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Evaluation of Native and Nonnative Ornamentals as Pollinator Plants in Florida: I. Floral Abundance and Insect Visitation

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Abstract. **Diverse floral resources impart immense value for pollinating insects of all types. With increasing popularity and demand for modern ornamental hybrids, cultivation by breeders has led to selection for a suite of traits such as extended bloom periods and novel colors and forms deemed attractive to the human eye. Largely understudied is pollinator preference for these new cultivars, as compared with their native congeners. To address this gap in understanding, 10 species of popular herbaceous flowering plants, commonly labeled as pollinator-friendly, were evaluated at two sites in Florida [U.S. Department of Agriculture (USDA) cold hardiness zones 8b and 9a] and across three seasons for their floral abundance and overall attractiveness to different groups of pollinating insects. Each genus, apart from pentas, encompassed a native and nonnative species. Native species included blanket flower (*Gaillardia pulchella*), lanceleaf coreopsis (*Coreopsis lanceolata*), pineland lantana (*Lantana depressa*), and scarlet sage (*Salvia coccinea*). Nonnative species included Barbican™ yellow-red ring blanket flower (*G. aristata* 'Gaiz005'), Bloomify™ rose lantana (*L. camara* 'UF-1011-2'), mysty salvia (*S. longispicata* ×*farinacea* 'Balsalmysty'), Lucky Star® dark red pentas (*Pentas lanceolata* 'PAS1231189'), ruby glow pentas (*P. lanceolata* 'Ruby glow') and Uptick™ Gold & Bronze coreopsis (*Coreopsis* × 'Baluptgonz'). Flower-visiting insects were recorded during five-minute intervals in the morning and categorized into the following morpho-groups: honey bees, large-bodied bees (bumble and carpenter bees), other bees (small to medium-bodied native bees), butterflies/moths, and wasps. Floral abundance and pollinator visitation varied widely by season, location, and species. Of the plant species evaluated, nonnative plants produced nearly twice as many flowers as native plants. About 22,000 floral visitations were observed. The majority of visits were by native, small to medium-bodied bees (55.28%), followed by butterflies and moths (15.4%), large-bodied native bees (11.8%), wasps (10.0%), and honey bees (7.6%). Among plant genera, both native and nonnative coreopsis and blanket flower were most attractive to native, small to medium-bodied bees (e.g., sweat bees, leafcutter bees) with the greatest number of visitations occurring during the early and midmonths of the study (May–August). Across the study, butterflies and moths visited lantana more frequently than all other ornamentals evaluated, whereas pentas were most attractive to wasps. Large-bodied bees visited plants most frequently in May and June, primarily foraging from both native and nonnative salvia. While results from this study showed nominal differences between native and nonnative species in their ability to attract the studied pollinator groups, care should be taken to making similar assessments of other modern plant types.**

Pollinating insects have long played a critical role in the success and health of our diverse natural and man-made ecosystems. Over time, some pollinating insects have experienced reductions in both abundance and diversity (Foley et al., 2005; Steffan-Dewenter and Westphal, 2008). Changes in land-use patterns—largely driven by agricultural intensification and accelerated urban development—negatively impact pollinators primarily due to loss of nesting habitat and adequate floral resources (Bates et al., 2011; Maxwell et al., 2016; McKinney, 2006; Winfree et al., 2009). Managed areas have an opportunity to impart value as resource-rich habitats for different foraging pollinator groups (Baldock et al., 2019; Pawelek et al., 2009; Wenzel et al., 2020). Sizable diversity in flowering types present in some managed landscapes such as residential lawns, public parks, and other urban gardens can contribute a range of available bloom periods for flower-feeding insects (Honchar and Gnatiuk, 2020; Theodorou et al., 2017).

Public consideration and involvement for pollinator conservation and well-being are also gaining momentum (Domroese and Johnson, 2017; Wagner and Kuhns, 2013). Prior research has revealed that nearly half of surveyed consumers with home landscapes purchase plants to attract pollinators and are even willing to pay higher prices for this commodity (Campbell et al., 2017). Further, Kalaman et al. (2020) reported 95.4% of Master Gardener Volunteers in Florida currently grow pollinator-friendly plants. To assist in plant selection, various organizations have published inventories of ornamentals to include in home pollinator gardens (Pollinator Partnership, 2017; Royal Horticultural Society, 2018; Xerces Society, 2017). More recently, interactive mobile applications such as Florida Friendly Landscaping Bee Gardens (Florida Friendly Landscaping, 2020) and BeeSmart Pollinator Gardener (Pollinator Partnership, 2019) have also become available.

As pollinator gardening continues to grow in purpose and popularity, so does a thriving ornamental industry. In the United States alone, the ornamental industry is valued at $4.8 billion [U.S. Department of Agriculture (USDA, 2018)]. Most modern plant breeding efforts have focused on selection for a suite of traits such as extended bloom periods and novel colors and forms intended to appeal chiefly to consumer preferences and aesthetics (Horn, 2002; Hoyle et al., 2017). While some of these new hybrids are marketed as pollinator-friendly, these claims can be largely anecdotal without knowledge of the actual resource-value and attraction these ornamentals offer to foraging insects (Garbuzov et al., 2017; Garbuzov and Ratnieks, 2015a).

The floral morphology and reproductive ability of certain modern cultivars (e.g., double blooms, unnatural symmetry, size, or sterility) may adversely affect the ability of foraging insects to receive floral rewards (Baisden et al., 2018; Comba et al., 1999; White, 2016). Altered floral color and pigment accumulation can also influence pollinator attraction (Chittka et al., 2001; Dyer et al., 2006; White, 2016). Conversely, other studies have indicated that some nonnative ornamentals in structurally modified areas may buffer temporal gaps in pollen and nectar resource availability (Erickson et al., 2020; Salisbury et al., 2015; Seitz et al., 2020).

Native and nonnative ornamentals have been investigated by some for their attractiveness to different pollinating insect groups, with varying results. Still, this variation may be indicative of more complex matters, with pollinator preferences influenced not only by plant species characteristics but environmental, spatial, and temporal fluctuation as well (Ebeling et al., 2008; Rader et al., 2012; Williams et al., 2010). Native plant species are typically defined as those that grew naturally within a region before European contact, not as a result of direct or indirect human influence (National Park Service, 2001). A higher quantity and diversity of native plants have been found to support a more prolific abundance and diversity of pollinator types (Pardee and Philpott, 2014; Pawelek et al., 2009). When planted in areas best suited for them, native plants can also exhibit higher drought tolerance, allow for reductions in fertilizer requirements, increase biodiversity, and serve as refuge and nutrient sources for pollinators and other wildlife (Alvarez et al., 2007; Ikin et al., 2013).

Given the complex nature of these results and plant–pollinator interactions, there is a need to evaluate proclaimed pollinator-friendly plants and their attractiveness to a wide variety of pollinating insects of different geographical regions (Corbet et al., 2001; Venturini et al., 2017). Inclusion of floral surveys can further reveal frequency of pollinator visitation and preference for a floral resource, as well as the comparative abundance of that resource (Kells et al., 2001; LeBuhn et al., 2003). Specifically, the objectives of this study were to assess the floral abundance, phenology, and display area among 10 ornamental plant species at two sites in Florida, and furthermore, to monitor pollinator visitation to determine influence by season, plant species, and native or nonnative origin.

Materials and Methods

Plant materials

Ten ornamental plant species were selected for use in this study based on the following criteria: their stature as commonly advertised pollinator-friendly plants (via nurseries, commercial retailers, and pollinator websites), their popularity for landscape-use based on generated annual revenue [USDA National Agricultural Statistic Service (NASS, 2018)], and their tendency to flower most prolifically during the summer and early fall months of this study. Represented species display a range of flower types, colors, and growth habits (Table 1, Fig. 1). Native species included blanket flower (*Gaillardia pulchella* Foug.), lanceleaf coreopsis (*Coreopsis lanceolata* L.), pineland lantana (*Lantana depressa* Small var. *depressa*), and scarlet sage (*Salvia coccinea* Buc'hoz ex Etl.). Nonnative species included Barbican yellow-red ring blanket flower (*G. aristata* 'Gaiz005'), Bloomify rose lantana (*L. camara* 'UF-1011-2'), mysty salvia (*S. longispicata* × *farinacea* 'Balsalmysty'), Lucky star dark red pentas (*Pentas lanceolata* 'PAS1231189'), ruby glow pentas (*P. lanceolata* 'Ruby glow'), and Uptick gold and bronze coreopsis (*Coreopsis* × 'Baluptgonz'). All native species were propagated by seed (Micanopy Wildflowers, Micanopy, FL), with the exception of pineland lantana that was propagated by vegetative stem cuttings at the University of Florida (UF) Gulf Coast Research and Education Center (GREC) in central Florida. Nonnative species were vegetatively propagated by stem cuttings and obtained from Riverview Flower Farm (Riverview, FL). Plants were obtained in 0.95-L pots, except Bloomify rose lantana that was obtained in 3.8-L pots.

Field conditions

Field plots were prepared similarly in two locations. The first site was at the UF Plant Science Research and Education Unit (PSREU) in northcentral Florida (Citra, FL, USDA cold hardiness zone 9a) and the second site was located at the UF North Florida Research and Education Center (NFREC) in north Florida (Quincy, FL, USDA cold hardiness zone 8b). Site preparation began in late March and early April of 2019. Both sites were tilled and the PSREU site was also fumigated. Fumigation at PSREU took place 30 d before planting using an application of Pic-Clor 60 EC (TriEst Ag Group, Inc., Greenville, NC) at 560.4 $kg \cdot ha^{-1}$. A white, low-density polyethylene mulch film (Guardian Agriculture Plastic Corporation, Tampa, FL) was laid over slightly raised beds for each block row at each site. Of note, within 400 m of the northcentral field site, there were ≈20 managed honey bee (*Apis mellifera*) hives and within 480 m of the northern field site there were common eastern bumble bee (*Bombus impatiens*) colonies as part of a watermelon study during the months of May to June.

Each subplot measured 3 m in length and 0.9 m in width, with 0.9 m of spacing between each row. A minimum of two and a maximum of three plants of each respective species were assigned to each split-plot, determined by their predicted size at full maturity. Specifically, larger-sized plants (Bloomify rose lantana, blanket flower, pineland lantana, ruby glow pentas, and scarlet sage) had two plants for each subplot. The ornamentals that are more compact at maturity (Barbican blanket flower, lanceleaf coreopsis, Lucky star pentas, mysty salvia, and Uptick coreopsis) had three plants per subplot. This modification in planting density allowed for a uniform floral display and better relates to how gardeners or land managers may plant according to spacing guidelines (Mallinger et al., 2019; Plascencia and Philpott, 2017). The experimental layout of plants was mirrored for both locations.

Plants were installed similarly on 30 Apr. 2019 at PSREU and on 1 May 2019 at NFREC. Following installation, plants were initially drip-irrigated for 2 h, four times per day until a point of establishment was reached (≈7 weeks). Once established, plants were drip-irrigated for 2 h, twice per day. Each plant received 28.4 g of 15N–3.9P–10K of 8–9-month controlled-release fertilizer (Osmocote Plus; Scotts, Maryville, OH) upon planting. For the first 3 months, plants at PSREU were supplementally fertigated weekly at 6N–0P–7.5K at 187.1 $L \cdot ha^{-1}$, then biweekly for the remainder of the study. Lastly, grass areas between block rows were mowed weekly, as needed, to reduce weeds and any potential pollinator interference.

Soil samples were collected from each row at both sites, mixed for uniformity, and air dried for standard analysis (UF Extension Soil Testing Laboratory, Gainesville, FL). Initial potassium (K), phosphorous (P), magnesium (Mg), and calcium (Ca) of soils based on Mehlich-3 extraction indicated sufficient nutrient ranges, with the exception that K was low at both field sites, and P was low in northern Florida. Maximum and minimum daily temperature at 2 m, total rainfall, and relative humidity were recorded on site by the Florida Automated Weather Network (FAWN, https://fawn.ifas.ufl.edu). Field conditions for northcentral Florida were as follows: 1.09% organic matter, pH 5.65, EC 0.10 mS/cm, average monthly rainfall 12.7 cm, mean minimum and maximum temperatures 18.1 and 35.2 °C, respectively, and 82% relative humidity. Field conditions for north Florida were as follows: 2.07% organic matter, pH 5.35, and EC 0.07 mS/cm, average monthly rainfall 13.7 cm, mean minimum and maximum temperatures 15.5 and 36.0 °C, respectively, and 81.0% relative humidity.

Floral abundance survey

Floral abundance of each species plot was quantified and recorded every other week at both sites. Capitulate inflorescences of Barbican blanket flower, blanket flower, lanceleaf coreopsis, and Uptick coreopsis were notated as a single flower. For species with spike (scarlet sage and mysty salvia), corymb (Lucky star pentas), and umbel (pineland and Bloomify rose lantana) inflorescence forms, the number of individual florets was standardized by multiplying the number of inflorescences in the species plot by the average number of florets on five representative inflorescences, as described by Rowe et al. (2020).

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Table 1. Ornamental plant characteristics and sources for all 10 species evaluated in this study. Plant species notated as native to the United States are those indicated by Wunderlin et al. (2021) and the International Plant Nomenclature Index (IPNI, 2021). Cold hardiness zones indicated based on USDA Cold Hardiness map (USDA, 2012).

Scientific name	Common name	Description	Native to U.S.
Coreopsis lanceolata L.	Lanceleaf coreopsis, Lanceleaf tickseed	Native to eastern and central United States, including Florida. Composite inflorescence of yellow disk flowers surrounded by yellow ray flowers. Green foliage and a branching, spreading growth habit. U.S. cold hardiness zone 3–8.	Yes
C. × ‘Baluptgonz’	UpTick™ gold and bronze coreopsis, Uptick coreopsis	‘Baluptgonz’ is a product of a plant breeding program introduced in 2016 by Ball Horticultural Company (Winner, 2018). Composite inflorescence of yellow disk flowers surrounded by yellow ray flowers with an orange-red colored eye zone. Green foliage and an upright-mounded growth habit. U.S. cold hardiness zone 4–9.	No
Gaillardia pulchella Foug.	Blanket flower	Native to northern Mexico, and the southern and central United States (Weakley et al., 2020). Composite inflorescence of yellow to dark red disk flowers surrounded by ray flowers that transition from a dark red center to yellow tips. Green foliage and a spreading growth habit. U.S. cold hardiness zone 3–11.	Yes
G. aristata ‘Gaid005’	Barbican™ Yellow-Red Ring blanket flower, Barbican blanket flower	‘GAIZ005’ is a product of a plant breeding program from an open pollination occurring in 2007, Enkhuizen, the Netherlands (Stemkens, 2017), released by Syngenta, Co. Composite inflorescence of yellow to dark brown disk flowers surrounded by ray flowers that transition from a dark red center to yellow tips. Green foliage and an upright-mounded growth habit. U.S. cold hardiness zone 4–9.	No
Lantana camara ‘UF-1011–2’	Bloomify™ Rose lantana	UF-1011-2 is a product of a planned breeding program at the University of Florida (Deng et al., 2017), released by BallFloraPlant. Umbel inflorescence of yellow, orange, and pink florets, green foliage, and a mounding growth habit. U.S. cold hardiness zone 8b–11.	No
L. depressa Small var. *depressa*	Pineland lantana, Gold lantana	Umbel inflorescence of yellow florets, green foliage, and spreading growth habit. U.S. cold hardiness zone 8a–11.	Yes
Pentas lanceolata ‘PAS1231189’	Lucky Star® dark red pentas	Corymb inflorescence of dark red florets, green foliage, and an upright growth habit. A PanAmerican Seed F1 hybrid introduction bred to be one of the fastest follow up bloomers on the market. U.S. cold hardiness zone 9b-11.	No
P. lanceolata ‘Ruby Glow’	Ruby glow pentas	Corymb inflorescence of dark red florets. Green foliage. Upright growth habit. Older variety reported to be richer in nectar than newer FI hybrids, sometimes called heirloom pentas. U.S. cold hardiness zone 9–11.	No

(*Continued on next page*)

Table 1. (*Continued*)

Scientific name	Common name	Description	Native to U.S.
Salvia coccinea Buc'hoz ex Etl.	Scarlet sage, Tropical sage	Native to central and south American, Mexico, and the southeastern United States, including Florida. Spike inflorescence of red and pink florets, green foliage, and an upright growth habit. U.S. cold hardiness zone 7–11.	Yes
S. longispicata × *farinacea* 'Balsalmysty'	Mysty salvia	'Balsalmysty' is a product of a controlled breeding program in Guadalupe, CA in 2012 as a result of a self-pollination of Mystic Spires Blue Improved 'Balsalmispim' (Trees, 2017). Introduced by Ball FloraPlant in 2018 for its compact growth habit and darker flower color. Spike inflorescence of blue florets, green foliage, with an upright-mounding growth habit. U.S. cold hardiness zone 7–10.	No

Floral display area

In addition to floral abundance for each whole plant replicate, the floral area of 10 representative flowers per species was calculated to better consider the total floral area serving as a visual cue for pollinators. For circular/non-labiate flowers (blanket flower, coreopsis, lantana, and pentas), flower area was measured as the area of the circle ($A = \pi r^2$) as described by Garbuzov and Ratnieks (2015b). For the bilabiate flowers of scarlet sage and mysty salvia, the diameter between two opposite petals of the lower lip area and the length of the corolla tube were multiplied to calculate the floral area, as described by Benitez-Veiryra et al. (2014). Total floral display area for each species was then reported as the mean flower area multiplied by the total flower number per sampling day as described by Rowe et al. (2020). Floral display areas among species were then grouped and presented by season (early, mid, and late) for each site. Early season was considered May to June, midseason July to August, and late season September to October of 2019.

Visual pollinator survey

Visual insect surveys were conducted at each site every 2 weeks, directly following floral abundance surveys. Surveys were performed only on days with permissible weather and favorable temperatures above 13 °C, adequate sunlight, no rainfall, and calm wind conditions. Observations were made within a 2-h time frame of 9:00 and 11:00 AM, when many pollinator communities are active (Buckley, 2011; Erickson et al., 2020; Potts et al., 2003). Thirteen surveys were made for both sites beginning 6 May and ending 28 Oct. 2019, totaling 26 surveys. Each subplot (replicate) was observed for a period of 5 min (Rowe et al., 2020) and foraging insect pollinators were recorded into the following distinct morpho-categories: honey bees, large-bodied bees (bumble and carpenter bees), other bees (primarily solitary, small to medium-bodied native bees), butterflies/moths, and wasps. A visit was defined as any insect that landed on an open flower and fed for a period of one second or more. Every visit to a single flower was recorded, including repeat visits by a single individual (i.e., an insect feeding, taking flight, then feeding again either on the same flower or a separate flower).

Experimental design and statistical analysis

A 5 × 5 Latin square design with a split-plot restriction was implemented at both field sites, where genus was assigned to whole plots. Within each whole plot, one subplot consisted of a native species and the other subplot a nonnative species (apart from pentas, as both species are nonnative). This design was chosen to account for variation in both directions by foraging pollinators that may be influenced by the vegetation surrounding the field plots. Ruby glow pentas

Fig. 1. Illustration of the four native (N) and six nonnative ornamental plants selected for this study. Photos courtesy of Heather Kalaman and Nicole Hazlett.

was removed from the analyses due to initially poor establishment. Response data were analyzed across locations using generalized linear mixed model procedures as implemented in SAS PROC GLIMMIX (SAS/STAT 15.1; SAS Institute, Cary, NC). Floral display area was analyzed using a normal distribution function. All insect count data were analyzed using a negative binomial distribution rather than a Poisson because of overdispersion issues indicated by the ratio χ 2/DF greatly exceeding unity. Location, species, season, and all their two- and three-way interactions were considered fixed effects. Random effects were based on the underlying Latin square design with a total of five replicates per location and species. To account for two or three plants per subplot, a three-way location × season × species interaction mean estimate was based on 10 or 15 plants.

The assumptions for linear models with respect to residuals were evaluated graphically by inspecting the residual plots as suggested by Kozak and Piepho (2018). Sampling each experimental unit repeatedly over seasons of the experiment required R-side modeling. The unstructured (UN) model was the best fit based on the AICc criterion (small sample corrected Akaike Information Criterion). Least squares interaction means were calculated using the "bottoms up approach," i.e., the highest order significant interaction determined the least squares means to be calculated. Species were compared within location × season or location and/or season using the SLICEDIFF option of the LSMEANS statement in the above-mentioned procedure means without correction for multiple comparisons as suggested by Milliken and Johnson (2009) and Saville (2015). The same analyses were run, replacing plant species with native status, to assess whether native origin affected pollinator visitations as a whole.

Results

Floral abundance

Assessed strictly on a flower count basis, regardless of native origin or site location, lantana typically had the greatest floral abundance, followed by pentas, salvia, coreopsis, and blanket flower, respectively (Table 2). In general, nonnative ornamental species produced nearly twice as many flowers than native plants for the 6-month study, although this did vary among genera. To illustrate, the nonnative Uptick coreopsis produced 1.7 times more flowers overall than the native lanceleaf coreopsis, whereas the nonnative Bloomify rose lantana produced 2.1 times more flowers than the native pineland lantana. However, both the native blanket flower and scarlet sage produced similar total flower counts as compared with the nonnative Barbican blanket flower and mysty salvia.

Floral abundance greatly differed by season. Average flower count among all species at both sites was 254.89 in early season (May–June), 974.50 in midseason (July–August), and 769.90 in late season (September–-October) (Table 2). In the early season, flowering of nonnative coreopsis, blanket flower, lantana, and salvia was 1.7 to 2.0 times more abundant than respective natives. In the midseason, flowering of nonnative coreopsis, blanket flower, lantana, and salvia was 1.1 to 2.0 times more abundant than respective native forms. In the late season, flowering of nonnative coreopsis and lantana and were 1.2 to 2.4 times more abundant than respective native forms, whereas the native blanket flower and salvia species had 1.0 to 1.8 times greater floral abundance than the nonnative forms (Table 2).

Floral area coverage

The floral display area of plants was significantly influenced by location, season, and species, revealing a three-way interaction ($P = 0.0230$) between location, species, and season. Thus, data for floral display area of all nine ornamental species are presented as the sliced interaction means for each of three seasons and two locations (Fig. 2).

In the early season (May–June), floral display area was relatively similar among native and nonnative plants, with a few exceptions. For example, in northcentral Florida, the floral display area of the nonnative Uptick coreopsis was 5.5 times larger than the native lanceleaf coreopsis, 3.4 times larger than the nonnative Bloomify rose lantana, and 5.0 times larger the native pineland lantana (Fig. 2). In north Florida, the floral display area of Uptick coreopsis was only larger than pineland lantana, with similar display areas exhibited among all other native and nonnative plants.

The midseason (July–August) of the study marked peak flowering times for species planted at both locations (Fig. 2). In northcentral Florida, scarlet sage exhibited the largest floral display area followed by Uptick coreopsis and Bloomify rose lantana. In north Florida, the native lanceleaf coreopsis exhibited the largest floral display area followed by Bloomify rose lantana, Uptick coreopsis, and Lucky star pentas. When comparing nonnative and native floral display areas of the same genera at both sites, nonnative Bloomify rose lantana had 2.3–2.6 times larger floral display than the native pineland lantana, yet the native scarlet sage had a 1.3–2.2 times larger floral display area compared with the nonnative mysty salvia.

In the late season (September–October), flowering began to decline at both locations, but more distinctly in north Florida (Fig. 2). Bloomify rose lantana and scarlet sage grown in northcentral Florida had the largest floral display areas that were similar to each other but significantly greater (1.8 to 8.4 times larger) than other species (Fig. 2). Similarly, in north Florida, Bloomify rose lantana and scarlet sage also had the largest floral display areas, significantly greater than some, but not all, other species including blanket flower and pineland lantana (Fig. 2).

Pollinator visitations

Nearly 22,000 insect counts were made across all nine ornamental species evaluated (Table 3). The majority were of bee visits (74.6%) and of these, over half (55.2%, 11,938) were of "other bees" (native, small to

Table 2. Floral abundance of all nine ornamental species evaluated at two sites (NF = north Florida, NCF = northcentral Florida). Total flower counts (n = 65) represent the entire 6 months study at each site. Means per sampling day are presented ± SE for the study and for each season early (May–June), mid (July–August), and late (September–October).

Plant name	Site	Native to United States	Total flower count	Avg flower count	Avg early season	Avg midseason	Avg late season
Lanceleaf coreopsis	NCF	Yes	3,650	56.15 ± 7.08	25.35	95.36	37.95
Lanceleaf coreopsis	NF	Yes	1,851	28.92 ± 4.13	36.45	44.00	10.08
Uptick coreopsis	NCF	No	6,583	101.28 ± 12.22	67.15	175.20	43.00
Uptick coreopsis	NF	No	2,518	39.34 ± 5.67	54.35	54.80	13.96
Blanket flower	NCF	Yes	4,874	74.98 ± 8.52	31.65	126.56	53.85
Blanket flower	NF	Yes	1,536	24.00 ± 3.00	25.70	31.15	43.90
Barbican blanket flower	NCF	No	5,186	79.78 ± 8.75	61.80	127.12	38.60
Barbican blanket flower	NF	No	1,630	25.47 ± 3.83	34.65	44.20	2.21
Pineland lantana	NCF	Yes	132,585	2,039.77 ± 236.14	609.90	3,080.60	2,168.60
Pineland lantana	NF	Yes	60,698	948.41 ± 181.57	393.75	1,300.60	1,117.13
Bloomify rose lantana	NCF	No	280,418	4,314.12 ± 481.66	754.85	5,995.92	5,771.15
Bloomify rose lantana	NF	No	119,107	1,861.05 ± 313.63	578.65	2,837.20	2,116.25
Lucky star pentas	NCF	No	40,937	629.80 ± 65.55	446.35	756.08	655.40
Lucky star pentas	NF	No	27,379	427.80 ± 65.83	477.70	659.20	193.38
Scarlet sage	NCF	Yes	40,284	619.75 ± 70.33	262.70	918.12	603.85
Scarlet sage	NF	Yes	9,238	144.34 ± 12.42	89.75	148.05	186.75
Mysty salvia	NCF	No	45,093	693.74 ± 96.59	344.65	893.44	793.20
Mysty salvia	NF	No	11,134	173.97 ± 26.72	292.55	253.45	8.92

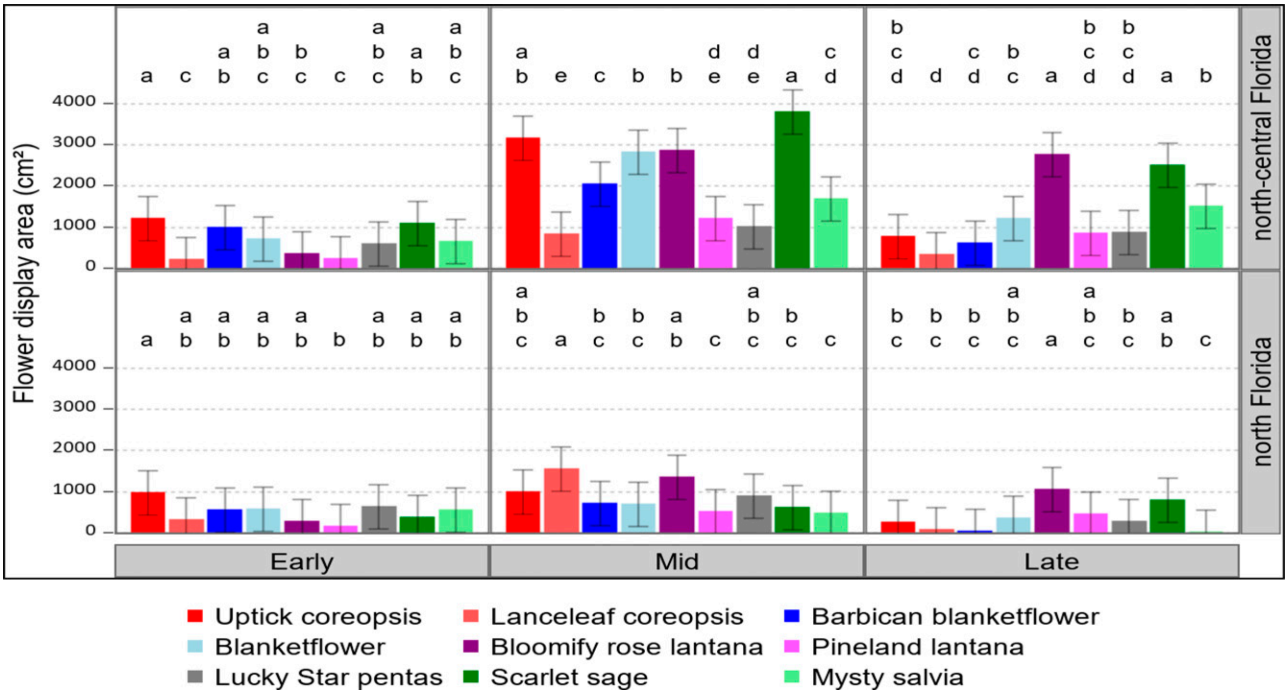

Fig. 2. Average floral display area (flower area multiplied by flower number) for each of the nine ornamental species evaluated in early (May–June), mid (July–August), and late (September–October) seasons at two sites (north Florida and northcentral Florida). Means ± 95% confidence limits are presented. Within each season at each site, means with similar letters are not significantly different at $P \leq 0.05$.

medium-bodied bees), followed by butterflies and moths (15.4%, 3328), large-bodied native bees (i.e., carpenter and bumble bees) (11.8%, 2555), wasps (10.0%, 2152), and honey bees (7.6%, 1635).

Plant provenance (native or nonnative plant status) had no significant effect on overall pollinator visitation rates. Rather, pollinator taxa displayed varying preferences for native and nonnative ornamental species across the three seasons of the study at both sites. For both honey bees and large-bodied bees, such as bumble and carpenter bees, no significant differences emerged from effects of location, plant species, or season. However, results indicated significant interactions for other bees, butterflies/moths, and wasps.

Other bees. The frequency of visitation by other bees revealed a two-way interaction (P = 0.0015) between season and species. There was no effect of location, thus, data are combined and presented from both locations (Fig. 3). Regardless of plant provenance status, "other bees" visited species with composite flowers significantly more often than noncomposite flowers in the early season, as shown by visitations per square meter of floral area. During early season, "other bees" also visited the nonnative Bloomify rose lantana significantly more than the native pineland lantana. Visitations were similar among both species of salvia, with the lowest visitations to pineland lantana and Lucky star pentas. In the midseason, visitations per square meter of flowers by "other bees" were still similar among all composite flower species, and the lowest visitations were observed for both species of lantana. In the late season of the study, visitations by "other bees" decreased overall. Still, the composite native blanket flower had more visitations by "other bees" than any other ornamental species, apart from the native scarlet sage, which was statistically similar (Fig. 3).

Butterflies/moths. The frequency of visitation per square meter of flowers by butterflies and moths was dependent on plant species (P < 0.0001), with no significant interaction effects or effects of season and location. Thus, data were combined for all seasons and both locations and presented for each of the nine ornamental species (Fig. 4). Results showed that butterflies and moths visited both the native and nonnative lantana 7.34–9.62 times more per square meter of floral display than all other ornamentals (Fig. 4).

Wasps. The frequency of visitation by wasps revealed a three-way interaction between location, species, and season (P = 0.0043). Thus, data are presented sliced for each of the nine ornamental species, at two sites, and across three seasons (Fig. 5). In the early season at

Table 3. Average number of recorded pollinator visitations per 5-min observation period on plots with open flowers for the 6-months study across two field sites (Citra, FL, USDA cold hardiness zone 9a and Quincy, FL, USDA cold hardiness zone 8b). Insect counts were recorded on five individual species plots per ornamental species and per site, and means were averaged among plots, 26 sampling dates and two sampling sites and presented ± SE. A visit was defined as any insect that landed on an open flower and fed for a period of one second or more.

Plant name	Honey bees	Large-bodied bees[z]	Other bees[y]	Butterflies/moths	Wasps
Uptick coreopsis	0.21 ± 0.12	0.39 ± 0.51	23.47 ± 3.32	0.33 ± 0.10	1.50 ± 0.40
Lanceleaf coreopsis	0.00 ± 0.00	0.33 ± 0.24	13.64 ± 1.86	0.40 ± 0.13	0.65 ± 0.16
Barbican blanket flower	1.18 ± 0.46	0.97 ± 0.64	25.26 ± 3.41	1.16 ± 0.35	0.77 ± 0.35
Blanket flower	0.03 ± 0.03	0.25 ± 0.13	24.86 ± 3.80	1.60 ± 0.92	1.03 ± 0.26
Bloomify rose lantana	3.18 ± 0.98	0.29 ± 0.30	1.13 ± 0.27	13.74 ± 2.31	0.54 ± 0.13
Pineland lantana	0.55 ± 0.21	0.00 ± 0.00	0.45 ± 0.12	5.45 ± 1.08	0.41 ± 0.18
Lucky star pentas	0.02 ± 0.02	0.01 ± 0.01	1.81 ± 0.60	0.53 ± 0.37	9.56 ± 1.56
Scarlet sage	2.44 ± 0.79	4.30 ± 1.41	7.83 ± 1.28	1.28 ± 0.53	1.82 ± 0.54
Mysty salvia	6.44 ± 1.56	4.44 ± 1.32	10.21 ± 1.78	3.07 ± 0.78	1.82 ± 0.56

[z]Large-bodied bees included bumble and carpenter bee species.

[y]Other bees included small to medium-bodied, primarily solitary, native bee species.

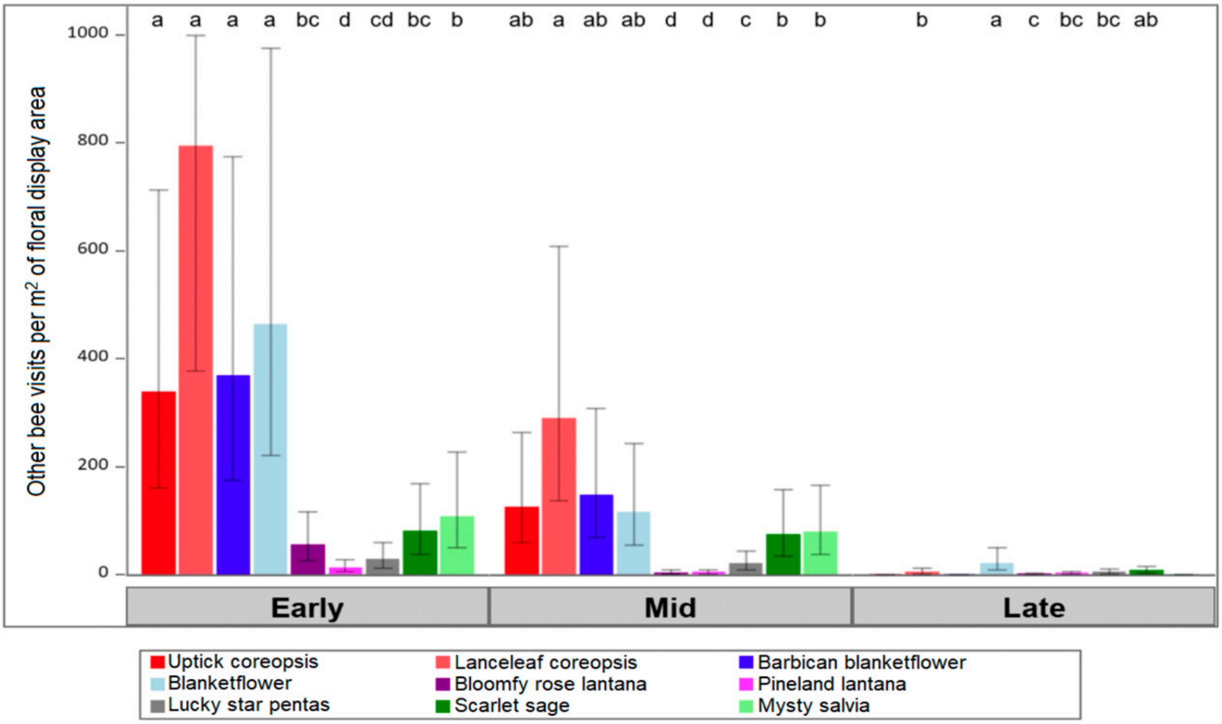

Fig. 3. Total visitations per square meter of floral display area for the insect group "other bees" (small to medium-bodied, native bees) evaluated in early, mid, and late seasons, across both sites. Early season was May to June, midseason was July to August, and late season was September to October. Means ± 95% confidence limits are presented. Within each season at each site, means with similar letters are not significantly different at $P \leq 0.05$.

northcentral Florida, wasps visited Lucky star pentas significantly more than any other ornamental species (Fig. 5). In north Florida, visitations by wasp pollinators to Lucky star pentas, pineland lantana, and Bloomify rose lantana were greater than visits to all other ornamentals. In the midseason at northcentral Florida, wasps visited Lucky star pentas more than all other ornamentals with the exception of lanceleaf coreopsis. In north Florida, visitations by wasp pollinators during the midseason were greatest for Lucky star pentas, scarlet sage, and mysty salvia. Wasp visitation waned in the late season at both northcentral Florida and north Florida sites, with the exception of Lucky star pentas (northcentral and north Florida) and Barbican blanket flower (northcentral Florida only).

Honey bees. Honey bees were the least abundant of the five pollinating morpho-groups and there were no statistically significant effects or interactions among plant species, location, or season for visitations per square meter of flowers. Still, honey bees were observed visiting

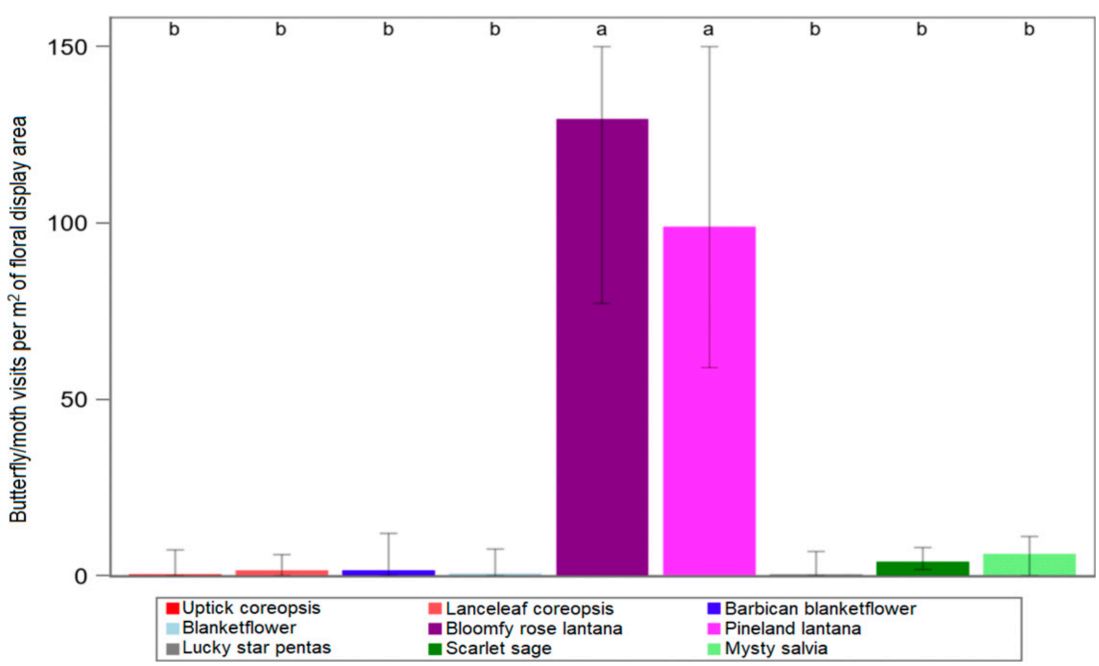

Fig. 4. Total visitations per square meter of floral display area for butterflies and moths evaluated at both sites for the entire 6-month study. Data collection took place from May through Oct. 2019. Means ± 95% confidence limits are presented. Means with similar letters are not significantly different at $P \leq 0.05$.

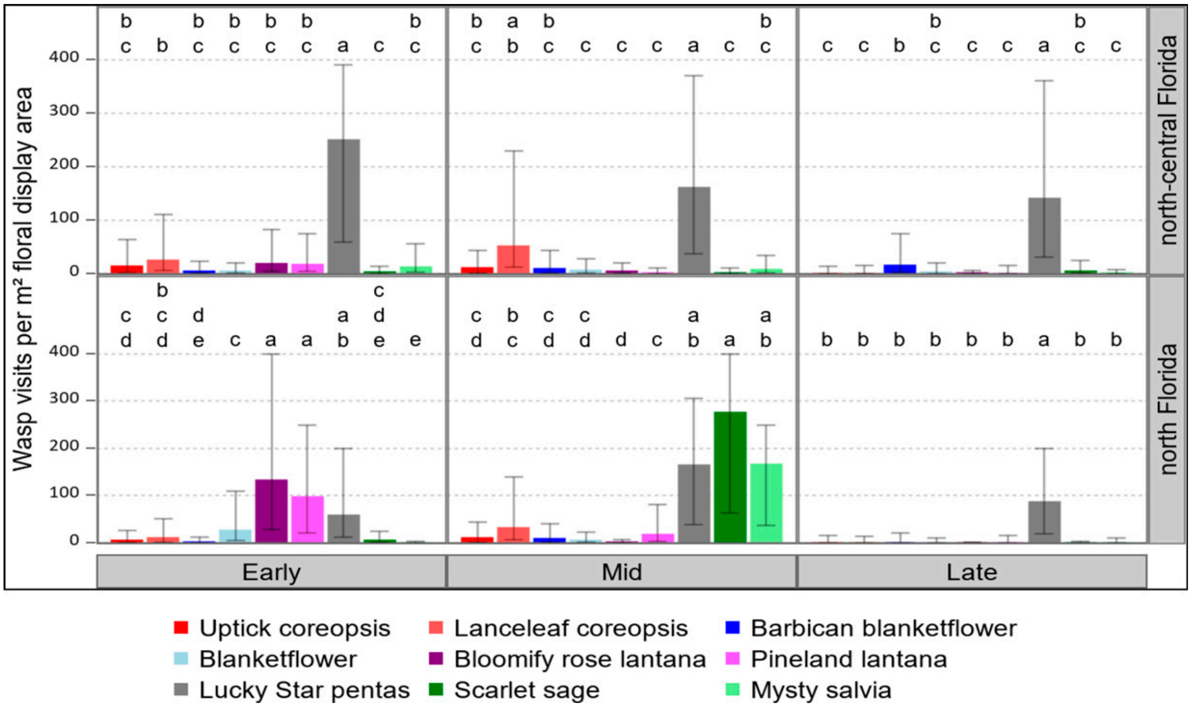

Fig. 5. Total visitations per square meter of floral display area for wasp pollinators evaluated in early, mid, and late seasons, at two sites, northcentral (top) and north (bottom), Florida. Early season was May to June, midseason was July to August, and late season was September to October. Means ± 95% confidence limits are presented. Within each season at each site, means with similar letters are not significantly different at $P \leq 0.05$.

nonnative species more frequently than native species in the same genus (Table 3).

Large-bodied bees. Large-bodied bees showed no statistically significant effects or interactions among plant species, location, or season for visitations per square meter of flowers, and with no significant differences between native and nonnative species (Table 3).

Discussion

To our knowledge, this study is the first in the southeastern United States to empirically compare the relative attraction of different pollinating insects to native and nonnative ornamentals, commonly advertised as pollinator-friendly, in controlled garden plots. Results of this survey showed that the nine ornamentals selected for this trial were in fact attractive to different pollinator types and served as floral resources. Interestingly, few significant differences were observed between native and nonnative ornamental species in their ability to attract different pollinator groups across this 6-month study. Rather, the composition of pollinator groups attracted to these ornamentals was more dependent upon season and variation in floral phenology, morphology, and area coverage.

Consideration of the floral area coverage allows for a better understanding of each species' value to pollinators, and it is widely recognized as one of the most distinct indicators of attractiveness in terms of both abundance and diversity of foraging insect groups (Grindeland et al., 2005; Rowe et al., 2020). The observed floral area coverage of both blanket flower and coreopsis was relatively high during the months of May through August. Consequently, these plants were highly attractive to 'other bees' (small to medium-bodied native bees) during that time, significantly more than non-composite ornamentals. Radially symmetric, solitary-type flowers exhibited by Asteraceae species are commonly foraged upon by native bees in North America (Dlusskii et al., 2004; Dow, 2019; Strange et al., 2020). The corolla lengths present in these flowers may be more conducive to visitation by bees with shorter proboscis (Dikmen et al., 2018; Hicks et al., 2016). This largely applies to the small to medium-bodied native bee group found visiting blanket flower and coreopsis. While previous studies have drawn similar conclusions of these native wildflowers as bee-friendly resources (Frankie et al., 2009; Pascarella, 2008), our study went a step further. Namely, the selected cultivars of blanket flower and coreopsis were equally attractive, with no significant differences between native and nonnative species. Of interest to note, the native origin of blanket flower in Florida was recently reclassified, as historical accounts now suggest that its occurrence east of Texas is adventive, rather than native (Weakley et al., 2020). As we observed no significant differences in native bee pollinator visitations between blanket flower and the cultivated Barbican blanket flower, this may be consistent with its currently confirmed nonnative status to the southeastern region. Still, blanket flower proved highly attractive to several generalist native bees and nonnative honey bees. Therefore, we recommend it be incorporated into residential and commercial landscapes, which may already be insufficient in plant diversity and nutrient resources.

Both salvia types displayed relatively high floral area coverage among all ornamentals across the three seasons in northcentral and north Florida. While some modern, compact cultivars have proven less attractive to pollinators than their native forms due to the production of smaller, less abundant flowers (Ricker et al., 2019), we did not observe this for mysty salvia. Bred to be a smaller, more compact variety than its two genetic predecessors, indigo spires sage (*S. longispicata ×farinacea* 'Indigo Spires') and mystic spires sage (*S. longispicata ×farinacea* 'Balsalmisp'), mysty saliva flowered abundantly throughout the study in greater or equal numbers as the native scarlet sage and attracted a variety of both hymenopteran and lepidopteran pollinators. Salvias are commonly advertised as highly attractive ornamentals for nonnative honey bees (*A. mellifera*), as well as native large-bodied bees such as bumble (*B.* sp.) and carpenter bees (*Xylocopa* sp.) (Celep et al., 2014; Giuliani et al., 2018; Pascarella, 2008). Indeed, we found that both honey bees and large-bodied native bees (e.g., bumble bees) visited salvia species plots across the study duration at both sites, with no significant preferences observed between the red native and blue-purple nonnative salvia. Further, when gardening to attract pollinators in an urban landscape, it may not always be possible to incorporate ornamentals that are more expansive in size at maturity. For containerized or small-scale garden areas, our results suggest that the more compact modern cultivar, mysty salvia, may serve as an attractive ornamental for some pollinating insects.

Lantana is frequently cited as a profoundly attractive ornamental plant for butterflies (Anderson and Dobson, 2003; Schemske, 1976; Wied, 2020). This is consistent with our finding that regardless of provenance or cultivated origin, lantana was significantly more attractive to butterflies and moths across all seasons than other ornamental species evaluated. Lepidopteran are known to have preferential foraging patterns based on criteria including floral abundance and area coverage (Bruner, 2005), color (Culin, 1997; Weiss, 1991), and nectar quantity and quality (Rusterholz and Erhardt, 1997). Yellow flowers in particular, as seen in the native pineland lantana, are thought to be favorable visual indicators to some lepidopteran insects (Bruner, 2005; Mohan Ram and Mathur, 1984; Weiss, 1991). Still, while considering the total floral area coverage of both lantana species, no significant differences in visitations were observed between the entirely yellow flowers of the native species and the mixed yellow, orange, and pink flowers of the nonnative lantana species. Other pollinators, including honey bees, wasps, and small to medium-bodied native bees, visited lantana but did not show a preference for it. While previous studies have indicated that wild-type lantana can serve as an important pollinator resource (Deyrup et al., 2002; Sheeja and Jobiraj, 2017), it is a currently listed as a Category I invasive plant for south and central Florida (Florida Exotic Pest Plant Council, 2019). As such, it is not recommended for use in residential or commercial landscapes. However, sterile cultivated lantana can be planted with less risk of invasion, but whether its ecosystem service value in terms of pollinator resource and attraction has been largely unknown. Herein, we found that breeding male and female sterility into non-invasive cultivars of lantana, such as Bloomify rose lantana (Deng et al., 2017), did not appear to negatively influence recorded pollinator visitations. In fact, we observed increased lepidopteran visitations to the nonnative Bloomify rose lantana as compared with the native pineland lantana.

Pentas are one of the three most endorsed ornamental plants for butterfly gardens in the southeastern United States (Garber, 2020). An herbaceous perennial, pentas produce flowers throughout the spring, summer, and fall months (notably in USDA cold hardiness zones 9–11) and are exceptionally drought and heat tolerant (Bruner et al., 2002; Gilman and Shiffit, 1999). Pentas breeding efforts have resulted in an array of floret shapes, sizes, and colors, yet pollinator preference for these newer hybrid forms has been largely understudied. Our findings did not show the modern cultivar Lucky star pentas to be attractive to lepidopteran pollinators. Results from previous studies likewise showed that visitations by lepidopteran pollinators to the red inflorescences of other modern cultivars of pentas were relatively low across all seasons, despite a high production of flowers (Bruner, 2005). Rather, we found Lucky star pentas to be the most attractive ornamental to foraging wasps throughout the study. There is little mention or marketed promotion of ornamental plants for wasps, despite these insects serving as important pollinators for a wide range of flowering plant species (Rader et al., 2016; Wiemer et al., 2011). Many wasp species additionally perform a critical role as biocontrol agents on a variety of garden pests, highlighting the importance of considering other facets of ecosystem services while interpreting the value of ornamental plants (Cox and Pinniger, 2007; Goldsmith and Henshaw, 2011; Kimber et al., 2010; Rebek et al., 2005).

The availability of other floral resources may have influenced visitation patterns, as the study plots were adjacent to agronomic, ornamental, and peripheral natural areas. The attractiveness and relative value of the plants evaluated in this study may differ slightly based on the species composition of urban landscapes, such as managed residential and commercial areas. Further, care should be taken when making similar statements about other modern plant types. The cultivars selected were based on suggestion and promotion by local growers and retailers, who in some cases have observed their pronounced attraction to pollinators firsthand. Thus, these observations may have inflated their relative attractiveness to pollinators compared with other cultivars or species of ornamentals currently available on the market.

Priority should be given to optimizing plant species richness in a garden, incorporating a wide range of bloom periods that provide improved nectar and pollen availability across several seasons (Ebeling et al., 2008; Venjacob et al., 2016). The influence of season and location on floral resource availability and subsequent pollinator visitation patterns have been demonstrated and should be considered for future studies. Moreover, while some nonnative ornamentals may aid in buffering nutrient gaps across human-dominated landscapes, they have been found to be largely attractive to primarily generalist pollinators (Urbanowicz et al., 2020). Specialized pollinator types have coevolved alongside native plants species for millions of years and are thus less able to take advantage of nonnative ornamentals in the landscape (Frankie et al., 2019; Seitz et al., 2020). Providing floral resources for these specialists in the form of more wild-type, native plants is important, along with a mixture of native and nonnative plants for generalists. Furthermore, nonnative plants in landscapes may impair native flora and fauna more broadly through multitrophic interactions with arthropod and wildlife communities, such as bottom-up reductions in larval host plants for developing pollinators and overall declines in the pollination and reproductive success of native species (Burghardt et al., 2010; Morales and Traveset, 2009). It is therefore suggested that nonnative ornamentals, which are proven pollinator-friendly, be incorporated into gardens as an accompaniment to native plant types.

In summary, nominal significant differences were seen between native and nonnative species in their ability to attract different morpho-groups of generalist pollinators. Still, there are factors not explored within the contents of this study that may have influenced pollinator visitation patterns across plant genera and species, such as floral resource-value. To further our understanding of the existing nutrient rewards these plants provide, nectar volume, pollen quantity, pollen viability, and protein content of these same 10 ornamental species were evaluated in a subsequent study.

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