Preliminary and Regional Reports

Herbaceous Perennial Producers Can Grow High-quality Blanket Flower in Bioplastic-based Plant Containers

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ADDITIONAL INDEX WORDS. **biocomposite, biocontainer, bioplastic, biopolyurethane, gaillardia, polylactic acid**

SUMMARY. **We quantified the growth and quality of 'Arizona Sun' blanket flower (*Gaillardia ×grandiflora*) grown in different bioplastic containers and characterized the interest of commercial perennial producers in using bioplastic-based biocontainers in their herbaceous perennial production schemes. Plants were grown in three types of #1 trade gallon (0.75 gal) containers at five commercial perennial producers in the upper-midwestern United States. Containers included one made of polylactic acid (PLA) and a proprietary bio-based filler derived from a coproduct of corn ethanol production, a commercially available recycled paper fiber container twice dip-coated with castor oil–based biopolyurethane and a petroleum-based plastic (control) container. Plant growth data were collected when most plants had open flowers, and plant shoots, roots, and containers were rated by commercial grower participants. Questionnaires were administered at the beginning and at the end of the experiment to characterize the perceptions and interest of growers in using these containers, their interest in different bioplastic-based container attributes, and their satisfaction from using the containers. Container type and grower interacted to affect growth index (GI), shoot dry weight (SDW), and container rating. Root rating was affected by container type or grower and shoot rating was unaffected by either. Our results indicate that commercial producers can adapt these bioplastic-based biocontainers to blanket flower production with few or no changes to their crop cultural practices.**

Floriculture sales in the United States totaled $5.87 billion in 2014 [U.S. Department of Agriculture (USDA), 2015], of which potted herbaceous perennials [excluding hardy/garden chrysanthemums (*Chrysanthemum ×morifolium*)] represented $742 million (13%) of total sales from just under 203 million units. About 107 million (62%) of these perennials were produced in #1 to #2 trade gallon-sized containers, for a total market value of $457 million. Horticultural containers are predominately manufactured from petroleum-based plastics (Evans and Hensley, 2004). Based on calculations updated with recent wholesale data (Schrader, 2013; USDA, 2015), more than 16,400 Mg of petroleum-based plastic were consumed in 2014 for the manufacture of #1 and #2 trade gallon containers used to produce herbaceous perennials in the United States.

Researchers reported that most (74%) nursery and greenhouse crop producers use containers manufactured with recycled petroleum plastics (Dennis et al., 2010). In addition, more than 75% of plant containers used by container-crop producers are recyclable (Yue et al., 2010). However, these findings do not indicate the total amount of recycled plastics used or the relative proportion of virgin plastics used to manufacture new plant containers. Diversion of used plant containers into recycling programs is uniquely problematic for horticultural containers because of ultraviolet degradation and the potential presence of pesticide residues (Hall et al., 2010). Thus, despite efforts to reduce plastic container waste by recycling, petroleum-based plastic containers continue to raise environmental concerns for container-crop producers.

Containers made from bioplastics and biocomposites may offer an environmentally friendly and effective alternative to larger petroleum-based plastic plant containers. Research conducted by Kratsch et al. (2015) using prototype #1 trade gallon plant containers manufactured from biocomposites and bioplastics yielded positive plant growth and container quality results when compared with conventional petroleum-plastic containers. In addition, commercially available paper fiber containers dip-coated with bio-based polyurethane produced plants of equal quality compared with plants grown in petroleum-plastic control containers (Kratsch et al., 2015; McCabe et al., 2014). However, these trials were conducted in research facilities and have not been tested in commercial cropping schemes.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
3.7854	gal	L	0.2642
0.5933	lb/yard^3	kg·m^{-3}	1.6856
28.3495	oz	g	0.0353
1	ppm	mg·L^{-1}	1
0.9072	ton(s)	Mg	1.1023
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

A wider variety of crop cultural practices and production environments may affect the performance of bioplastic containers and plant growth in these containers differently and affect the ease of use by commercial crop producers. Research has shown that ease of implementation strongly affects commercial grower adoption of sustainable practices (Hall et al., 2009). To ensure that the use of these containers would not be prohibitive, if and when they become commercially available, we performed a coordinated trial in commercial nursery settings to compare growth of plants in these containers and their appearance and durability to results seen when using conventional petroleum-plastic pots.

Commercial grower trials with new technologies such as soil moisture sensor-controlled irrigation have proven valuable in testing new crop production technologies (Chappell et al., 2013). In addition, smaller bioplastic plant containers have yielded positive results and garnered interest of commercial greenhouse growers for use with annual bedding plant production (Flax et al., 2017). Thus, our objectives were to 1) quantify and compare growth of herbaceous perennials grown in different (predominately unprotected, outdoor) production environments using two types of bioplastic-based biocontainers to plants grown in petroleum-plastic containers and 2) characterize commercial perennial producers' perceptions of and interest in using bioplastic-based biocontainers in their cropping systems through a series of questionnaires and qualitative assessments of plant shoot and root quality and container quality.

Materials and methods

Container types. Successful molding of containers using standard commercial manufacturing machinery and positive results for plant growth and container degradation served as the basis for container selection for this experiment (Kratsch et al., 2015; McCabe et al., 2014). Three types of #1 trade gallon containers were evaluated: 1) bioplastic-based biocontainers (0.75 gal) molded by a commercial container manufacturer (Nursery Supplies, Chambersburg, PA) composed of (by weight) 80% PLA, a commercial bioplastic, and 20% BR, a bio-based filler derived from dried distiller's grains and solubles (BioRes; Laurel Biocomposite, Laurel, NE); 2) recycled paper fiber containers [0.71 gal; Myers Industries, Akron, OH] twice dip-coated in castor oil-based biopolyurethane (PUR); and 3) petroleum-plastic containers [PP (control) 0.75 gal; Nursery Supplies].

Experimental design, grower facilities, and crop culture. This experiment was conducted using a randomized complete block design in factorial arrangement with grower (five levels) and container type (three levels) as factors. There were 20 replicates (individual containers) per container type per facility.

Experiment plots were setup at five commercial grower facilities (coded as growers A through E) in the upper-midwestern United States between 1 and 5 June 2015. Production areas at Growers A, B, and E were outdoors and unprotected, Grower C produced plants in a high tunnel and removed the covering after ≈4 weeks, and Grower D produced plants in a glass-glazed greenhouse. Soilless substrate comprised composted bark, sphagnum moss, perlite, and vermiculite (Metromix 300; Sun Gro Horticulture, Agawam, MA) was provided to growers B, C, and D. Growers A and E furnished their own soilless substrate containing controlled-release fertilizer because the use of water-soluble fertilizer was not part of their containerized perennial cropping scheme. Containers were filled by hand, and seedlings of 'Arizona Sun' blanket flower grown by a commercial seedling producer were transplanted into containers; seedlings were brought with containers to each facility. Data loggers (Watchdog Plant Growth Station model 2475; Spectrum Technologies, Aurora, IL) were placed among plants to record environmental parameters throughout production (Table 1). Fertilizer source and concentration were also reported, and growers who used water-soluble fertilizers alternated fertilizer applications with clear water (Table 1).

Data collection and calculations. Questionnaires approved by an Institutional Review Board were administered to grower participants responsible for managing experiment crops. Preproduction questionnaires that characterized growers' perceptions and interest in using bioplastic-based biocontainers were administered before experiment initiation (Table 2). When crop production was concluded, an identical postproduction questionnaire was administered to characterize any changes in opinions or perceptions after producing plants in bioplastic-based biocontainers. In addition, grower participants responded to two questionnaires that evaluated their satisfaction when producing plants in our containers and their interest in unique properties intrinsic to other bioplastic-based containers (Tables 3 and 4).

Growers rated plant shoots (stems, leaves, and flowers), roots, and quality of containers when 75% of plants had open flowers. Quality of shoots, roots, and containers was rated on a 1 to 5 Likert scale, with 1 being very poor and 5 being excellent. Blinding measures that prevented growers' ratings from being influenced by container types and criteria supplied for rating shoots, roots, and containers (respectively) included 1) plants sampled for shoot ratings that were placed into unused PP containers (blinding), and grower participants were asked to rate shoots based on plant size, greenness, abundance or absence of flowers, signs of chlorosis or necrosis, stunting, or abnormal growth (Schrader et al., 2013); 2) root profiles sampled for root evaluations had shoots and containers removed (blinding) and ratings were assigned based on robustness of root system and root morphology characteristics such as branching, color, fibrousness, circling or root-bound habit, or presence of pathogen symptoms; and 3) containers sampled for ratings had shoots and substrate removed (blinding) and containers were rated based on discoloration, durability, ease of handling, and the presence of microbial growth or arthropods colonizing the container surface. Plants with shoots rated 1.0 were considered

We gratefully acknowledge Bailey Nurseries, Country Landscapes, Plantpeddler Greenhouses, Swift Greenhouses, and Tangletown Gardens and all affiliated grower participants for their contributions to this experiment; Kellie Walters, Kenneth McCabe, Brianna Vest, and Alexander Litvin for data collection assistance; and the U.S. Department of Agriculture Specialty Crops Research Initiative and the National Institute of Food and Agriculture for funding.

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https://doi.org/10.21273/HORTTECH03922-17

Table 1. Facility, environmental parameters, and crop cultural practices were recorded, including average daily temperature (ADT), daily light integral (DLI), fertilizer source [water-soluble (WSF) or controlled-release (CRF)], analysis, and percent nitrogen (N), phosphorous (P), and potassium (K) concentration, for 'Arizona Sun' blanket flower grown in two types of #1 trade gallon [0.75 gal (2.839 L)] bioplastic-based biocontainers and a petroleum-based plastic (control) container at five commercial nurseries in the upper-midwestern United States. Applications of WSF to crops were alternated with clear water irrigations.

Grower	ADT [mean ± SD (°F)][z]	DLI ($mol\cdot m^{-2}\cdot d^{-1}$)	Production environment (unprotected, high-tunnel, and greenhouse)	Fertilizer (source, N–P–K, concn)[z]
A	72.9 ± 11.3	49.5	Unprotected	Proprietary soilless substrate[y]
B	68.7 ± 12.5	30.4	Unprotected	WSF, 20–4.4–17.6, 150 ppm N
C	70.9 ± 10.6	30.8	High-tunnel (glazing removed after ≈4 weeks)	WSF, 16–1.3–14.1, 200 ppm N
D	75.2 ± 8.8	21.1	Glass-glazed greenhouse	WSF, 17–0–14.1, 250 ppm N + MKP[x], 10 ppm
E	69.7 ± 11.0	32.4	Unprotected	CRF[y], 16–2.2–9.1, 5 lb/yard³

[z]°F = (°C × 1.8) + 32, 1 ppm = 1 $mg\cdot L^{-1}$, 1 lb/yard³ = 0.5933 $kg\cdot m^{-3}$.
[y]In-house soilless substrate with CRF incorporated was used in place of the soilless substrate brought to the other facilities, as this was the primary source of mineral nutrients in their normal herbaceous perennial cropping scheme. Substrate was composed of sphagnum moss, composted sudangrass (*Sorghum* ×*drummondii*), composted rice (*Oryza sativa*) hulls, and CRF; relative proportions and formulations have not been disclosed per the participant's request.
[x]Monopotassium phosphate.

Table 2. Commercial nursery grower perceptions of and interest in using bioplastic-based plant containers before and after producing 'Arizona Sun' blanket flower in two types of #1 trade gallon [0.75 gal (2.839 L)] bioplastic-based biocontainers and a petroleum-based plastic (control) container at five commercial nurseries in the upper-midwestern United States.

	Response (1 to 4 scale)		
Question	Before	After	Sig.[z]
I am ___ in using biocontainer in containerized greenhouse crop production.[y]	2.4	3.0	NS
I am ___ in using biocontainers in containerized greenhouse crop production that affect crop development and management.[y]	2.6	3.2	NS
I am ___ that I can produce a high-quality crop of plants in biocontainers.[x]	2.6	3.4	NS
The appearance of a biocontainer ___ my perception of the ability to produce a high-quality crop of plants in biocontainers.[w]	2.0	1.8	NS

[z]Significance using Wilcoxon's signed-rank test; NS = nonsignificant.
[y]Likert scale response; 1 = very uninterested, 2 = uninterested, 3 = interested, 4 = very interested.
[x]Likert scale response; 1 = very unconvinced, 2 = unconvinced, 3 = convinced, 4 = very convinced.
[w]Likert scale response; 1 = really does not affect, 2 = does not affect, 3 = affects, 4 = strongly affects.

Table 3. Commercial nursery grower satisfaction producing 'Arizona Sun' blanket flower in two types of #1 trade gallon [0.75 gal (2.839 L)] bioplastic-based biocontainers and a petroleum-based plastic (control) container at five commercial nurseries in the upper-midwestern United States was measured via a questionnaire administered to grower participants after plants were harvested.

	Response (1 to 4 scale)					
	Grower					
Question	A	B	C	D	E	F
To what level did growing plants in these biocontainers match your expectations?[z]	4.0	3.0	4.0	4.0	3.0	4.0
How did you like growing plants in the biocontainers provided?[y]	4.0	4.0	4.0	3.0	3.0	4.0

[z]Likert scale responses; 1 = did not meet expectations by far, 2 = did not meet expectations, 3 = exceeded expectations 4 = exceeded expectations by far.
[y]Likert scale responses; 1 = really did not like, 2 = did not like, 3 = liked, 4 = really liked.

unsalable, whereas plants with a 5.0 rating were considered premium quality. Root ratings of 1.0 were considered very poor in health, whereas roots rated 5.0 were considered to be in excellent health. Containers rated 1.0 were considered very undesirable, whereas containers rated 5.0 were considered very desirable. Information on the different container types and container parent materials was withheld from growers until the conclusion of the experiment to avoid bias. Grower participants were instructed to assign all ratings objectively, one at a time, and not compare shoots, roots, or containers to other samples (Flax et al., 2017).

Plant growth data were collected after grower participants assigned shoot, root, and container ratings; data were collected over a period of 5 d. Plant height from the substrate surface to the tallest growing point, widest diameter (diameter 1), and width 90° from the widest diameter (diameter 2) were collected from randomly sampled plants (n = 15 per container type per facility). The GI, an integrated measurement of plant size (Jeong et al., 2009), was calculated for each plant (GI = {plant height + [(diameter 1 + diameter 2)/2]}/2). Plants were harvested at the substrate surface and dried and then SDW was calculated.

Table 4. Commercial nursery growers demonstrated interest in a range of intrinsic physical and chemical properties, categorized by Schrader et al. (2015), after producing 'Arizona Sun' blanket flower in two types of #1 trade gallon [0.75 gal (2.839 L)] bioplastic-based biocontainers and a petroleum-based plastic (control) container at five commercial nurseries in the upper-midwestern United States through responses to a questionnaire administered after plants were harvested.

Question	Response (1 to 4 scale)[z]
Would you be interested in a container that biodegrades quickly in soil when planted with the container?	3.2 a[y]
Would you be interested in a biocontainer that biodegrades when placed into the compost?	2.8 a
Would you be interested in a biocontainer that releases fertilizer during crop production (i.e., N, P, and K)?	3.4 a
Would you be interested in a biocontainer that reduces circling root formation?	3.2 a
Would you be interested in a biocontainer that appears nearly identical to petroleum-plastic containers?	3.0 a
Would you be interested in a biocontainer if it were not made of 100% bio-based materials?	2.6 a
Would you be interested in a biocontainer if it appeared identical to a colored petroleum-plastic container, but the coloring agent was not bio-based material?	3.0 a

[z]Likert scale; 1 = very uninterested, 2 = uninterested, 3 = interested, 4 = very interested.
[y]Means that share letters are similar using Tukey's honestly significant difference test at $P \leq 0.05$.

Table 5. Analyses of variance of container type (C) and grower (G) on growth index (GI), shoot dry weight (SDW), and aesthetic quality of shoots, roots, and containers for 'Arizona Sun' blanket flower grown in two types of #1 trade gallon [0.75 gal (2.839 L)] bioplastic-based biocontainers and a petroleum-based plastic (control) container at five commercial nurseries in the upper-midwestern United States. Significance of main effects and interactions were detected using PROC GLM of SAS (version 9.4; SAS Institute).

	C	G	C × G
Parameter	Blanket flower		
GI	NS	***	**
SDW	**	***	**
Shoot rating	NS	NS	NS
Root rating	***	**	NS
Container rating	***	***	***

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

STATISTICAL ANALYSES. Analyses of variance (Table 5) were performed by using PROC GLM of SAS (version 9.4; SAS Institute, Cary, NC) and mean separations were performed by using Tukey's honestly significant difference (HSD) test at $P \leq 0.05$. Nonparametric analysis (Wilcoxon's signed-rank test, PROC UNIVARIATE of SAS) was used to analyze changes in grower perceptions and interest in using biocontainers in commercial nursery crop production.

Results

PLANT GROWTH. Container type and grower interacted to affect GI and SDW of blanket flower (Table 5). For example, across container types and within growers, GI was similar at growers A, C, D, and E, whereas plants produced in PLA-BR containers by grower B were smaller compared with other container types (Table 6). Alternatively, across growers and within container types, GI of plants produced in PUR containers was similar for growers A, B, and E (27.6–29.9), but blanket flower grown in PLA-BR containers by grower B were 26% and 23% smaller than growers A and E, respectively (Table 6).

Shoot dry weight was similar across container types and within growers A, D, and E, whereas SDW of plants produced in PLA-BR containers were 32% and 23% smaller than those grown in PP containers at growers B and C, respectively (Table 6). Within PLA-BR containers and across growers, SDWs were largest at grower C (24.4 g), smaller but similar among growers A, D, and E (9.6–12.0 g), and smallest at grower B (2.8 g).

SHOOT AND ROOT RATINGS. Shoot ratings were unaffected by container type or grower (Table 5). Ratings ranged from 3.7 to 3.9 within container types (pooled across growers) or 3.3 to 4.2 within growers (pooled across container types; data not shown).

Root ratings were affected by container type and grower (Table 5). Within container type, ratings were highest for plants produced in PUR containers (4.7) and lowest for those grown in PLA-BR (3.1) and PP containers (3.1) (Table 7). The effect of grower on root ratings (pooled across container types) was significant ($P < 0.01$) and ratings ranged from 3.1 to 4.1 of 5.0 (data not shown); however, no differences were detected by Tukey's HSD test.

CONTAINER RATINGS. Interaction of container type and grower affected container ratings (Table 5). For instance, grower C rated PUR and PP containers 5.0 and 3.0 of 5.0, respectively, whereas grower B rated PUR and PP containers 3.0 and 5.0 of 5.0, respectively (Table 6). Conversely, within container type, PLA-BR containers were rated highest by grower E (5.0) and lower (4.0 of 5.0) by other growers and PUR containers were rated lowest by growers B and D and highest by growers A and C (Table 6).

QUESTIONNAIRES. No changes in growers' perceptions and interest in using biocontainers in containerized perennial production were observed between pre- and postproduction questionnaires (Table 2). On a Likert scale of 1 to 4 (1 = really did not like and 4 = really liked), growers liked or really liked producing herbaceous perennials in the bioplastic-based containers provided (Table 3). Responses to the biocontainer attributes questionnaire suggest that perennial producers are interested in containers that provide additional functions during production, although no single attribute was more important (Table 4).

Discussion

Growth and development of blanket flower can be affected by environmental factors and crop cultural practices (Evans and Lyons, 1988; Pilon, 2006; Yuan et al., 1998). Thus, differences observed among growth within container types and across grower facilities were expected because of varying environmental parameters and crop cultural practices used by grower participants (Table 1). Within growers, SDW was the only growth parameter affected by container type. However, we do not believe that these differences are commercially significant, as GI was largely unaffected by

Table 6. Growth index (GI), shoot dry weight (SDW), and grower quality ratings of containers used to produce 'Arizona Sun' blanket flower in two types of #1 trade gallon [0.75 gal (2.839 L)] bioplastic-based biocontainers and a petroleum-based plastic (control) container at five commercial nurseries in the upper-midwestern United States. Data were collected when 75% of plants were in flower at a given grower facility.

	Grower				
Container type[z]	A	B	C	D	E
GI[y]					
PLA-BR	30.8 aC[x]	22.9 bD	46.6 aA	39.7 aB	29.6 aC
PUR	29.9 aC	27.6 aC	46.8 aA	37.2 aB	28.1 aC
PP	30.6 aC	26.3 aD	47.5 aA	40.4 aB	29.0 aCD
SDW (g)[w]					
PLA-BR	12.0 aB	2.8 cC	24.4 bA	10.8 aB	9.6 aB
PUR	11.5 aB	5.2 aC	28.2 abA	10.7 aB	9.6 aB
PP	12.2 aB	4.1 bC	31.7 aA	11.2 aB	9.7 aB
Container rating (1 to 5 scale)[v]					
PLA-BR	4.0 bB	4.0 bB	4.0 bB	4.0 bB	5.0 aA
PUR	5.0 aA	3.0 cC	5.0 aA	3.0 cC	4.0 bB
PP	4.0 bB	5.0 aA	3.0 cC	5.0 aA	3.0 cC

[z]PLA = polylactic acid; BR = a proprietary bio-based filler derived from dried distiller's grains and solubles; PUR = commercially available recycled paper fiber container twice dip-coated in castor oil–based biopolyurethane; PP = petroleum-based plastic (control).
[y]Growth index = {plant height + [(diameter 1 + diameter 2)/2]}/2.
[x]Means within columns (lowercase letters) and within rows (uppercase letters) that share letters are not different according to Tukey's honestly significant difference test at $P \leq 0.05$; n = 15 per container type, per species, and per grower.
[w]1 g = 0.0353 oz.
[v]Ratings were assigned by commercial grower participants in charge of managing experiments at each nursery on a Likert scale; 1 = very poor quality, 2 = below average quality, 3 = average quality, 4 = above-average quality, 5 = excellent quality.

Table 7. Grower quality ratings for root systems of 'Arizona Sun' blanket flower grown in two types of #1 trade gallon [0.75 gal (2.839 L)] bioplastic-based biocontainers and a petroleum-based plastic (control) container at five commercial nurseries in the upper-midwestern United States. Data were collected when 75% of plants were in flower at a given grower facility and data were pooled across grower facilities and within container types.

Container type	Root rating (1 to 5 scale)[z]
PLA-BR	3.1 b[y]
PUR	4.7 a
PP	3.6 b

[z]Ratings were assigned by commercial grower participants in charge of managing experiments at each nursery on a Likert scale; 1 = very poor quality, 2 = below average quality, 3 = average quality, 4 = above-average quality, 5 = excellent quality.
[y]Means within columns followed by the same letters are not different according to Tukey's honestly significant difference test at $P \leq 0.05$.
PLA = polylactic acid; BR = a proprietary bio-based filler derived from dried distiller's grains and solubles; PUR = commercially available recycled paper fiber container twice dip-coated in castor oil–based biopolyurethane; PP = petroleum-based plastic (control).

container type and plants were of salable size and quality across containers.

Shoot ratings were unaffected by container type (Table 5). This agrees with the other research that investigated the use of bioplastic-based biocontainers in greenhouse crop production of annual bedding plants, where container type seldom affected shoot ratings within a given grower facility (Flax et al., 2017). In addition, the bioplastic-based biocontainers used in our experiment were larger containers manufactured using the same materials as the PLA-BR and PUR containers used by Flax et al. (2017). Shoot ratings of plants grown in PLA-BR and PUR containers are consistently similar to those of plants grown in PP containers in this experiment and the petroleum-based plastic controls in the experiment conducted by Flax et al. (2017). This suggests that PLA-BR and PUR containers may be strong candidates for use in the perennial crops industry, as well as in annual bedding plant production.

We have found limited information on biocontainer appearance and grower preferences of containers in nursery crop production. However, research has reported that aesthetics of different biocontainers is affected by properties intrinsic to container materials (Flax et al., 2017; Lopez and Camberato, 2011). For example, compostable containers such as PLA-BR were rated differently when used in annual bedding plant production (Flax et al., 2017), and differences in appearance ranged from 1.0 to 5.0 of 5.0. Similarly, Lopez and Camberato (2011) also reported that the appearance of biocontainers used to produce 'Eckespoint Classic Red' poinsettia (*Euphorbia pulcherrima*) ranged from 1.4 to 5.0 of 5.0 after 14 weeks in production. In both experiments, more degradable and porous containers were often rated lower than petroleum-based plastic containers because of the presence of algae on containers or physical degradation. In this experiment, container ratings varied considerably among growers and container types, and although most container types received above-average ratings (3.0 or higher of 5.0), PP containers were rated lower than PLA-BR or PUR containers 50% of the time (Table 6). This suggests that perennial crop producers may be more interested in using alternative nursery containers manufactured from bioplastics.

Grower participants demonstrated confidence in their ability to produce blanket flower in the bioplastic-based containers provided. Although scores improved between pre- and postproduction questionnaires, no statistical changes were detected in responses to questionnaires investigating perceptions and interest in using bioplastic-based biocontainers, and grower's responses also demonstrated their interest in using these types of containers (Table 2). In addition, grower's expectations of the containers provided were exceeded overall and they liked producing plants in bioplastic containers (Table 3). This suggests that commercial nursery producers would be willing to integrate these types of containers into their crop production systems if the containers are made commercially available. Similarly to Flax et al. (2017), grower participants were interested in different attributes intrinsic to bioplastic-based containers, but no particular additional container function was demanded more than others.

Conclusions

Our findings demonstrate that commercial herbaceous perennial producers can successfully grow blanket flower in bioplastic-based biocontainers and these containers show potential for replacing conventional petroleum-based plastic containers in perennial production schemes. Plant size was generally unaffected by container type, and shoot and root quality of plants produced in bioplastic containers was greater than or equal to that of plants grown in PP containers. Container quality ratings did not appear to be a function of container type; rather, they were more subject to personal preferences of individual growers. Overall, growers seemed less interested in the PP containers compared with PLA-BR and PUR containers. Because of the relatively short crop time (8–9 weeks) in this experiment compared with production times for some woody perennials, we recommend that further research be conducted using these containers with crops that span multiple production seasons. Additional data on air and substrate temperature extremes may be valuable to the interpretation of container characteristics (both aesthetic and physical) in subsequent experiments that investigate a broader range of bioplastic-based nursery containers and herbaceous perennials. Commercial producers should conduct their own trials as bioplastic-based nursery containers become commercially available to determine whether they can be easily integrated into their production schemes.

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