Use of Alternative Containers for Long- and Short-term Greenhouse Crop Production

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SUMMARY. While research on the use of alternative containers for greenhouse production is growing, most studies have focused on a limited number of types of alternative containers and primarily on short-term greenhouse crops. With the recent release of several new bioplastic alternatives, comparisons to established alternative containers and production of longer rotation ornamental crops should be investigated. Our work, therefore, investigates the performance of ten commercially available alternative containers and their effects on both a short-term ‘Sunpatiens Compacta’ impatiens (*Impatiens* × *hybrida*) and a long-term greenhouse crop ‘Elegans Ice’ lavender (*Lavendula angustifolia*) at four different locations. Results indicated that plant growth in terms of dry weight differed by container at most locations. Combined analysis of all locations showed that only straw and a bioplastic sleeve outperformed plastic pots in terms of shoot dry weight and then only after 12 weeks of production. Leachate pH, but not electrical conductivity (EC), varied by container in both the short- and long-term crop with alternative containers made from composted cow manure and peat showing consistently higher and lower pH readings, respectively. Postharvest container strength varied significantly by container, with the plastic control maintaining the highest puncture resistance after both 6 and 12 weeks, in some instances matched by the puncture strength of coconut fiber pots. Some alternative containers, in particular, wood, manure, and peat showed algal growth after 6 and 12 weeks of greenhouse production. We conclude that while some alternative containers were linked to increased growth, most showed growth equal to the plastic control, and could therefore make appropriate alternatives to plastic pots. However, changes in pH, low puncture strengths after production, higher denesting times, and algal growth on manure, wood, and peat may make these pots less desirable alternatives than other pots under investigation. However, other factors not studied here, such as compostability, biodegradability in the landscape, water use, consumer preference, aesthetics, compatibility with mechanized operations, and cost may also need to be taken into account when deciding on an appropriate container for greenhouse production.

Recent decades have seen tremendous strides in improving the sustainability of greenhouse production (Nelson, 2012). The introduction of closed-loop irrigation, integrated pest management, energy-efficient greenhouse designs, improvements in lighting technology, alternative heating sources, and greenhouse media have all led to improved efficiencies and decreased impacts on the environment (Nelson, 2012). However, more recently, the heavy use of plastic as pots in greenhouse production has come under scrutiny and has been identified as a target for improving sustainability. Alternative containers made from recycled materials, bioplastic, and various organic materials have all been suggested as replacements for the very

successful, efficient, easy-to-use, and cheap plastic pot that has been in use in the industry for the last 50 years (Koeser et al., 2014; Nambuthiri et al., 2015). With only a few containers on the market a decade ago, more than 10 alternative containers types are now available for purchase

or in the testing phase of development (Evans and Karcher, 2004; Evans et al., 2010; Koeser et al., 2014; Nambuthiri et al., 2015).

Alternative containers differ from petroleum-based plastic pots in that they are made of plant-derived materials and are plantable or compostable. To break down in soil or in a composting environment, alternative containers are essentially designed to degrade over a relatively short period of time. However, a recent study showed that alternative containers that perform well after 1 year of production in a pot-in-pot nursery setting fail American Society for Testing and Materials (ASTM) compostability tests and do not properly degrade during composting tests (Wang, 2013). These same pots failed as container during the second year of the study before the end of the scheduled production period (Li et al., 2015).

While the easy to compost design characteristic may reduce end-of-use landfill waste for some compostable alternative containers used in short-term greenhouse production, both premature failure and limited compostability of new containers may also limit alternative containers compatibility with medium- to long-term or multiseason ornamental nursery crop production systems (Li et al., 2015; Wang, 2013). This potential limitation is reflected in the market. Alternative containers are more readily available in sizes commonly used in commercial greenhouse production (short-term production), while they are much less prevalent in larger sizes most suitable for woody nursery production (long-term production) (Nambuthiri et al., 2015). Additionally, a survey of greenhouse professionals and nursery producers and researchers found that compatibility with existing equipment and production practices was a minor

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
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch ²	cm ²	0.1550
16.3871	inch ³	cm ³	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	(°C × 1.8) + 32

hindrance for greenhouse professionals but a significant obstacle for nursery producers when adopting sustainable production practices like alternative containers (Dennis et al., 2010; Koeser et al., 2013a).

The integrity and longevity of alternative containers are impacted by the specific conditions of the greenhouse. High-input greenhouse production accelerates plant growth and shortens production time. However, the elevated temperature, humidity, and substrate nitrogen levels associated with these controlled environments hasten organic matter degradation as well as plant development. As such, even the comparatively short crop rotations common in greenhouse operations may be too long with respect to container appearance and integrity (Evans and Karcher, 2004; Evans et al., 2010; Kuehny et al., 2011). Given that unsightly or damaged containers may be largely unsellable to the plant-buying public, both of these measures of container performance may ultimately affect the economic sustainability of alternative containers (Hall et al., 2009, 2010).

Past research has investigated alternative containers degradation and strength loss after simulated greenhouse

production. However, these assessments are generally limited to short-term crop production and a limited number of alternative containers. In 2004, Evans and Karcher assessed residual pot strength for plastic, peat, and feather pots after a 5-week growing period (Evans and Hensley, 2004; Evans and Karcher, 2004). Evans et al. (2010) later expanded on this work by measuring pot crush and puncture strength for eight commercially available alternative containers after 4 weeks in production. While a longer, 10-week study was conducted by Helgeson et al. (2009), the sole alternative containers tested in the work was a prototype container constructed by hand using a zein-based bioplastic, which is not commercially available to greenhouse producers. In addition to production limitations based on the physical integrity and appearance of alternative containers, questions have been raised and some cases answered about the environmental impact (Koeser et al., 2014), consumer and producer acceptance and adoption (Hall et al., 2009, 2010; Yue et al., 2011), and water use (Evans et al., 2010; Koeser et al., 2013b). These factors together with cost will also undoubtedly have impact on acceptance and adoption of alternative containers.

The study reported herein investigated plant growth, pH and EC, residual container strength, and potential for algal growth for nine alternative containers and a plastic control. In addition to two new container types, bioplastic and bioplastic sleeve, our research expands on the past work of Evans et al. (2010) and Kuehny et al. (2011) by investigating two crop lengths, a short-term (6 weeks) production period and a long-term (12 weeks) production period. In adding the longer production cycle, this work investigates the feasibility of alternative containers use in the production of slower-growing greenhouse plants and limits of alternative containers designed for short-term production. Beyond measures of container performance, this study also investigates impacts on plant growth and quality. The combined results are intended to assist commercial growers interested in adopting alternative containers in their own greenhouse operations.

Materials and methods

LOCATIONS. The greenhouse trials for this study were conducted at the University of Arkansas, Fayetteville (lat. 36.08°N, long. 94.16°W), the University of Illinois at Urbana-Champaign, Urbana (lat. 40.11°N, long. 88.20°W), the University of Kentucky, Lexington (lat. 38.03°N, long. 84.49°W), and West Virginia University, Morgantown (lat. 39.63°N, long. 79.95°W). Two of the four sites (Arkansas and West Virginia) repeated the experiment over a second growing season for a total of six trials. Container strength testing and algal growth assessment were conducted at the University of Arkansas, Fayetteville.

CONTAINERS. Ten container types were used in this study (Table 1 and Fig. 1). One 4-inch plastic standard pot was selected as the study's control. For the nine alternative containers alternatives, the manufacturer's closest substitution (with regard to volume) to the control pot was selected for comparison.

EXPERIMENTAL DESIGN, GROWING CONDITIONS, AND PLANT CARE. Two species, impatiens and lavender, were selected as representative short- and long-term ornamental crops, respectively, for the greenhouse trials. Given differences in production length and watering requirements, 6 weeks and high water requiring for impatiens and 12 weeks and low water requiring for lavender, each species was studied and assessed separately during analysis. The trial length for the short-term crop (impatiens) was set at 6 weeks. The trial length for the long-term crop (lavender) was 12 weeks. All trials were arranged as completely randomized designs, with trays containing six identical containers serving as the experimental unit (total $n = 180$ trays across all six trials). Each of the six individual pots constituted a pseudoreplicate of its associated tray (total $n = 1080$ pots across all six trials). Each tray was replicated three times for a total of 18 plants per container type in each trial. This was repeated for lavender and impatiens in separate trials at each site for a total of 12 experiments (six lavender trials and six impatiens trials).

All containers were filled with ≈ 80 g of a commercial soil-less, dry, growing mix (Fafard 2; Conrad Fafard, Agawam, MA) and planted with either an impatiens or a lavender plug obtained

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Table 1. Container type, product name, volume, and manufacturer of container used to evaluate plant performance, electrical conductivity, and pH levels, and container physical characteristics during and the end of a 6- and 12-week greenhouse production cycle.

Container type	Product name ^z	Volume (cm ³) ^z	Manufacturer
Bioplastic	TerraShell 10cm H wheat pot	473 ^y	Summit Plastic Co., Akron, OH
Coconut fiber	Coir 4.0-inch fiber gro pot	406 ^y	Dillen Products, Middlefield, OH
Control (plastic)	Dillen 4.0 standard thinwall green	480 ^y	Myers Industries, Middlefield, OH
Dairy manure	Number 4 square CowPot	450 ^y	CowPots of America, Lorain, OH
Peat	4-inch Jiffy Pot	379 ^x	Jiffy Products of America, Lorain, OH
Sleeve (bioplastic)	4.5-inch standard assembled SoilWrap	709 ^x	Ball Horticultural Co., West Chicago, IL
Solid rice hull	4-inch rice pot	473 ^y	Summit Plastic Co.
Slotted rice hull	4.5-inch NetPot	591 ^y	Summit Plastic Co.
Straw	Straw pot	646 ^x	Ivy Acres, Baiting Hollow, NY
Wood fiber	10 × 10 cm round Fertipot	430 ^x	Fertil SAS, Boulogne Billancourt, France

^z1 cm = 0.3937 inch, 1 inch = 2.54 cm, 1 cm³ = 0.0610 inch³.

^yAs indicated in manufacturers on-line or print catalogs.

^xNot included in manufacturers' catalogs; volume approximated by substrate displacement.

Fig. 1. Images of container treatments used to grow a short-term (6 weeks) crop and long-term crop (12 weeks) of impatiens and lavender, respectively. Plants were grown under greenhouse conditions for 6 or 12 weeks to gauge the effect of container type on growth, electrical conductivity and pH, puncture strength, algal growth, and denesting. Containers used included (A) plastic control, (B) bioplastic, (C) coconut fiber, (D) dairy manure, (E) peat, (F) sleeve (bioplastic), (G) slotted rice hull, (H) solid rice hull, (I) straw, and (J) wood fiber.

from commercial sources. Trays were arranged tightly together on raised greenhouse benches. A border row surrounded the outer edge of the experiment. Trial start dates and environmental conditions are listed in Table 2.

Irrigation was supplied by hand on an as-needed basis at the experiment (i.e., tray) and treatment (i.e., container type) level. For lavender, this watering threshold was defined as the point when soil moisture levels at or below 30% volumetric water content (VWC) were detected for a given container type. Similarly, impatiens plants were watered when soil moisture readings of 40% VWC or lower were detected. These watering thresholds were determined through trial and error in a preliminary experiment (data not shown). Soil moisture levels were originally measured with the aid of

an electronic soil moisture sensor calibrated for use in soilless media [Theta-Probe Soil Moisture Sensor—ML2x (Delta-T Devices, Cambridge, UK) or Field Scout TDR 100 Soil Moisture Meter (Spectrum Technologies, Aurora, IL) depending on trial location]. Once the visual indicators of drying for each of these moisture thresholds were identified (e.g., graying of the substrate surface), watering demand was assessed by sight (as repeated measurements with the sensor in the same soil space can lead to questionable measurements and channeling). In addition to this watering, plants were fertigated at every watering with a 150 ppm 20N-4.4P-16.6K solution based on location (see Table 2 for environmental and production conditions) (Plantex 20-10-20 All Purpose High Nitrate; Plant Products, Brampton, ON, Canada).

MEASUREMENTS. Shoot dry weight was measured at the end of the experiment to assess plant growth over each respective trial period. In addition, biweekly EC and pH measurements of growing mix leachate were collected and aggregated to assess media growing conditions. Electrical conductivity (data not shown) and pH measurements were taken at the individual tray level from a leachate sample of ≈ 50 mL using a portable multiparameter solution tester [pH/EC meter (Myron L, Carlsbad, CA), HI 98130 pH/Conductivity/TDS Tester (Hanna Instruments, Woonsocket, RI)].

After the completion of each trial, pots were emptied and sent to the Arkansas testing facility to measure postharvest container puncture strength and postharvest container

fungus/algal coverage. Data were also collected on unused containers (data not shown). Puncture strength was defined as the amount of pressure required to punch through a dried container's wall with a 5-mm ball probe. This test was performed using a texture analyzer (TAXT 2I; Texture Technologies, Scarsdale, NY). Eighteen measurements (replications) were taken on each of the alternative container.

Algal growth was quantified with a leaf area meter (LI-3100C; LI-COR, Lincoln, NE). Patches of algal growth were removed from the container with a razor utility knife and run through the area meter to gauge total area covered as compared with the surface area of a reference container.

DENESTING. Fourteen people were divided into seven groups of two. Each group consisted of a person placing pots into shuttle trays and

a timekeeper. The subjects were asked to place 24 tightly stacked pots into shuttle trays and record the time this operation needed including dislodging of pots from the stack. Each member (2) of the group performed this task once. The time to denest 24 pots was recorded and subjected to a one-way analysis of variance (ANOVA) followed by separation of means (Tukey's). The denesting experiment was only performed once and only at the West Virginia University site.

DATA ANALYSIS. All end-of-harvest measurements (i.e., shoot dry weight, algal growth, and container punch strength) were analyzed as a series of one-way ANOVAs separated by species. Analyses were conducted individually by trial and on the combined pseudoreplication and repeated measures in pH were averaged away before data analysis in R (de Mendiburu, 2012; R

Core Team, 2012) or Sigma Plot (Sigmaplot, San Jose, CA). Additionally, treatment means on dry weight measurements were normalized as a percentage of each trial's overall mean and combined in an overall ANOVA to assess cross-trial patterns with the measured responses. Differences among individual treatments were tested using the Tukey–Kramer method for means separation. All decisions were made at $\alpha \leq 0.05$ significance level of type I error.

Results and discussion

SHOOT DRY WEIGHT. Shoot dry weight for impatiens varied by container type in all six of the trials (Table 3). When normalized and combined in a single ANOVA model to assess cross-trial significance, dry weight was marginally significant (Table 3), above our stated threshold for

Table 2. Start date, mean daily temperatures, and relative humidity for each of six trial locations/growing seasons used in testing the performance of nine alternative containers in a 6-week ‘Sunpatiens Compacta’ impatiens and 12-week ‘Elegans Ice’ lavender production cycle.

		Start date	Site					
			AR1 ^z	AR2	IL	KY	WV1	WV2
			25 Apr. 2011	15 May 2012	25 Apr. 2011	7 May 2011	2 May 2011	15 May 2012
Impatiens	Temperature (°C) ^y	Median	25.6	26.1	26.5	NA ^x	22.5	25.6
	Relative humidity (%)	Median	62	64	62	NA	NA	NA
Lavender	Temperature (°C)	Median	27.7	28.8	26.5	NA	24.3	27.8
	Relative humidity (%)	Median	68	63	62	NA	NA	NA

^zAR 1, 2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, 2 = West Virginia University, Morgantown 2011, 2012.

^y(1.8 × °C) + 32 = °F.

^xNA = not available.

Table 3. Comparison of average final shoot dry weight of ‘Sunpatiens Compacta’ impatiens grown in nine alternative containers for 6 weeks in six trials across four locations.

Container type	Avg shoot dry wt (g/plant) ^z						
	AR1 ^y	AR2	IL	KY	WV1	WV2	N/CM ^y
Bioplastic	7.62 a ^x	9.43 c	2.36 ab	3.55 ab	3.58 c	4.26 ab	89%
Coconut fiber	5.95 a	9.03 c	2.37 ab	2.92 b	3.71 bc	3.55 bc	90%
Control (plastic)	6.96 a	10.21 c	2.00 ab	3.87 ab	4.36 abc	4.53 a	101%
Dairy manure	6.37 a	11.24 b	2.16 ab	3.56 ab	4.06 abc	4.65 a	100%
Peat	6.47 a	10.01 c	2.48 ab	3.63 ab	3.89 abc	3.98 ab	98%
Slotted rice hull	6.31 a	10.50 bc	2.74 a	4.28 a	4.41 ab	3.49 bc	103%
Solid rice hull	6.04 a	9.42 c	2.44 ab	3.65 ab	3.78 abc	3.99 ab	95%
Straw	7.28 a	16.28 a	2.33 ab	4.72 a	3.78 abc	3.44 bc	110%
Sleeve (bioplastic)	7.91 a	13.14 b	1.72 b	4.78 a	4.56 a	4.88 a	112%
Wood fiber	5.52 b	10.28 c	1.82 ab	3.58 ab	4.05 abc	4.39 ab	93%
Significance	0.004	<0.001	0.0325	<0.001	0.0008	<0.001	0.059

^z1 g = 0.0353 oz.

^yAR1, AR2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, WV2 = West Virginia University, Morgantown, 2011, 2012.

^xData were analyzed using a one-way ANOVA and subsequent means were compared using the Tukey–Kramer method ($P \leq 0.05$). Values are the mean of three replications, each consisting of six pseudoreplications. Means within a column that share a lowercase letter do not significantly differ from each other.

^wN/CM = normalized/combined; means of each site were normalized by averaging all alternative container measurements and expressing means of each alternative container as a percentage of the overall mean per site.

significance ($\alpha \leq 0.05$). In four of the six trials, the bioplastic sleeve treatment showed the highest average shoot dry weight, which also resulted in the highest overall normalized/combined measurement. This result corroborates previous work in which the bioplastic sleeve outperformed plastic and alternative containers alternatives as well (Koeser et al., 2013b). For lavender, shoot dry weight varied by container type for all but one of the trials (WV2). In contrast with the impatiens, lavender shoot growth varied by container type when assessed across all six trials as a whole (Table 4). Again the bioplastic sleeve performed well especially when compared with plastic and coconut fiber pots. Similarly to work by Koeser et al. (2013b), coconut fiber pot performed poorly in our study, a result further supported by some data presented by Kuehny et al. (2011). Our inability to detect overall differences in shoot dry weight of impatiens across multiple trials reflects the variability among sites and growing seasons despite our best efforts to standardize our experiments (Table 2). It also speaks to a larger trend among similar work. When multiple sites are used to assess plant performance in alternative containers, it is common to have differing patterns among the performance rankings. For example, Kuehny et al. (2011) noted inconsistencies in the rankings of shoot and root growth of bedding plants for six different 4-inch

alternative containers (compared with a plastic control) grown in greenhouse facilities at three locations. The authors noted this inconsistency in statistical rankings for all three species tested; geranium (*Pelargonium ×hortorum*), common impatiens (*Impatiens wallerana*), and vinca (*Catharanthus roseus*) (Kuehny et al., 2011). Several potential explanations for these differences exist. First, significant interaction between pot and cultural procedures or environmental factors may be present. Since our experiments were not set up to test this hypothesis, we can only speculate on this interaction, but perhaps future work should be directed at elucidating environmental and cultural impact on alternative containers performance. We do know that alternative containers in some instances require more frequent irrigation, but it is unclear how these differences affected overall plant growth (Koeser et al., 2013b). Second, materials used to produce alternative containers are less uniform than plastic and therefore could lead to results that are more difficult to interpret and may require more replications to point to differences. Finally, but probably of most practical value, we conclude that the differences in plant growth between most alternative containers are insignificant and that only straw and bioplastic sleeve pots may outperform coconut and plastic pot in plant growth and then only in long-term greenhouse production.

EC AND pH. No significant differences in EC were observed between alternative containers treatments in the short- and long-term experiments (data not shown) corroborating previous work in which EC varied from week to week but not among pot type (Koeser et al., 2013b). pH measurements however varied in five of six trials in both the short- and long-term production experiments. Measurements were consistently lower than the control plastic pots in peat alternative containers, ranging from a pH of 5.19 in the Kentucky trial to 6.76 in the Illinois trial, and high in the manure alternative containers with values ranging from a pH of 5.79 in the Arkansas 1 trial to 7.56 in the Illinois trial (Table 5 and 6). These values are indicative of the parent material used in the construction of the alternative containers. The pH of sphagnum peat can range from 3.0 to 4.0 while composted dairy manures have pHs in the 8.0 range (Nelson, 2012). These respective low and high pHs of the parent material combined with the pour through method used in our pH and EC measurements may have led to relatively low and high pH measurements. Despite differences in pH between trials and significant differences in pH between peat, manure, and some other alternative containers, these differences did not seem to affect shoot dry weight in a discernible pattern. Similar conclusions were made in recent work with six alternative containers and a control plastic

Table 4. Comparison of final shoot dry weight of ‘Elegans Ice’ lavender grown in nine alternative containers for 12 weeks in six trials across four locations.

Container type	Avg shoot dry wt (g/plant) ^z						
	AR1 ^y	AR2	IL	KY	WV1	WV2	N/CM ^w
Bioplastic	14.41 a ^x	13.45 cd	1.26 cd	6.60 bcd	2.88 b	5.66	92% ab
Coconut fiber	9.04 b	13.44 cd	2.58 a	5.67 cd	3.47 ab	5.72	87% b
Control (plastic)	9.08 b	14.75 c	1.59 bcd	5.53 d	3.15 ab	6.00	88% b
Dairy manure	10.11 b	11.29 d	1.72 bc	7.49 bcd	3.65 ab	7.65	98% ab
Peat	10.42 b	14.85 c	1.60 bcd	6.73 bcd	3.96 a	5.87	96% ab
Sleeve (bioplastic)	14.06 a	18.78 b	0.800 d	8.66 ab	3.96 a	7.23	118% a
Slotted rice hull	10.49 b	14.53 c	1.91 abc	8.48 ab	3.26 ab	6.58	102% ab
Solid rice hull	10.41 b	13.74 cd	1.63 bc	6.98 bcd	3.95 a	5.39	95% ab
Straw	11.85 ab	23.53 a	2.12 ab	9.81 a	3.28 ab	7.36	114% a
Wood fiber	11.65 b	13.02 cd	1.77 bc	7.71 bc	3.74 a	7.75	104% ab
Significance	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	0.058	<0.001

^z1 g = 0.0353 oz.

^yAR1, AR2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, WV2 = West Virginia University, Morgantown, 2011, 2012.

^xData were analyzed using a one-way ANOVA and subsequent means were compared using the Tukey–Kramer method ($P \leq 0.05$). Values are the mean of three replications, each consisting of six pseudoreplications. Means within a column that share a lowercase letter do not significantly differ from each other.

^wN/CM = normalized/combined; means of each site were normalized by averaging all alternative container measurements and expressing means of each alternative container as a percentage of the overall mean per site.

pot in which the pour through method was also used (Koeser et al., 2013b). That research concluded that the differences they observed in pH were “not of biological significance for the species tested (coleus) (*Solenostemon scutellaroides*),” a conclusion we can also support with the data presented here.

PUNCTURE STRENGTH. Significant differences in punch strength of the control and alternative containers used in this study were observed in both short- and long-term production schemes and in all six trials (Tables 7 and 8). Control plastic pots consistently showed higher punch strength than most alternative containers in both the impatiens short-term experiment and the lavender

long-term experiment. In some instances, punch strength of coconut fiber pots rivaled or exceeded that of plastic pots in the short-term study. At the end of the 12-week lavender experiment, however, punch strength of coconut fiber pots was the same or lower than the plastic pot indicating a gradual decrease in punch strength over time. Solid rice hull alternative containers often followed plastic control pots and coconut fiber in punch strength, a trend observed in both short- and long-term production experiments. Manure, peat, and wood fiber consistently showed lower puncture strengths than most other alternative containers in both the 6- and 12-week studies. If pots were to be handled individually, these pots would

consistently fail. However, when placed in shuttle trays, this may be less of an issue. Clearly, with the exception of coconut fiber pots, all alternative containers in this study showed lower punch strengths than the control. As in previous reports, manure, peat, and wood alternative containers proved to be weaker than many other alternative containers tested (Evans et al., 2010). Interestingly, coconut fiber pots performed better in our study than in previous work on punch strength of alternative containers (Evans et al., 2010), although the exact reason for this discrepancy is unclear. Slight re-engineering—addition of a lip to the rim of the pot—and perhaps reformulation of ingredients may account for these observations.

Table 5. Comparison of the combined average leachate pH measured at weeks 0, 2, 4, and 6 of nine alternative containers with ‘Sunpatiens Compacta’ impatiens grown for a total 6 weeks in six trials across four locations.

Container type	Avg pH					
	AR1 ^z	AR2	IL	KY	WV1	WV2
Bioplastic	5.56	6.44 b ^y	6.97 b	5.51 b	6.28 b	6.29 c
Coconut fiber	5.26	6.95 ab	7.10 b	5.37 c	6.47 ab	6.37 b
Control (plastic)	5.25	6.48 b	7.07 b	5.61 b	6.23 b	6.13 c
Dairy manure	5.79	6.95 ab	7.56 a	6.71 a	7.00 a	6.97 a
Peat	5.38	5.70 c	6.76 c	5.19 c	6.05 b	5.66 d
Sleeve (bioplastic)	5.29	6.77 ab	7.05 b	5.60 b	6.42 ab	6.62 a
Slotted rice hull	5.09	6.66 ab	7.13 b	5.99 b	6.75 a	6.74 a
Solid rice hull	5.04	6.47 b	7.01 b	5.58 b	6.28 b	6.02 cd
Straw	5.37	7.05 a	7.14 b	5.49 b	6.68 ab	6.62 a
Wood	5.28	6.62 ab	7.19 ab	5.77 b	6.48 ab	6.37 b
Significance	0.9	<0.001	<0.001	<0.001	<0.001	<0.001

^zAR1, AR2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, WV2 = West Virginia University, Morgantown, 2011, 2012.

^ypH values at weeks 0, 2, 4, and 6 for each trial and alternative container type were averaged and subsequent values were analyzed using a one-way ANOVA. Means were separated using the Tukey–Kramer method ($P \leq 0.05$). Values are the average of three replications per time point, each consisting of six pseudoreplications. Means within a column that share a lowercase letter do not significantly differ from each other.

Table 6. Comparison of combined average leachate pH measured at weeks 0, 2, 4, 6, 8, 10, and 12 of nine alternative containers with ‘Elegans Ice’ lavender grown for a total 12 weeks in six trials across four locations.

Container type	Avg pH					
	AR1 ^z	AR2	IL	KY	WV1	WV2
Bioplastic	6.41	6.45 b ^y	6.74 b	5.15 a	6.22 bc	6.19 c
Coconut fiber	5.68	6.98 a	6.85 ab	5.15 a	6.32 bc	6.58 b
Control (plastic)	6.15	6.47 b	6.83 ab	5.36 a	6.21 c	6.16 c
Dairy manure	6.28	6.94 ab	7.17 a	6.36 a	7.16 a	7.10 a
Peat	5.84	5.77 c	6.62 b	5.09 b	6.11 c	5.96 c
Sleeve (bioplastic)	5.52	6.80 ab	6.89 ab	5.70 a	6.38 bc	6.73 a
Slotted rice hull	5.3	6.65 ab	7.00 ab	5.90 a	6.91 ab	6.82 ab
Solid rice hull	5.2	6.47 b	6.75 b	5.40 a	6.27 bc	6.13 c
Straw	5.52	7.07 a	7.00 ab	5.31 a	6.57 b	6.61 b
Wood	5.53	6.64 ab	6.78 b	5.18 a	6.51 bc	6.18 c
Significance	0.278	<0.001	<0.001	0.022	<0.001	<0.001

^zAR1, AR2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, WV2 = West Virginia University, Morgantown, 2011, 2012.

^ypH values at weeks 0, 2, 4, 6, 8, 10 and 12 for each trial and alternative container type were averaged and subsequent values were analyzed using a one-way ANOVA. Means were separated using the Tukey–Kramer method ($P \leq 0.05$). Values are the average of three replications per time point, each consisting of six pseudoreplications. Means within a column that share a lowercase letter do not significantly differ from each other.

Table 7. Comparison of punch strength of nine alternative containers at the end of a 6-week production cycle with ‘Sunpatiens Compacta’ impatiens in six trials across four locations.

Container type	Punch strength (kg) ^z					
	AR1 ^y	AR2	IL	KY	WV1	WV2
Bioplastic	2.82 bc ^x	5.58 c	4.45 d	4.71 b	4.47 b	3.87 b
Coconut fiber	15.77 a	18.00 a	7.96 b	17.87 a	22.33 a	19.12 a
Control (plastic)	19.76 a	15.66 b	19.48 a	19.48 a	19.88 a	14.41 ab
Dairy manure	0.28 c	0.94 d	0.30 f	0.70 d	0.20 c	0.31 c
Peat	0.77 bc	1.31 d	0.39 f	0.96 d	0.23 c	0.68 c
Sleeve (bioplastic)	1.29 bc	2.12 d	3.38 e	2.13 bc	2.41 bc	0.99 c
Slotted rice hull	3.37 bc	2.87 cd	2.00 e	3.18 bc	2.56 bc	2.09 bc
Solid rice hull	8.15 b	9.28 b	6.05 c	5.94 b	6.73 b	6.74 b
Straw	5.46 bc	2.38 cd	2.08 e	3.77 b	2.78 bc	6.74 bc
Wood fiber	0.39 c	9.71 d	0.27 f	0.29 d	0.27 c	0.32 c
Significance	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

^x1 kg = 2.2046 lb.^yAR1, AR2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, WV2 = West Virginia University, Morgantown, 2011, 2012.^zData were analyzed using a one-way ANOVA and subsequent means were compared using the Tukey–Kramer method ($P \leq 0.05$). Values are the mean of three replications. Means within a column that share a lowercase letter do not significantly differ from each other.**Table 8. Comparison of punch strength of nine alternative containers at the end of a 12-week production cycle with ‘Elegans Ice’ lavender in six trials across four locations.**

Container type	Punch strength (kg) ^z					
	AR1 ^y	AR2	IL	KY ^v	WV1	WV2
Bioplastic	2.11 c ^x	5.11 c	3.77 d	NA	3.51 c	NA
Coconut fiber	15.91 a	14.90 a	13.65 b	NA	7.65 b	12.51 b
Control (plastic)	19.50 a	16.48 a	20.66 a	NA	19.64 a	20.03 a
Dairy manure	0.34 c	0.56 d	0.25 e	NA	0.11 e	0.23 e
Peat	0.30 c	1.19 d	0.44 e	NA	0.18 e	0.46 de
Sleeve (bioplastic)	1.10 c	1.21 d	3.07 d	NA	2.48 d	0.58 de
Slotted rice hull	2.56 c	2.27 d	1.60 de	NA	1.40 de	1.72 de
Solid rice hull	6.97 b	9.52 b	6.74 c	NA	6.40 b	7.24 c
Straw	1.83 c	2.32 d	3.71 d	NA	1.34 de	2.22 d
Wood fiber	0.23 c	0.82 d	0.32 e	NA	0.19 e	0.28 e
Significance	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

^x1 kg = 2.2046 lb.^yAR1, AR2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, WV2 = West Virginia University, Morgantown, 2011, 2012.^vData were analyzed using a one-way ANOVA and subsequent means were compared using the Tukey–Kramer method ($P \leq 0.05$). Values are the mean of three replications. Means within a column that share a lowercase letter do not significantly differ from each other.

ALGAL GROWTH. Only three alternative containers types, wood, manure, and peat, showed algal growth in at least one of the trials of the short-term 6-week impatiens study (Table 9). The two alternative containers types that showed algal growth in every trial were peat and wood. Manure alternative containers showed algae only in the second year of the Arkansas and West Virginia trials. Algal growth was observed in four alternative container treatments in the longer term (12 weeks) lavender study, but only consistently in manure peat and wood treatment (Table 10). Overall, much larger areas were covered with algae after 12 weeks than 6 weeks of production. Materials that allow the walls of the containers to stay damp because of wicking and do not dry

quickly due to large pore spaces seem to be especially prone to algal growth. Pots that did not show algal growth in our study but showed algal presence in previous studies were straw alternative containers (Evans et al., 2010). Clearly, environmental and cultural factors play an important role in the presence or absence of algae.

DENESTING. Peat alternative containers are especially difficult to separate and place into shuttle trays and in our hands took 5 s per pot to denest and place in trays (Table 11). Peat and manure alternative containers take significantly more time to denest than control plastic pots (up to three to five times longer than control pots, respectively). Conversely, the best performing pots in

this test, solid and slotted rice hull container types needed less than 1 s per pot to be dislodged from a stack of pots and placed into a shuttle tray, a time similar to the control plastic pots. Denesting is not only an issue for manually placing pots into shuttle trays in smaller operations but may also significantly impede automated procedures in larger greenhouses. When pots were subjected to automated filling, spacing, and shipping by Koeser et al. (2013b), manure and peat also showed significantly longer filling times, and filling and shipping damage not observed in most other alternative containers. Here we show that manual denesting, which may be routine in smaller operations, may also be a major concern when deciding on

Table 9. Comparison of algal growth on nine alternative containers at the end of a 6-week production cycle with ‘Sunpatiens Compacta’ impatiens in six trials across four locations.

Container type	Algal growth (cm ²) ^z					
	AR1 ^y	AR2	IL	KY	WV1	WV2
Bioplastic	0.00 b ^x	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Coconut fiber	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Control (plastic)	0.00 b	0.00b	0.00 b	0.00 b	0.00 b	0.00 c
Dairy manure	0.00 b	45.31 a	0.00 b	0.00 b	0.00 b	24.13 b
Peat	21.82 a	54.42 a	5.58 a	3.56 a	34.02 a	37.55 a
Sleeve (bioplastic)	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Slotted rice hull	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Solid rice hull	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Straw	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Wood fiber	21.99 a	40.70 a	0.97 b	0.36 b	38.42	40.15 a
Significance	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

^z1 cm² = 0.1550 inch².

^yAR1, AR2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, WV2 = West Virginia University, Morgantown, 2011, 2012.

^xData were analyzed using a one-way ANOVA and subsequent means were compared using the Tukey–Kramer method ($P \leq 0.05$). Values are the mean of three replications. Means within a column that share a lowercase letter do not significantly differ from each other.

Table 10. Comparison of algal growth on nine alternative containers at the end of a 6-week production cycle with ‘Elegans Ice’ lavender in six trials across four locations.

Container type	Algal growth (cm ²) ^z					
	AR1 ^y	AR2	IL	KY	WV1	WV2
Bioplastic	0.00 b ^x	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Coconut fiber	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Control (plastic)	0.00 b	0.00b	0.00 b	0.00 b	0.00 b	0.00 c
Dairy manure	0.00 b	45.31 a	0.00 b	0.00 b	0.00 b	24.13 b
Peat	21.82 a	54.42 a	5.58 a	3.56 a	34.02 a	37.55 a
Sleeve (bioplastic)	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Slotted rice hull	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Solid rice hull	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Straw	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 c
Wood fiber	21.99 a	40.70 a	0.97 b	0.36 b	38.42	40.15 a
Significance	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

^z1 cm² = 0.1550 inch².

^yAR 1, 2 = University of Arkansas, Fayetteville, 2011, 2012; IL = University of Illinois, Urbana, 2011; KY = University of Kentucky, Lexington, 2011; WV1, 2 = West Virginia University, Morgantown, 2011, 2012.

^xData were analyzed using a one-way ANOVA and subsequent means were compared using the Tukey–Kramer method ($P \leq 0.05$). Values are the mean of three replications. Means within a column that share a lowercase letter do not significantly differ from each other.

a pot type to use in a greenhouse operation.

Conclusions

Using alternative containers as replacements for plastic containers is not a clear-cut proposition. Environmental, cultural, aesthetic, and economic factors can all have a significant impact on how containers are perceived by the consumer or perceived to perform by the producer relative to the conventional plastic container they are intended to replace. Generally, if a plant is in flower, plant size seems to be the main difference that is used to judge appearance and overall plant quality. Here we showed that differences in plant size between different alternative containers and a

plastic control pot are not significant after 6 weeks of production with an impatiens crop when data across multiple sites are combined. After 12 weeks with lavender plants, only sleeve and wood fiber pots outperformed the control plastic pots in terms of plant growth, a trend that was also observed in the short-term study but did not reach the level of statistical significance. Depending on one’s tolerance for differences in top growth, container strength, pot appearance, handling, and cost may be more pressing concerns. Several of the less-processed containers (dairy manure, peat, wood pulp) supported algae growth. These same containers are also among the most fragile, especially when used for long-term

Table 11. Average time required to denest 24 tightly stacked alternative containers and control plastic pots and place them in shuttle trays.

Container type	Denesting time (s)
Bioplastic	30.4 bcd ^z
Coconut fiber	39.2 bcd
Control (plastic)	28.4 cd
Manure	70.6 b
Peat	126.4 a
Sleeve (bioplastic)	27.0 cd
Slotted rice hull	21.9 d
Solid rice hull	22.9 d
Straw	59.1 bcd
Wood	65.2 bc
Significance	<0.001

^zData were analyzed using a one-way ANOVA and subsequent means were compared using the Tukey–Kramer method ($P \leq 0.05$). Values are the mean of 14 replications. Means within a column that share a lowercase letter do not significantly differ from each other.

production. As such, they may be best suited for short-term production in shuttle trays. When interpreting the findings of this work, it must be restated that the main marketable characteristic of alternative containers is their ability to degrade in soil or compost. The same characteristics that allow them to break down readily also contribute to their limited stability during production. This is the trade-off, but one that waste-conscious producers and consumers may be willing to overlook. Finally, greenhouse producers should be aware that some of the alternative containers on the market may be much more cumbersome to handle than plastic pots and could significantly slow down greenhouse operations.

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