb	kg	2.2046
28.3495	oz	g	0.0353
1	ppm	mg·L^{-1}	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Solution, 2010; Relf, 2009). This will also prevent the peat pot from degrading quickly and reduce root growth into the soil.

Recently, many types of biodegradable containers that are "plantable" (containers that can be used for greenhouse production and then planted directly in the landscape) have become available for the production of bedding plants. These include Fertilpots (Fertil International, Boulogne Billancourt, France) or DOT pots (Bethel Organics, Arcadia, FL) that contain no glue or binders and are composed of 80% spruce fibers and 20% peat; coir fiber or coco fiber containers (ITML Horticultural Products, Brantford, ON, Canada), which are manufactured by using high pressure to bond coco peat and latex from rubber trees; CowPots (CowPots Co., Brodheadsville, PA) that are manufactured from composted cow manure; and Strawpots (Ivey Acres, Baiting Hollow, NY), which are made from 80% compressed rice straw, 20% coco fiber, and a binder (Fig. 1).

Compostable containers are another type of biodegradable container and are not designed to be planted directly into the ground. Once they have been used for greenhouse production, they can be discarded into a compost or landfill facility where they will decompose. These containers include rice hull containers (Summit Plastic Co., Tallmadge, OH), which are made from ground rice hulls and a binder to form a solid container; OP47 containers (Summit Plastic Co.) that are bioplastics made up of 100% renewable starch-based product; and paper containers (Western Pulp Products, Corvallis, OR) that are composed of pressed wood pulp and a minimum of 74% recycled paper, with at least 37% post-consumer recycled (on dry weight basis) (Fig. 1).

Growth of marigold (*Tagetes erecta*), vinca, impatiens, geranium, and tomato (*Solanum lycopersicum*) in petroleum-based plastic, peat, and feather containers was investigated by Evans and Hensley (2004). Plants grown in plastic containers had the highest amount of growth followed by plants grown in feather containers, and those plants grown in peat containers had the lowest growth and attributed this to the drying of the peat containers at a much faster rate than either the plastic or feather containers. This was due to the hydrophobic properties of the plastic and feather containers. The mild water stress imposed by the higher rate of water loss may have been instrumental in the reduced plant shoot dry weight in the two biodegradable containers.

Growth of tomato seedlings in biodegradable containers composed of maize, palm, or plastic (control) was investigated by Sakurai et al. (2005a). Seedlings grown in biodegradable containers developed shorter shoots and roots, fewer leaves, lower leaf area and showed a lower dry weight compared with the seedlings grown in plastic containers. Results from this study indicated that irrigation frequency and not nutrient absorption ability was responsible for reduced growth of plants grown in the plastic controls compared with those grown in the biodegradable containers.

Biodegradable containers are a sustainable product that might easily adapt to floriculture production, reduce the use of plastics, and provide excellent marketing opportunities (Rodda, 2008). Marketing studies indicated that the appeal of biodegradable containers has been limited because of their less-than-satisfying appearance. A consumer acceptance study by Hall et al. (2010) showed that on average, consumers prefer rice hull pots the most followed by straw pots. However, previous studies conducted using biodegradable containers indicate that there are significant effects of these containers on plant growth. Although this research provided significant insight into the feasibility of these containers, a more comprehensive study using a wide variety of biodegradable containers to test the performance in greenhouse production and in the landscape is important to determine the overall value of these containers in horticulture production. Therefore, the objective of this research was to evaluate greenhouse and landscape growth of 'Score Red' geranium, 'Grape Cooler' vinca, or 'Dazzler Lilac Splash' impatiens grown in plastic and various types of biodegradable containers at different geographic locations.

Fig. 1. Biodegradable and plastic containers evaluated for greenhouse production of 'Grape Cooler' vinca. From left to right (A) OP47 (Summit Plastic Co., Tallmadge, OH), rice straw (Ivey Acres, Baiting Hollow, NY), paper (Western Pulp Products, Corvallis, OR), 4-inch plastic (Dillen Products, Middlefield, OH), and coconut fiber (ITML Horticultural Products, Brantford, ON, Canada). (B) Rice hull (Summit Plastic Co.), CowPots (CowPots Co., Brodheadsville, PA), peat (Jiffy Products of America, Batavia, IL), Fertilpot (Fertil International, Boulogne Billancourt, France), and 5-inch plastic (Dillen Products); 1 inch = 2.54 cm.

Materials and methods

Locations. A greenhouse study was conducted at LSU Agriculture Center's Burden Center, Baton Rouge, LA (lat. 30°N, long. 91°W, USDA Hardiness Zone 8b), LWG, Kennett Square, PA (lat. 39°N, long. 75°W, USDA Hardiness Zone 6b), and UA, Fayetteville, AR (lat. 36°N, long. 94° W, USDA Hardiness Zone 6b). A landscape study was conducted at LWG.

Containers. The types of containers evaluated included 4-inch plastic [9.5 cm top diameter, 7.0 cm bottom diameter, 8.0 cm tall, 470 mL volume (Dillen Products, Middlefield, OH)], 5-inch plastic [12.5 cm top diameter, 9.5 cm bottom diameter, 9 cm tall, 760 mL volume (Dillen Products)], 4-inch OP47 [9 cm top diameter, 7.4 cm bottom diameter, 8.4 cm tall, 430 mL volume (Summit Plastic Co.)], 5-inch OP47 [12.5 cm top diameter, 9.5 cm bottom diameter, 9.25 cm tall, 840 mL volume (Summit Plastic Co.)], 5-inch rice straw [10 cm top diameter, 7.5 cm bottom diameter, 13 cm tall, 765 mL volume (Ivey Acres)], 4-inch Fertil [9.75 cm top diameter, 6.25 cm bottom diameter, 10 cm tall, 465 mL volume (Fertil International)], 4-inch CowPots [9 cm top diameter, 6.5 cm bottom diameter, 9 cm tall, 460 mL volume (CowPots Co.)], 4-inch coconut fiber [10 cm top diameter, 6.5 cm bottom diameter, 8.5 cm tall, 420 mL volume (ITML Horticultural Products)], 4-inch peat [9.5 cm top diameter, 6.5 cm bottom diameter, 9 cm tall, 400 mL volume (Jiffy Products of America)], 4-inch rice hull [9 cm top diameter, 7 cm bottom diameter, 8.75 cm tall, 440 mL volume (Summit Plastic Co.)], and 4-inch paper [10 cm top diameter, 7 cm bottom diameter, 10 cm tall, 635 mL volume (Western Pulp Products)]. The 4-inch plastic container served as the control for all 4-inch biocontainers, whereas the 5-inch plastic container served as the control for the 5-inch OP47 and 5-inch rice straw container.

Greenhouse production. 'Score Red' geranium, 'Grape Cooler' vinca, or 'Dazzler Lilac Splash' impatiens were seeded in 288 plug trays with a volume of 5 mL per plug cell. Three-week-old plugs were transplanted into the test containers filled with 400 or 700 mL LC1 mix (Sun Gro, Bellevue, WA) and placed in glass-glazed greenhouses. All three species were planted on 2 Apr. 2009 at LSU. Geranium germination rate was low at LSU, and so rice straw and 5-inch plastic containers were not evaluated for this crop. Impatiens were planted on 2 Apr. 2009, vinca were planted on 6 Apr. 2009, and geranium were planted on 14 Apr. 2009 at LWG. Impatiens were planted on 16 Feb. 2009 and the geranium were planted on 16 Feb. 2009 at UA. The minimum temperature set point for greenhouse air temperature at all locations was 20 °C with a daytime high temperature of 28 °C during the experiment. Plants were fertilized at each irrigation with 200 $mg \cdot L^{-1}$ N using a 15N–2.2P–12.5K fertilizer (Excel 15–5–15 Cal–Mag®; Scotts, Marysville, OH). On the day of planting, the substrate was drenched with 50 mL of 15% etridiazole and 25% thiophanate-methyl (Banrot®, Scotts) fungicide per container according to label directions. Plants were irrigated when ≈25% of the substrate surface was visually determined to be dry.

Plants were harvested after 4 weeks for impatiens, 5 weeks for vinca, and 8 weeks for geranium at LSU, and shoot and root dry weights were determined. The same data were collected at LWG for impatiens after 6 weeks, vinca after 7 weeks, and geranium after 8 weeks. Impatiens and geranium plants were harvested after 8 weeks at UA, and shoot and root dry weights were determined.

The experimental design at LSU and LWG was a complete randomized block with four blocks and one flat of each container type appearing once in a block. Container type served as the main treatment effect, and each flat was considered to be an independent experimental unit. The experimental design at UA was completely randomized with a single container serving as an experimental unit. For all three locations, an analysis of variance was conducted to determine if significant differences in shoot dry weight, root dry weight, and R:S ratio occurred among the 5-inch or 4-inch container types. A least significant difference mean separation test ($\alpha = 0.05$) was conducted to determine individual differences between means. Because of differences in experimental design, direct comparisons among LSU, LWG, and UA were not made.

Landscape establishment. Bedding plants produced in the greenhouse study at LWG were planted in raised landscape beds to test field performance. Impatiens, vinca, and geraniums were planted on 14 May, 28 May, and 10 June 2009, respectively. The soil was sandy loam with a pH 6.7. Impatiens were overgrown and pinched back before planting to an average height of 11 cm and width of 13.5 cm. Impatiens were equally spaced in a planting area of 4.5 × 2.0 m. Plants were in full sun until ≈1430 HR when shade from surrounding trees reduced light levels by 50% to 75%. Vinca and geraniums were not pinched, grown in full sun, and equally spaced in a planting area of 3 × 1.9 and 4 × 1.9 m, respectively. Treatments were arranged in a completely randomized design with six container types (CowPot, coconut fiber, rice straw, peat, Fertil, and 4-inch plastic), with four replications and four plants per rep, for a total of 96 plants of each species. All containers were left intact when planting except for plastic containers, which were removed before planting. Plants were hand watered immediately after planting and as needed through the growing period. Plants were harvested 8 weeks after transplanting into the field. Data recorded were width (measured two times; one width perpendicular to the other), height, and shoot dry weight.

Results

Greenhouse production

Geranium shoot dry weight. Geranium grown at LWG had higher shoot dry weights when grown in 5-inch plastic and OP47 containers compared with those grown in the rice straw container (Table 1). Geranium grown in 5-inch plastic containers at UA had the highest shoot dry weights followed by those grown in OP47 and rice straw containers, respectively. Thus, when comparing the larger containers, plastic provided for the best shoot growth of geranium, regardless of location. At LSU and LWG, geranium shoot dry weights for those plants grown in 4-inch containers was higher in paper containers than in peat containers and intermediate in all other containers. Thus, regardless of location (LSU or LWG), plants grown in paper containers had the highest geranium shoot growth compared with all other 4-inch pots, and geranium in the coconut fiber and peat containers had the lowest shoot growth, with all other containers showing intermediate growth. However, shoot dry weights in the study conducted at UA were higher in the plastic control followed by CowPot, rice hull, and paper containers and were lowest in Fertil, coconut fiber, and peat containers.

IMPATIENS SHOOT DRY WEIGHT. There was no difference in shoot dry weights for impatiens grown in 5-inch containers at LSU, LWG, or UA (Table 2). The impatiens shoot dry weights at LSU in 4-inch containers were significantly higher for those plants grown in paper containers than those grown in OP47, rice hull, coconut fiber, or peat containers. However, at LWG, there was no difference in impatiens shoot dry weights. At UA, those plants grown in plastic, CowPot, rice hull, and paper containers had higher shoot dry weights when compared with the Fertil or coconut fiber containers, respectively. Of all the pots tested at all locations, there was no significant difference between the 5-inch containers and no one single container stood out among the 4-inch types.

VINCA SHOOT DRY WEIGHT. The shoot dry weights of vinca when grown in 5-inch containers at LSU were similar, whereas those grown at LWG were higher in plastic and

Table 1. Average shoot and root dry weights and root:shoot (R:S) ratios for 'Score Red' geranium grown in 5-inch or 4-inch (12.7 or 10.2 cm) plastic containers (control) and various comparable biocontainers at Louisiana State University (LSU; Baton Rouge, LA), Longwood Gardens (LWG; Kennett Square, PA), and University of Arkansas (UA; Fayetteville, AR).

	LSU			LWG			UA		
Container type[z]	Shoot dry wt (g)[y]	Root dry wt (g)	R:S ratio	Shoot dry wt (g)	Root dry wt (g)	R:S ratio	Shoot dry wt (g)	Root dry wt (g)	R:S ratio
5 inch									
Plastic	—	—	—	9.6 a	0.39 a	0.04 a	12.1 a	0.68 a	0.06 b
OP47	—	—	—	8.3 a	0.34 a	0.04 a	9.4 b	0.47 b	0.05 b
Rice straw	—	—	—	5.9 b	0.28 a	0.05 a	7.6 c	0.57 ab	0.08 a
4 inch									
Plastic	6.2 ab[x]	0.79 a	0.13 a	5.5 bcd	0.25 b	0.05 a	7.9 a	0.39 ab	0.05 c
Fertil	5.7 ab	0.68 ab	0.12 a	6.0 ab	0.28 b	0.05 a	5.5 c	0.32 c	0.06 b
CowPots	6.0 ab	0.58 b	0.10 b	5.5 bc	0.28 b	0.05 a	6.8 b	0.40 ab	0.06 ab
Coconut fiber	5.8 ab	0.65 ab	0.11 ab	4.6 cd	0.24 b	0.05 a	5.2 c	0.34 bc	0.06 a
Peat	5.3 b	0.65 ab	0.12 a	4.5 d	0.24 b	0.06 a	5.7 c	0.32 c	0.06 b
Rice hull	6.0 ab	0.66 ab	0.11 ab	5.6 b	0.27 b	0.05 a	6.8 b	0.42 a	0.06 ab
Paper	6.6 a	0.80 a	0.12 a	6.9 a	0.37 a	0.06 a	6.9 b	0.40 ab	0.06 ab

[z]All 4-inch containers were filled with 400 mL (24.4 inch^3) of substrate, and all 5-inch containers were filled with 700 mL (42.7 inch^3) of substrate. The plastic containers were obtained from Dillen Products (Middlefield, OH); OP47 bioplastic containers were obtained from Summit Plastic Co. (Tallmadge, OH); rice straw containers were obtained from Ivey Acres (Baiting Hollow, NY); Fertil containers were obtained from Fertil International (Boulogne Billancourt, France); CowPots were obtained from CowPots Co. (Brodheadsville, PA); coconut fiber containers were obtained from ITML Horticultural Products (Brantford, ON, Canada); peat containers were obtained from Jiffy Products of America (Batavia, IL); rice hull containers were obtained from Summit Plastic Co.; and paper containers were obtained from Western Pulp Products (Corvallis, OR).
[y]1 g = 0.0353 oz.
[x]Mean separation within column by least significant difference test at $P \leq 0.05$.

Table 2. Average shoot and root dry weights and root:shoot (R:S) ratios for 'Dazzler Lilac Splash' impatiens grown in 5-inch or 4-inch (12.7 or 10.2 cm) plastic containers (control) and various comparable biocontainers at Louisiana State University (LSU; Baton Rouge, LA), Longwood Gardens (LWG; Kennett Square, PA), and University of Arkansas (UA; Fayetteville, AR).

	LSU			LWG			UA		
Container type[z]	Shoot dry wt (g)[y]	Root dry wt (g)	R:S ratio	Shoot dry wt (g)	Root dry wt (g)	R:S ratio	Shoot dry wt (g)	Root dry wt (g)	R:S ratio
5 inch									
Plastic	2.7 a[x]	0.64 a	0.26 a	1.8 a	0.13 a	0.07 a	6.0 a	0.64 b	0.11 b
OP47	—	—	—	1.9 a	0.19 a	0.10 a	5.8 a	0.57 b	0.10 b
Rice straw	2.2 a	0.58 a	0.26 a	1.6 a	0.14 a	0.09 a	6.6 a	1.20 a	0.19 a
4 inch									
Plastic	2.3 ab	0.68 bc	0.30 b	1.4 a	0.16 ab	0.11 ab	5.3 a	0.43 a	0.09 a
Fertil	2.3 ab	0.65 bc	0.29 b	1.7 a	0.13 b	0.08 b	4.5 b	0.37 bc	0.09 a
CowPots	2.3 ab	0.99 a	0.44 a	1.7 a	0.20 ab	0.12 ab	5.7 a	0.40 ab	0.07 bc
Coconut fiber	2.0 b	0.56 bc	0.27 b	1.7 a	0.13 b	0.08 b	3.5 c	0.25 d	0.07 bc
Peat	1.9 b	0.62 bc	0.33 ab	1.6 a	0.21 a	0.13 a	4.9 ab	0.31 c	0.06 c
Rice hull	1.9 b	0.45 c	0.24 b	1.5 a	0.16 ab	0.10 ab	5.4 a	0.41 ab	0.08 ab
Paper	2.7 a	0.77 ab	0.29 b	1.7 a	0.17 ab	0.10 ab	5.6 a	0.40 ab	0.07 bc
OP47	2.1 b	0.71 abc	0.337 ab	—	—	—	—	—	—

[z]All 4-inch containers were filled with 400 mL (24.4 inch^3) of substrate, and all 5-inch containers were filled with 700 mL (42.7 inch^3) of substrate. The plastic containers were obtained from Dillen Products (Middlefield, OH); OP47 bioplastic containers were obtained from Summit Plastic Co. (Tallmadge, OH); rice straw containers were obtained from Ivey Acres (Baiting Hollow, NY); Fertil containers were obtained from Fertil International (Boulogne Billancourt, France); CowPots were obtained from CowPots Co. (Brodheadsville, PA); coconut fiber containers were obtained from ITML Horticultural Products (Brantford, ON, Canada); peat containers were obtained from Jiffy Products of America (Batavia, IL); rice hull containers were obtained from Summit Plastic Co.; and paper containers were obtained from Western Pulp Products (Corvallis, OR).
[y]1 g = 0.0353 oz.
[x]Mean separation within column by least significant difference test at $P \leq 0.05$.

OP47 than in rice straw containers (Table 3). The shoot dry weights of vinca grown in 4-inch containers at LSU were higher in paper and plastic compared with those in all other containers except Fertil. The shoot dry weight of vinca grown at LWG was higher in paper compared with rice hull and plastic containers, which were significantly lower, with the remaining containers producing the lowest shoot dry weight. These results indicate that, although there was a difference in shoot growth by location and container type at each location, the highest vinca shoot dry weight occurred in paper containers and was higher than or equal to the growth that occurred in 5-inch containers.

Geranium root dry weight. The root dry weights of geranium grown in 5-inch containers at LWG were similar, whereas plants grown in plastic at UA had higher root dry weights than those grown in OP47 containers (Table 1). Root dry weights of geranium grown in 4-inch containers at LSU were higher for those plants grown in paper and plastic containers compared with those grown in CowPots containers. The root dry weights of geraniums at LWG were greatest in paper containers compared with all other containers. The root dry weights at UA were greater for rice hull containers compared with coconut fiber, Fertil, and peat containers, with the latter two being significantly lower than roots from all other pots.

Impatiens root dry weight. Impatiens root dry weights were similar among 5-inch container types at LSU and LWG; however, at UA, the plants grown in rice straw containers had higher root dry weights than the plants grown in OP47 and plastic containers (Table 2). The root dry weight of impatiens at LSU grown in 4-inch containers was higher in the CowPots than in the coconut fiber, peat, rice hull, plastic, and Fertil containers. Impatiens in peat containers at LWG had higher root dry weights than the impatiens in coconut fiber and Fertil containers. The root dry weights at UA were higher for impatiens grown in plastic containers than for those plants grown in Fertil, coconut fiber, or peat containers.

Vinca root dry weight. Root dry weights of vinca at LSU were the highest in 5-inch plastic containers compared with rice straw; however, there was no difference in root dry weights for LWG (Table 3). Root dry weights in 4-inch containers at LSU were highest in plastic and paper containers compared with all other containers and were the lowest in coconut fiber containers. Root dry weights at LWG were also higher in paper containers. Overall, the highest root growth of vinca occurred in paper containers, which was significantly higher than the root growth in peat and coconut fiber, respectively, at both locations.

Geranium R:S ratio. The R:S ratio of geraniums grown in 5-inch containers were similar at LWG but were higher at UA when grown in rice straw compared with the other containers (Table 1). Geraniums grown in CowPots containers at LSU had a lower R:S than all other 4-inch containers except coconut fiber and rice hull. At LWG, R:S ratio of plants in all 4-inch containers were similar; however, the R:S ratio at UA was lower for those plants grown in plastic containers compared with all other 4-inch containers.

Impatiens R:S ratio. At LSU and LWG, there was no effect of container types on R:S ratio for impatiens grown in 5-inch containers (Table 2). However, at UA, the R:S ratio was highest in rice straw containers compared with all other 5-inch-type containers. The R:S ratio of impatiens grown in 4-inch containers at LSU was higher in CowPots containers when compared with all containers except peat and OP47. The R:S ratio of impatiens grown at LWG was higher in plants grown in peat than the plants grown in coconut fiber and Fertil containers. At UA, R:S ratio of impatiens was higher in plastic and Fertil containers compared with all other 4-inch–type containers except rice hull. Overall, impatiens grown in CowPots and peat containers had higher R:S ratio than those grown in rice hull or 5-inch plastic containers.

Vinca R:S ratio. The R:S ratio of vinca grown in 5-inch containers was similar at LSU but was higher in rice straw containers at LWG than those plants grown in plastic containers (Table 3). When grown in 4-inch containers at LSU, the R:S ratio was higher in plastic than in OP47, coconut fiber and rice hull, and Fertil. At LWG, the R:S ratio of vinca was higher in peat containers compared with all other 4-inch containers except for Fertil containers.

Table 3. Average shoot and root dry weights and root:shoot (R:S) ratios for 'Grape Cooler' vinca grown in 5-inch or 4-inch (12.7 or 10.2 cm) plastic containers (control) and various comparable biocontainers at Louisiana State University (LSU; Baton Rouge, LA), Longwood Gardens (LWG; Kennett Square, PA), and University of Arkansas (Fayetteville, AR).

	LSU			LWG		
Container type[z]	Shoot dry wt (g)[y]	Root dry wt (g)	R:S ratio	Shoot dry wt (g)	Root dry wt (g)	R:S ratio
5 inch						
Plastic	1.3 a[x]	0.30 a	0.24 a	2.4 a	0.23 a	0.10 b
OP47	—	—	—	2.3 a	0.30 a	0.13 ab
Rice straw	1.1 a	0.2 b	0.18 a	1.8 b	0.32 a	0.18 a
4 inch						
Plastic	1.5 a	0.36 a	0.24 a	1.8 bc	0.21 b	0.12 b
Fertil	1.4 ab	0.23 b	0.17 c	1.6 cd	0.24 ab	0.15 ab
CowPots	1.2 bc	0.25 b	0.21 abc	1.6 cd	0.22 b	0.13 b
Coconut fiber	0.8 d	0.14 c	0.18 bc	1.6 cd	0.22 b	0.14 b
Peat	1.14 c	0.23 b	0.22 ab	1.4 d	0.26 ab	0.19 a
Rice hull	1.2 bc	0.20 b	0.18 bc	2.0 b	0.24 ab	0.12 b
Paper	1.5 a	0.32 a	0.21 abc	2.4 a	0.32 a	0.14 b
OP47	1.1 bc	0.23 b	0.20 b	—	—	—

[z]All 4-inch containers were filled with 400 mL (24.4 inch^3) of substrate, and all 5-inch containers were filled with 700 mL (42.7 inch^3) of substrate. The plastic containers were obtained from Dillen Products (Middlefield, OH); OP47 bioplastic containers were obtained from Summit Plastic Co. (Tallmadge, OH); rice straw containers were obtained from Ivey Acres (Baiting Hollow, NY); Fertil containers were obtained from Fertil International (Boulogne Billancourt, France); CowPots were obtained from CowPots Co. (Brodheadsville, PA); coconut fiber containers were obtained from ITML Horticultural Products (Brantford, ON, Canada); peat containers were obtained from Jiffy Products of America (Batavia, IL); rice hull containers were obtained from Summit Plastic Co.; and paper containers were obtained from Western Pulp Products (Corvallis, OR).

[y]1 g = 0.0353 oz.

[x]Mean separation within column by least significant difference test at $P \leq 0.05$.

LANDSCAPE ESTABLISHMENT. At LWG, there were no significant differences in shoot dry weights of geranium or vinca for all containers tested (Table 4). However, impatiens had higher shoot dry weights when planted and grown in Fertil containers than when grown in CowPots and coconut fiber containers. Plants in the 4-inch plastic, Fertil and CowPots containers produced taller geraniums than those in coconut fiber when planted in the landscape. Plant heights in impatiens were similar to those in geraniums, in that those plants grown in 4-inch plastic and Fertil containers were the tallest and impatiens in the coconut fiber containers were the shortest. There was no difference in vinca plant height regardless of container type in the LWG landscape. Container type did not have an effect on the plant width for geraniums, impatiens, or vinca.

Discussion

Overall, in 5-inch containers, the best geranium shoot growth occurred in the plastic control. Four-inch paper containers produced the best geranium shoot growth and peat containers produced the lowest shoot growth in two of the three locations. When growing impatiens, no one container stood out among all three locations. Shoot growth of vinca was similar to that of geranium, where vinca grown in paper containers had significantly higher shoot growth than when produced in peat or coconut fiber containers, which had the lowest shoot growth. Evans and Hensley (2004) found similar results, in that marigold, vinca, impatiens, geranium, and tomato grown in plastic containers grew best followed by plants grown in feather containers and those grown in peat containers had the lowest growth. When ornamental conifers were grown in plastic, peat, or Fertil containers, plants grown in plastic container usually performed the best, followed by those grown in Fertil containers, while those grown in peat containers showed satisfactory growth (Hellemans, 1997b). However, in another study using biocontainers in a tree nursery, Hellemans (1997a) found that peat containers were the most satisfactory, and plastic containers had poor rooting-through and durability.

Root dry weights of all three plant species were either mixed (geranium and vinca) or similar (impatiens) when grown in 5-inch containers at all locations. There was no difference in root growth of geranium or impatiens when all container sizes and types were considered. However, vinca had higher root growth in paper containers and the lowest root growth in peat and coconut fiber containers. These results were similar to the shoot growth response of vinca. Ueno et al. (2002b) found that a root ball was observed in all plastic containers when growing pumpkin (*Cucurbita moschata*); however, there was rarely any root ball found in paper containers. They also found that there was about a 60% lower root dry weight in paper vs. plastic containers.

Results for R:S ratio of geraniums were similar or mixed for all pot sizes, types, and locations. However, the R:S ratio was higher for impatiens grown in peat and CowPots containers than those grown in rice hull. The R:S ratio of vinca was highest in both sizes of plastic containers at LSU and lowest in both plastic containers at LWG, whereas vinca grown in rice straw containers had similar ratios at both locations. No differences were observed in the R:S ratio of pumpkin seedlings grown in biodegradable paper or plastic containers (Uneo et al., 2002a). However, they found that dry weight of whole plant top and root in the paper containers accounted for ≈60% of that in the plastic containers.

On the basis of the results from landscape at LWG, it is unclear if any one of the direct plant containers tested had a significant impact on the field growth of the three crops tested. Results do indicate that once planted in the field, plants grown in direct plant containers will generally perform just as well as the plants grown in traditional plastic containers, which would be removed before planting. These results suggest the direct plant containers do not inhibit root growth of bedding plants. Sakurai et al. (2005b) found that tomato seedlings grown in biodegradable containers made of maize and palm developed shorter shoots and fewer leaves than those plants grown in plastic containers at 11 d after transplanting. However, in the period after 11 d after transplanting, the plants in biodegradable pots given heavy fertilizer applications grew similarly to plants given standard fertilization. They suggested that the low growth rate of the plants in biodegradable pots within the initial 11 d after transplanting was caused by the restricted root zone of the plants. However, Hellemans (1997a) found that when tree seedlings grown in biocontainers were potted into 3-L plastic pots, growth and rooting of all

Table 4. Average shoot dry weight, height, and width for 'Score Red' geranium, 'Dazzler Lilac Splash' impatiens, or 'Grape Cooler' vinca grown at Longwood Gardens (Kennett Square, PA) in 4-inch (10.2 cm) plastic containers (control) and various comparable biocontainers and planted into raised landscape beds on 14 May, 28 May, and 10 June 2009, respectively.

	Geranium			Impatiens			Vinca		
Container type[z]	Shoot dry wt (g)[y]	Ht (cm)[y]	Width (cm)	Shoot dry wt (g)	Ht (cm)	Width (cm)	Shoot dry wt (g)	Ht (cm)	Width (cm)
Plastic	27.9 a[x]	29.4 a	31.2 a	10.2 ab	12.1 a	32.1 a	18.1 a	23.8 a	26.5 a
Fertil	33.2 a	30.0 a	30.3 a	11.2 a	12.2 a	30.9 a	19.5 a	26.2 a	27.3 a
CowPots	27.9 a	29.3 a	30.6 a	7.1 c	11.2 ab	29.0 a	19.8 a	25.7 a	28.8 a
Coconut fiber	22.2 a	25.2 b	26.6 a	8.4 bc	10.4 b	30.8 a	19.3 a	36.4 a	28.0 a
Peat	24.7 a	27.8 ab	29.5 a	8.9 abc	10.8 ab	30.0 a	18.2 a	24.2 a	27.6 a
Rice straw	22.3 a	28.5 ab	28.6 a	8.6 abc	11.6 ab	29.9 a	20.4 a	25.6 a	27.3 a

[z]All 4-inch containers were filled with 400 mL (24.4 inch^3) of substrate, and all 5-inch containers were filled with 700 mL (42.7 inch^3) of substrate. The plastic containers were obtained from Dillen Products (Middlefield, OH); Fertil containers were obtained from Fertil International (Boulogne Billancourt, France); CowPots were obtained from CowPots Co. (Brodheadsville, PA); coconut fiber containers were obtained from ITML Horticultural Products (Brantford, ON, Canada); peat containers were obtained from Jiffy Products of America (Batavia, IL); and rice straw containers were obtained from Ivey Acres (Baiting Hollow, NY).

[y]1 g = 0.0353 oz, 1 cm = 0.3937.

[x]Mean separation within column by least significant difference test at $P \leq 0.05$.

test plants from all container types was similar.

Conclusion

The growth of geranium, impatiens, and vinca in this study varied by container type and location. Those plants grown in 5-inch plastic control or paper containers generally performed better than those grown in other containers. However, plant growth in all the containers used in the greenhouse portion of this study produced marketable plants for both the retail and landscape markets. Cultural practices and the growing environment should be closely monitored during greenhouse production when using biocontainers as differences in plant growth can occur, which may be attributed to differences in physical properties (Evans et al., 2010). This study indicated that direct plant biodegradable containers provide landscapers with suitable alternatives to plastic or compostable containers. Thus, greenhouse managers and landscapers looking for alternatives to plastic containers have a significant number of biocontainers that can be used successfully for greenhouse production and landscape planting based upon production practices and landscape requirements.

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