Summary of 26 Heavenly Bamboo Selections Evaluated for Invasive Potential in Florida

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Summary. Over the course of nearly 2 decades, the resident or wild-type form of heavenly bamboo (*Nandina domestica*) and 25 additional selections have been evaluated for landscape performance and invasive potential in various trial locations in Florida. Overall, in northern Florida (Quincy and Citra), 'Royal Princess', 'Umpqua Chief', 'Gulf Stream', 'Monfar' (Sienna Sunrise®), 'Emerald Sea', 'Greray' (Sunray®), 'Lemon-Lime', 'Murasaki' (Flirt™), 'SEIKA' (Obsession™), and 'Twilight' performed well throughout much of the study with average ratings between 3.0 and 4.9 (1 to 5 scale). In southern Florida (Balm and Fort Pierce), 'AKA' (Blush Pink™), 'Compacta', 'Emerald Sea', 'Firestorm'™, 'Greray', 'Gulf Stream', 'Harbour Dwarf', 'Jaytee' (Harbor Belle™), 'Lemon-Lime', 'Monum' (Plum Passion®), 'Murasaki', and 'SEIKA' performed well with average ratings between 3.0 and 5.0. Among selections evaluated, plant sizes were categorized as small, medium, or large, where the final plant height ranged from 20 to 129 cm, and the plant perpendicular width ranged from 15 to 100 cm. Almost three-fourths of the selections evaluated had little to no fruiting when compared with the wild-type form. 'AKA', 'Chime', 'Filamentosa', 'Firehouse', 'Firepower', 'Firestorm', 'Greray', 'Lemon- Lime', 'Moon Bay', and 'SEIKA' did not fruit at any of the trial sites. In northern Florida, small amounts of fruit (94% to 99.9% reduction) were observed for 'Gulf Stream', 'Harbour Dwarf', 'Jaytee', 'Monfar', 'Murasaki', 'Royal Princess', 'Twilight', and the twisted leaf selection. Moderate amounts of fruit (62% to 83% reduction) were observed for 'Alba', 'Emerald Sea', 'Lowboy', 'Moyer's Red', and 'Umpqua Chief'. Heavy fruiting comparable or greater than the wild type was observed for 'Compacta' and 'Monum'. Pregermination seed viability ranged from 67% to 100% among fruiting selections with 5.5% to 32.0% germination in 60 days. Germination was considerably higher (58% to 82%) when the germination time was extended to 168 days. Nuclear DNA content of selections were comparable to the wild type suggesting they are diploid. Thus, ploidy level does not appear to be associated with female infertility of those little-fruiting heavenly bamboo selections. Overall, our findings revealed certain selections of heavenly bamboo that have little potential to present an ecological threat and thus merit consideration for production and use. As a result, the University of Florida(UF)/Institute of Food and Agricultural Sciences' (IFAS) *Status Assessment on Non-native Plants in Florida's Natural Areas* infraspecific taxon protocol has concluded that 'Firepower' and 'Harbour Dwarf' are noninvasive and can be recommended for production and use in Florida. In addition, due to acceptable plant performance and low to no fruiting capacity, our research supports that 'Firehouse', 'AKA', 'Firestorm', 'Gulfstream', 'Jaytee', 'Monfar', 'Royal Princess', 'Greray', 'Lemon-Lime', 'Murasaki', and 'SEIKA' be considered for future noninvasive status approval.

While the majority of introduced ornamental plants do not escape cultivation, some plants spread into natural areas, develop self-sustaining populations, and subsequently disrupt function and form of natural ecosystems (Pimentel et al., 2005; van Kleunen et al., 2018). Through the U.S. Executive Order 13112, an invasive species is defined as an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health [U.S. Department of Agriculture (USDA), National Invasive Species Information Center, 2021]. This is a global issue with worldwide efforts under way to increase our understanding of invasion biology (Dai et al., 2020; Dehnen-Schmutz et al., 2007; Theoharides and Dukes, 2007), management/control (Kettenring and Adams, 2011; Strgulc Krajšek et al., 2020), and risk/prevention (Bayón and Vilà, 2019; Brusati et al., 2014; Conser et al., 2015).

Alien (exotic non-native) species are thought to comprise as much as 80% of the nursery stock held by U.S. nurseries (Hulme et al., 2018). Traits that might be economically beneficial to a nursery professional, such as disease/pest resistance, uniform germination and plant growth, and high fertility are traits that could also increase invasive potential (Anderson et al., 2006a, 2006b). The probability of plants becoming naturalized increases significantly with the number of years the plants were marketed and their ornamental value (Pemberton and Liu, 2009). Hence, unintentionally but indisputably, the ornamental horticulture industry has long been the primary source for invasive plants; and this is a targeted issue of many countries (Bradley et al., 2011; Dehnen-Schmutz et al., 2007; Hulme et al., 2018; Lehan et al., 2013; Peters et al., 2006; Pyšek et al., 2011; Reichard and White 2001; van Kleunen et al., 2018).

In the past 2 decades, significant progress has been made by the ornamental industry to minimize the risk of invasive PIs. As early as 2001, experts from around the world met for a workshop designed to explore and develop workable approaches for reducing the introduction and spread on non-native invasive plants (Fay, 2001). Resultant voluntary codes of conduct have been adopted nationally by botanic gardens and the horticulture trade to help reduce the pathway of invasive plants (Burt

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1	ppm	$mg \cdot L^{-1}$	1
1	ppm	$\mu g \cdot mL^{-1}$	1
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

et al., 2007; Heywood, 2014). Regional results of such efforts are promising, as a recent survey revealed that of the 6885 species grown by mid-Atlantic U.S. nurseries, only 4% were considered invasive in these respective states (Coombs et al., 2020). Simultaneously, plant breeders have been looking for and developing new cultivars with much reduced or eliminated invasive potential that can replace invasive ones (Ranney, 2006; Trueblood et al., 2010; Vining et al., 2012). To illustrate, in a 2015 survey of the southeastern U.S. nursery industry, 74% of participants expressed a positive opinion of sterile cultivar research and a willingness to sell sterile cultivars (Bechtloff et al., 2019). Moreover, growers have indicated that they would share information about alternatives to invasive species with their customers (Burt et al., 2007; Coats et al., 2011; Peters et al., 2006). Still, it can be acclaimed that attitude change alone is simply not enough to curtail landscape use of invasive ornamentals as newly released cultivars are largely not subject to invasive screening or introduction fees (Barbier et al., 2013).

Florida has the second largest ornamental industry in the country with total annual industry sales estimated at $10.7 billion (Hodges et al., 2016). Significant efforts have been made to accurately assess and predict the invasiveness of some exotic plant species commonly grown in Florida (Fox and Gordon, 2009; Gordon et al., 2008a, 2008b). The Florida Department of Agriculture and Consumer Services (FDACS) is the only agency with regulatory authority to prevent the sale and distribution of invasive plants in the state (FDACS, Division of Plant Industry, 2021); yet, it is often too late for effective control once a plant species makes it to a governed noxious weed list. Many of the ornamentals listed as invasive by Florida's Exotic Pest Plant Council (FLEPPC, 2019) or the UF/IFAS *Status Assessment on Non-native Plants in Florida's Natural Areas* (UF/IFAS, 2021) are still in commercial production as cultivated forms that differ from the wild-type or resident species (Bechtloff et al., 2019; Wirth et al., 2004). In Florida, if a species is designated as invasive, all cultivars fall under this classification unless proven otherwise through an internally approved UF/IFAS infraspecific taxon protocol (ITP) evaluation. This protocol consists of 12 questions to determine 1) if the selection displays invasive traits that cause greater ecological impact than the wild-type or resident species and if it can be readily distinguished; and 2) the fecundity of the selection and its chances of regression or hybridization to characteristics of the wild-type (or naturalized resident species) (Lieurance et al., 2016).

Thus, over the past 2 decades, UF researchers have been working to determine the invasive potential of nearly 20 ornamental species and their cultivars (Wilson et al., 2012), including popular landscape plants, such as trailing lantana [*Lantana montevidensis* (Steppe et al., 2019; Wilson et al., 2020)], lantana [*Lantana camara* (Czarnecki and Deng, 2020; Czarnecki et al., 2014)], porterweed [*Stachytarpheta* sp. (Qian et al., 2021)], butterfly bush [*Buddleja davidii* (Wilson et al., 2004)], mexican petunia [*Ruellia simplex* (Wilson et al., 2009)], privet [*Ligustrum* sp. (Fetouh et al., 2020; Wilson et al., 2014b)], and japanese silver grass [*Miscanthus* sp. (Wilson and Knox, 2006)]. As part of planned breeding programs, UF breeders have developed genetic and molecular techniques to reduce the fecundity of plants, leading to sterile cultivars of mexican petunia (Freyre et al., 2012, 2016) and lantana (Czarnecki et al., 2012; Deng and Wilson, 2017; Deng et al., 2017, 2020). As a result of these efforts, the invasive wild types of mexican petunia and lantana are gradually being replaced with the new noninvasive, UF/IFAS ITP-approved cultivars that are also superior in flowering and performance (Knox et al., 2018a, 2018b, 2018c).

In addition to traditional breeding, a number of transgenic approaches have been explored to more quickly develop sterile cultivars, such as: 1) targeted expression of cytotoxin genes in reproductive tissues, 2) use of fusion genes to alter specific metabolic or hormone signaling pathways, and 3) alteration of specific reproductive tissue via ectopic expression of homeotic genes (Li et al., 2004). Still, there have been no deregulated or approved sterile, transgenic cultivars available for the industry; and concern surrounds the public perception of labels indicating genetic modification and the potential ability of other closely related plants to serve as a pollen source.

Heavenly bamboo (*Nandina domestica*) is a popular landscape plant with traits that have made it invasive in some locations. Heavenly bamboo is an evergreen, rhizomatous shrub with an upright multitrunked growth habit and tolerance of a variety of sun and soil conditions (Gilman, 1999). It is considered drought tolerant once established, with cold hardiness in zones 6 to 10 (USDA, Agriculture Research Service, 2012), thus its growing range and landscape use extend well beyond the southeastern and southwestern parts of the United States. Leaves have an alternate branching pattern and are tripinnately compound, often turning hues of pink to red in response to cooler temperature during the onset of winter. In spring, it produces panicles of white flowers held above the foliage. In fall, heavenly bamboo boasts an abundant display of red berries (each having one to three seeds) that persist through the winter and beyond. Berries contain cyanide and other alkaloids that, in large doses, have been proven

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toxic to cedar waxwings [*Bombycilla cendrorum* (Woldemeskel and Styer, 2010)]. Heavenly bamboo is versatile in the landscape, used as a specimen or in a container, border, or mass planting; and able to withstand heavy pruning. Commercial propagation is typically by cuttings, micropropagation, and division due to the inherent morpho-physiological dormancy of seeds that delays germination (Davies et al., 2018; Dehgan, 1984; Dirr and Heuser, 2006; Rhie et al., 2016). Combined, these ornamental features have led to the wide cultivation of the species, as well as its increased sales and availability over time. In Florida alone, the total economic output impact of heavenly bamboo was estimated at \$2.35 million (Wirth et al., 2004). In the southeastern United States, heavenly bamboo was grown by 70% of survey respondents with reported sales of \$15.7 million to \$22.8 million in 2015 (Bechtloff et al., 2019).

Heavenly bamboo is native to forest understories of central China and Japan and west to India, and was introduced to the United States before 1804 (Langeland et al., 2008). It has escaped cultivation in nine states in the southeastern United States (USDA, Natural Resources Conservation Service, 2021), including Florida (eight counties) (Wunderlin et al., 2021). The FLEPPC lists heavenly bamboo as a Category I invasive species because it is ecologically damaging to natural areas (FLEPPC, 2019). Self-sustaining and expanding populations of heavenly bamboo have been found in natural plant communities of northern and central Florida where it is altering the light environment (Cherry, 2002) and displacing native vegetation (Langeland et al., 2008). Consequently, the UF/IFAS status assessment has concluded the species to be invasive and does not recommend its planting in northern Florida and central Florida; and recommends caution if planting in southern Florida (UF/IFAS, 2021). All cultivars or selections fall under this recommendation, unless evaluated and approved as noninvasive by the UF/IFAS ITP assessment.

Although the heavenly bamboo wild type is still commercially available, the nursery inventory predominately consists of cultivated selections that have been bred for improved and novel form and foliage color. In fact, there are 65 named cultivars in Japan and more than 40 cultivars have been catalogued in the JC Raulston Arboretum, Raleigh, NC (Roethling et al., 2003). The invasive status of heavenly bamboo cultivars is dynamic, as we gradually learn more about their reproductive biology, ploidy, phenotypic stability, and long-term consequences. For nearly 2 decades, we have conducted a series of experiments that have evaluated more than 25 heavenly bamboo selections at multiple locations in Florida. Although some of these results have been asynchronously published (Knox and Wilson, 2006; Wilson et al., 2014a), a comprehensive review of these cultivars is lacking, and both growers and consumers remain largely confused about which cultivars are appropriate to plant. This paper serves to summarize the current status of heavenly bamboo and its selections, and provide recommendations for its landscape use in the United States.

Materials and methods

Expt. 1. In our initial study, plant performance and fruiting were evaluated for 10 selections of heavenly bamboo in comparison with the wild-type resident species at two locations in Florida (Wilson and Knox, 2006). Selections included were 'Compacta', 'Filamentosa', 'Firepower', 'Gulf Stream', 'Harbour Dwarf', 'Jaytee', 'Moon Bay', 'Monum', 'Royal Princess', and 'Umpqua Chief' heavenly bamboo as described in Table 1 and Fig. 1. The study sites were located in northern Florida [Quincy (USDA hardiness zone 8b)] and southern Florida [Fort Pierce (USDA hardiness zone 9b)]. On 28 Jan. 2003, 1-gal container plants were installed on 4-ft centers in slightly raised beds covered with polyethylene mulch (Synthetic Industries, Alto, GA). Plants were irrigated and fertilized (15N–3.9P–8.3K Osmocote Plus; Scotts Co., Marysville, OH) similarly at the two sites for 100 weeks (encompassing two fruiting seasons). Details of field conditions, including rainfall, humidity, temperature, and soil analysis are reported by Wilson and Knox (2006).

Observations of flower initiation, flowering period, and fruit production were recorded every 4 weeks. At the onset of fruiting, mesh bags were used to cover fruit to prevent predation or premature senescence. Once every 3 months, plants were rated for visual quality (plant performance) using a scale of 1 to 5, where 1 = very poor quality, not acceptable, severe leaf necrosis or chlorosis; 2 = poor quality, not acceptable or marketable, large areas of necrosis or chlorosis, poor form; 3 = fair quality, somewhat desirable form and color, fairly marketable; 4 = good quality, very desirable color and form; and 5 = excellent quality, perfect condition, premium color and form. Plant size was assessed by recording the height (measured from crown to natural break in foliage) and two perpendicular widths of each plant, thereby generating a growth index [height + (width1 + width2)/2].

Mature, red fruit (berries) were removed from plants, counted, and manually depulped with a dehulling trough (Hoffman Manufacturing, Albany, OR). To determine pregermination seed viability, tetrazolium (TZ) testing was adapted from the Association of Official Seed Analysts rules for TZ testing (Peters, 2017). Staining was performed twice on a subset of 100 seeds for each fruiting selection collected from northern Florida. Cleaned seeds were pretreated by soaking in water overnight at room temperature. Seeds were then cut longitudinally completely through the seed and stained overnight at 30 to 35 °C in 1.0% TZ (2,3,-5-triphenyl chloride) solution with positive staining patterns confirming seed viability (Mid-West Seed Services, Brookings, SD).

A randomized complete block experimental design was used with selections placed in three-plant plots replicated three times by row (blocks). Data were subjected to analysis of variance (ANOVA), and significant means among selections separated by least significant difference at $P \leq 0.05$ using SAS statistical software (version 9.2 for Windows; SAS Institute, Cary, NC). Where there was a significant location effect, data for each location were analyzed and presented separately. Percentage data for the seed viability studies were transformed by a square root arcsin before conducting an ANOVA. Transformed means were separated by a Duncan's multiple range test ($P \leq 0.05$) with untransformed selection means presented.

Table 1. Selection name, description, and corresponding reference of experiments conducted to determine landscape performance, growth, fruiting, and ploidy level of heavenly bamboo.

Selection	Description[z]	Reference
AKA Blush Pink™	Discovered in 2004 by A. Herring, K. Herring, and A. Garza (Magnolia Gardens Nursery, Magnolia TX) as a natural whole plant mutation in a cultivated planting of 'Firepower'. Upright, dense habit with long-lasting blush red color of young foliage retained year-round. Patented as 'AKA' in 2009 (PP19916P2), trademarked as Blush Pink, and marketed as part of the Southern Living plant collection (Southern Living Plants, Birmingham, AL).	Wilson et al., 2014a
Alba	Whitish fruit and light green foliage. Reported to be less cold hardy than the wild type. Not patented.	Wilson et al., 2014a
Chime	Compact mounded form with thread-like, chartreuse green finely dissected foliage that turns orange-red in winter. Introduced by Monrovia Nursery Co., Azusa, CA, as part of their Dan Hinkley Collection.	
Compacta	Semi-dwarf in habit selected for dense foliage turning reddish bronze in the fall. Not patented.	Knox and Wilson, 2006
Emerald Sea	Upright habit with emerald green foliage having a purplish tint near base. Introduced by Monrovia Nursery Co.	
Filamentosa	Dwarf form and thinly dissected leaves. Imported from Japan and named by Ray Yoshimura, San Gabriel Nursery, San Gabriel, CA.	Knox and Wilson, 2006
Firehouse	Red color throughout winter with green growth in the spring and a mounding growth habit. Selected and introduced by Greenleaf Nursery Co., El Campo TX.	Wilson et al., 2014a
Firepower	Selected as a sport of 'Atropurpurea Nana', a selection that was developed by New Zealand Nurseries Ltd., New Plymouth, New Zealand. Short and wide growth often marketed as dwarf because it is shorter than the standard species type. Not patented. Distributed by Monrovia Nursery Co.	Knox and Wilson, 2006; Wilson et al., 2014a
Firestorm™	A sport of 'Gulf Stream'. The new growth is copper red maturing to green-blue. Introduced in 2005 by Plant Development Services Inc., Loxley, AL.	Wilson et al., 2014a
Greray Sunray®	Mutation of 'Harbour Dwarf' found by R. Young in a cultivated bed at Greenleaf Nursery Co. Symmetrical shape with an orange hue to young foliage. Patented as 'Greray' in 1994 (PP8530) and registered as Sunray.	Knox et al., 2007

(Continued on next page)

Table 1. (*Continued*).

Selection	Description[z]	Reference
Gulf Stream	Discovered by W. Barr as a mutant of 'Compacta' at Hines Wholesale Nurseries, Houston, TX. Dense growth that does not "sucker" like 'Harbour Dwarf'. Young leaves are multicolored in hues of green, orange, and reddish copper maturing to a medium green color. Patented in 1986 (PP5656).	Knox and Wilson, 2006; Wilson et al., 2014a
Harbour Dwarf	Named for C.L. Harbour in 1956. Low growing with summer foliage blue-green changing to tints of red in winter. Distributed by Monrovia Nursery.	Wilson et al., 2014a
Jaytee Harbor Belle™	A chance seedling found in a bed of 'Harbour Dwarf' and other unnamed heavenly bamboo. Selected in 2001 by R. Rushing (Rushing Nursery, Semmes, AL) for its dwarf mounding form and unique leaf coloration with new foliage dark, reddish brown. Patented as 'Jaytee' in 2004 (PP14668P3) and trademarked as Harbor Belle.	Knox et al., 2007
Lemon-Lime	Selected in 2004 by R. Davis, Locustville, VA, from open pollinated seedings of 'Aurea'. Compact plant habit with chartreuse new foliage and contrasting green interior foliage. Patented in 2014 (PP24749) by Plants Nouveau, LLC (Mobile, AL) and marketed as part of the Southern Living plant collection.	
Lowboy	A chance seedling selected from a bed of unnamed heavenly bamboo. Introduced in 1983 by R. Rushing (Rushing Nursery) for its dense compact growth habit. New foliage bronze color, with reddish-purple tint in the winter. Patented in 1985 (PP5560).	
Monfar Sienna Sunrise®	A product of a cross-pollination made in 1993 of two unidentified heavenly bamboo selections. Selected in 1996 by M. Farrow (Holly Hill Farms, Earleville, MD). Mounded habit and intense burgundy-red winter foliage with a green summer color. Patented as 'Monfar' in 2004 (PP14693) and registered as Sienna Sunrise by Monrovia Nursery Co.	Wilson et al., 2014a
Monum Plum Passion®	A product from a naturally occurring whole plant mutation discovered in a cultivated planting of 'Compacta' by D. Huang in 1993. Upright habit with new growth purplish red foliage, green in summer, reddish-purple in winter. Patented as 'Monum' in 2001 (PP12069P2) and registered as Plum Passion by Monrovia Nursery Co.	Knox and Wilson, 2006; Knox et al., 2007

(Continued on next page)

Table 1. (*Continued*).

Selection	Description[z]	Reference
Moon Bay™	A chance seeding in a population of heavenly bamboo seedlings selected by W. Barr at Hines Wholesale Nurseries. Mounded growth habit with shiny green summer foliage and red hued winter foliage. Patented in 1983 (PP05659).	Knox et al., 2007
Moyer's Red	Foliage denser than standard species. Winter foliage is glossy red. The flower buds are pinkish unlike most other selections. Reported to be less cold hardy. Not patented.	Knox and Wilson, 2006; Knox et al., 2007
Murasaki Flirt™	A whole plant mutation of 'Harbour Dwarf' discovered by A. Herring, K. Herring, and J. Herrera during Stage 3 of micropropagation in 2005. Compact, mounding habit with wine-red colored young foliage and gray green mature foliage. Patented in 2010 as 'Murasaki' (PP21391), trademarked as Flirt, and marketed as part of the Southern Living plant collection.	
Royal Princess	Upright growth habit with narrow leaves. Winter foliage has reddish-purple color. Not patented.	Knox et al., 2007; Knox and Wilson, 2006
SEIKA Obsession™	A naturally occurring whole plant mutation discovered in a 72-cell tray of 'Gulf Stream' by A. Herring and A. Garza (Magnolia Gardens) in 2005. Dense compact form with bright red young foliage that is retained while the plant is actively growing. Patented as 'SEIKA' in 2011 (PP21891), trademarked as Obsession, and marketed as part of the Southern Living plant collection.	
Twilight	A naturally occurring whole plant mutation discovered in a commercial laboratory by N. Marek (Magnolia, TX) in 2010 among a population of 'Gulf Stream'. Compact form with pink young foliage with white variegation; mature foliage with green, pink, and white variation. Patented in 2015 (PP26025).	
Twisted leaf	This selection does not have a cultivar name. Rachis is slightly bent creating a nonlinear appearance. Leaflets are curved and margins are undulate (not in the same linear plane as with the standard species). Panicle axis is also nonlinear. Not patented.	Knox et al., 2007
Umpqua Chief	Upright form with new growth copper or purple-red and turns blue-green. Not patented.	Knox et al., 2007; Knox and Wilson, 2006

[z]PP = Plant Patent.

Expt. 2. In our second study, plant performance and fruiting were evaluated for eight additional heavenly bamboo selections in comparison with the wild-type resident species at the same two locations in Florida that were used in Expt. 1 (Wilson et al., 2014a). Selections included were 'Alba', 'AKA', 'Firehouse', 'Firepower', 'Firestorm', 'Gulf Stream', 'Monfar', and 'Moyer's Red' heavenly bamboo as described in Table 1 and Fig. 1. The experimental design and data collection methodology were similar to that of Expt. 1, except rows were covered with black semi-impermeable landscape fabric (Lumite, Baldwin, GA) and 2- or 3-gal plants were installed 6 May 2008. The study timeframe was longer, extending to 144 weeks. Seeds were subjected not only to pregermination viability tests like Expt. 1, but also to germination tests. Four replications of 100 seeds were placed in incubators with 8-h photoperiod at 30 °C and cool-white, fluorescent lamps, followed by an 18-h darkness at 20 °C. Final germination was taken at 60 d.

Unique to the second study, ploidy levels were inferred using flow cytometry (model Acuri C6; BD Biosciences, San Jose, CA) to determine nuclear DNA content (Wilson et al., 2014a). Leaf tissue was chopped in the LB01 nuclei isolation buffer, and the released nuclei were stained with 50 $\mu g \cdot mL^{-1}$ propidium iodide and 50 $\mu g \cdot mL^{-1}$ RNase (New England BioLabs, Ipswich, MA) before analysis. Cereal rye [*Secale cereale* (nuclear DNA diploid content value = 16.19 pg)] was used as the internal reference.

Expt. 3. In our third study, plant performance and fruiting were evaluated for seven additional heavenly bamboo selections in comparison with the wild-type resident species. Experiments were conducted at the same location in northern Florida (North Florida Research and Education Center, Quincy, FL) as previously described for Expts. 1 and 2, plus two new locations in north-central Florida [Plant Science Research Center, Citra, FL (USDA cold hardiness

Fig. 1. Images of 25 heavenly bamboo selections evaluated in Florida since 2003. Yellow stars indicate selections have been designated as noninvasive by an infraspecific taxon protocol evaluation (University of Florida, Institute of Food and Agricultural Sciences, 2021); blue stars indicate selections merit future consideration for noninvasive status. Photos courtesy of Greenleaf Nursery (El Campo, TX), Monrovia Nursery Co. (Azusa, CA), Southern Living Plants (Birmingham, AL), and JC Raulston Arboretum (Raleigh, NC). Image of wild-type resident species not shown.

Zone 9a)] and southwestern Florida [Gulf Coast Research and Education Center, Balm, FL (USDA cold hardiness Zone 9b)]. Plants included in this study were 'Chime', 'Greray', 'Emerald Sea', 'Lemon-Lime', 'Murasaki', 'SEIKA' and 'Twilight' heavenly bamboo (Table 1, Fig. 1). The beds were prepared, and field plots were maintained as previously described for Expts. 1 and 2 with a few exceptions. Namely, larger 3-gal plants were installed on the week of 22 May 2019 with final data collected after 90 weeks (at the end of the second winter). A randomized complete block experimental design was used with selections placed in single-plant plots replicated five times (blocks) for each of three locations.

Seed handling and processing were similar to that of Expts. 1 and 2, but methods were refined to improve germination (germination paper was folded over seed and germinates were removed from boxes following germination to avoid contamination). Mature fruit were collected from plants at each location. Seeds were counted, cleaned, and submitted to a seed testing facility (U.S. Forest Service National Seed Laboratory, Dry Branch, GA) to determine initial seed viability and germination. For viability tests, seeds were cut laterally and stained overnight (12–18 h) at 37 °C in a 1.0% TZ solution. Seeds were considered viable when firm embryos stained evenly red. X-ray analysis (Faxitron Ultrafocus, Tucson, AZ) was used to nondestructively determine embryo presence. To test germination, four replicates of 100 cleaned seeds were placed in 17 × 12 × 6.5-cm transparent polystyrene germination boxes containing one sheet of 22-point creped cellulose germination paper folded over and moistened with tap water. Germination boxes were placed in temperature and light-controlled grow rooms equipped with cool-white, fluorescent lamps. The germination condition was 8 h light at 25 °C followed by 16 h dark at 15 °C. Germination of seeds was recorded every 7 d for a period of 168 d. A seed was considered germinated when root, shoot, and cotyledons were visible. Seeds were removed once germination occurred to prevent contamination and inaccurate data collection. At the end of 168 d, nongerminated seeds were subjected to postgermination viability tests to determine remaining dormancy.

For determining nuclear DNA content, a similar technique was used as described in Expt. 2, but tomato (*Solanum lycopersicum*) served as the internal reference (2C nuclear DNA content = 1.96 pg) with a

Table 2. Range of final plant heights and perpendicular widths, visual quality range, and fruit reduction of 26 heavenly bamboo selections grown in northern Florida (Quincy or Citra) and southern Florida (Fort Pierce or Balm).

				Visual quality (1 to 5 scale)[x]		Fruit reduction (%)[w]	
Selection	Size category[z]	Plant ht (cm)[y]	Plant width (cm)	Northern	Southern	Northern	Southern
AKA Blush Pink	Medium	28–41	34–47	2.67–4.44	3.44–5.00	100	100
Alba	Large	55–77	55–65	2.00–3.00	2.00–3.50	67.74	79.83
Chime	Medium	26–36	26–43	3.00–3.98	1.80–3.43	100	100
Compacta	Large	62–71	49–69	3.10–3.35	4.17–4.33	0[v]	0
Emerald Sea	Medium	83–129	81–94	3.96–4.48	4.20–4.73	83.26	91.47
Filamentosa	Dwarf	20–23	15–28	1.88–3.07	1.73–2.28	100	100
Firehouse	Medium	29–62	25–35	2.00–3.00	2.00–3.44	100	100
Firepower	Medium	26–39	28–30	2.51–2.71	3.14–3.55	100	100
Firestorm	Medium	32–38	29–39	2.00–3.78	3.00–4.67	100	100
Greray Sunray	Large	54–68	41–70	4.09–4.58	3.00–3.63	100	100
Gulf Stream	Medium	36–92	36–37	2.47–2.61	3.56–4.20	98.14	100
Harbour Dwarf	Dwarf	20–21	23–32	2.20–2.72	3.56–3.88	97.21	100
Jaytee Harbor Belle	Dwarf	18–22	24–34	2.12–2.61	3.38–4.01	99.80	98.65
Lemon-Lime	Large	52–71	38–66	4.40–4.49	3.00–3.60	100	100
Lowboy	Medium	63–83	66–100	2.0–5.00	N/A[u]	82.82	N/A
Monfar Sienna Sunrise	Medium	48–80	33–76	2.67–4.89	2.67–3.44	93.72	97.01
Monum Plum Passion	Large	84–93	50–69	3.15–3.22	3.74–4.09	0	0
Moon Bay	Medium	29–32	19–19	1.98–2.43	3.03–3.23	100	100
Moyer's Red	Large	66–91	42–75	2.22–3.89	2.44–3.78	62.01	50.00
Murasaki Flirt	Dwarf	25–29	36–47	4.47–4.82	4.20–4.65	99.90	100
Royal Princess	Large	43–49	42–46	2.68–3.50	3.11–3.28	95.14	20.95
SEIKA Obsession	Large	66–83	47–77	4.68–4.87	4.40–4.48	100	100
Twilight	Large	57–73	26–69	3.73–4.60	3.80–5.00	99.75	99.95
Twisted leaf	Dwarf	45–61	45–61	2.00–3.00	N/A[u]	95.51	N/A
Umpqua Chief	Large	54–60	34–48	2.34–3.42	3.41–3.95	76.51	32.43
Wild type	Large	82–113	40–67	2.89–4.72	2.33–4.56	N/A	N/A

[z]Overall plant sizes were used to assign size categories of small, medium, or large.
[y]1 cm = 0.3937 inch.
[x]Visual quality ratings used a scale of 1 to 5, where 1 = poor quality, 3 = average quality, and 5 = excellent quality; presented as a range across all months.
[w]Percent fruit reduction of selections was calculated as the total number of fruit divided by the total number of wild-type fruit.
[v]Zero value indicates plants produced as much or more fruit than the wild type.
[u]N/A indicates that data were not collected.

newer model ploidy analyzer (CyFlow Cube 6; Sysmex Partec, Münster, Germany).

Results

Plant size and performance. Visual quality of plants varied by selection, location, and season (Table 2, Fig. 2). Overall, in northern Florida (Quincy and Citra), 'Royal Princess', 'Umpqua Chief', 'Gulf Stream', 'Monfar', 'Emerald Sea', 'Greray', 'Lemon-Lime', 'Murasaki', 'Seika', and 'Twilight' performed well throughout much of the study with average ratings between 3.0 and 4.9 (1 to 5 scale). In southern Florida (Balm and Fort Pierce), 'AKA', 'Compacta', 'Emerald Sea', 'Firestorm', 'Greray', 'Gulfstream', 'Harbour Dwarf', 'Jaytee', 'Lemon-Lime', 'Monum', 'Murasaki', and 'SEIKA' were top performers with average ratings between 3.0 and 5.0.

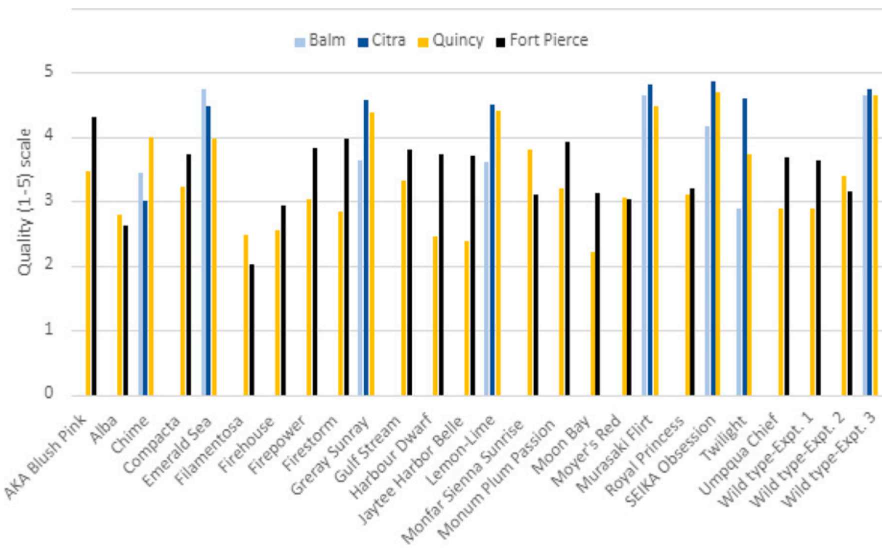

Fig. 2. Average visual quality ratings (1 = poor, 3 = average, 5 = excellent) of 26 heavenly bamboo selections planted in northern Florida (Quincy and Citra) and southern Florida (Fort Pierce and Balm). Means were averaged across all 3-month ratings throughout the entire study.

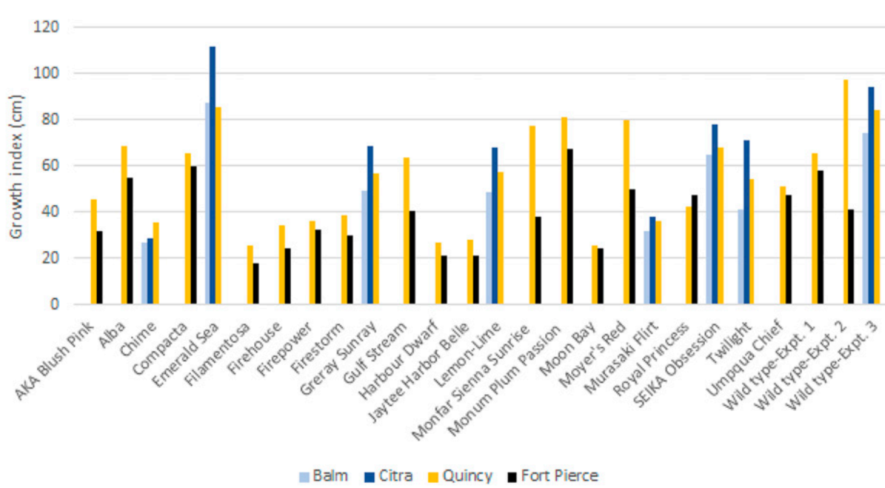

Fig. 3. Average growth index [height + (average width 1 + width 2)/2] per plant of 26 heavenly bamboo selections planted in northern Florida (Quincy and Citra) and southern Florida (Fort Pierce and Balm) for 90 to 144 weeks. 'Gulf Stream' heavenly bamboo is presented as an average from its replication in Expts. 1 and 2; 1 cm = 0.3937 inch.

Plant heights and widths varied among selections and sites (Table 2, Fig. 3). Of the 26 heavenly bamboo selections evaluated, 10 were assigned to the same large size category as the wild-type form, 10 were considered medium-sized, and 5 were considered to be dwarf forms (Table 2). Plant size (height, width, and growth index) was influenced by the different geographic locations in which plants were grown (Fig. 3). In Expts. 1 and 2, plants typically grew larger in northern Florida (Quincy) than southeastern Florida (Fort Pierce) except for 'Firepower', 'Harbour Dwarf', 'Moon Bay', and 'Royal Princess' that grew similarly at both locations. In Expt. 3, plant growth was less dramatically different between locations than in Expts. 1 and 2; but was slightly greater for selections grown in northcentral Florida (Citra) than those grown in northern (Quincy) or southwestern (Balm) Florida except for 'Chime' that was larger in the most northern site (Quincy).

Fruit production, seed viability, and germination. During the three experiments in both northern or southern Florida, no fruit were observed for 'AKA', 'Chime', 'Filamentosa', 'Firehouse', 'Firepower', 'Firestorm', 'Greray', 'Lemon-Lime', 'Moon Bay', and 'SEIKA' heavenly bamboo (Tables 2 and 3). In addition, 'Gulf Stream', 'Harbour Dwarf', and 'Murasaki' did not fruit at the southern Florida location and had 98.14%, 97.21%, and 99.9% fruit reduction, respectively, at the northern Florida location when compared with fruit reduction of the wild-type plants. 'Jaytee' had 99.8% and 98.64% fruit reduction in northern and southern Florida, respectively. 'Monfar' had 93.72% and 97.01% fruit reduction in northern and southern Florida, respectively. For the remaining selections, fruit reduction ranged from 20.95% to 95.14% ('Alba', 'Emerald Sea', 'Lowboy', 'Moyer's Red', 'Royal Princess', 'Twilight', 'Twisted Leaf', and 'Umpqua Chief') when compared with the wild type, except for those plants that produced more fruit than the wild type ('Compacta' and 'Monum' heavenly bamboo). Fruiting was subsequently classified on a scale of 0 to 3 where 0 = no fruiting, 1 = low fruiting, 2 = moderate fruiting, and 3 = heavy fruiting, as presented in Table 4.

Fruiting heavenly bamboo selections produced viable seed, with pregermination seed viability

Table 3. Final fruit number (average per fruiting plant) of 26 heavenly bamboo selections grown in northern Florida (Quincy or Citra) and southern Florida (Fort Pierce or Balm). Pregermination viability tests were determined on a subsample of seeds. Remaining seeds were subjected to germination tests. Postgermination viability tests were used to determine percent dormancy of nongerminated seeds.

	Avg fruit (no.)				
Selection	Northern	Southern	Pregermination viability (%)	Germination (%)	Dormant (%)
AKA Blush Pink	0	0	—[z]	—[z]	—[z]
Alba	411	35	69.0	12.5[y]	74.5[y]
Chime	0	0	—[z]	—[z]	—[z]
Compacta	1728	607	86.0	—[x]	—[x]
Emerald Sea	37	5	85.0[x]	—[x]	—[x]
Filamentosa	0	0	—[z]	—[z]	—[z]
Firehouse	0	0	—[z]	—[z]	—[z]
Firepower	0	0	—[z]	—[z]	—[z]
Firestorm	0	0	—[z]	—[z]	—[z]
Greray Sunray	0	0	—[z]	—[z]	—[z]
Gulf Stream	141	3	87.5	31.8[y]	47.5[y]
Harbour Dwarf	42	0	N/A[w]	58.0[v]	—[v]
Jaytee Harbor Belle	2	3	N/A	—[x]	—[x]
Lemon-Lime	0	0	—[z]	—[z]	—[z]
Lowboy	1240	N/A	96.0	64.0[u]	18.0[u]
Monfar Sienna Sunrise	80	4	86.5	27.8[y]	54.5[y]
Monum Plum Passion	1542	1503	73.0	—[x]	—[x]
Moon Bay	0	0	—[z]	—[z]	—[z]
Moyer's Red	67	484	74.5	5.5[y]	77.5[y]
Murasaki Flirt	0.2	0	100.0[x]	—[x]	—[x]
Royal Princess	73	117	N/A	N/A	N/A
SEIKA Obsession	0	0	—[z]	—[z]	—[z]
Twilight	0.5	0.4	66.6[x]	—[x]	—[x]
Twisted Leaf	36	N/A	98.0	—[x]	—[x]
Umpqua Chief	353	100	80.0	—[x]	—[x]
Wild type—Expt. 1	1503	148	85.0	56.0[v]	—[v]
Wild type—Expt. 2	1274	134	86.5	6.8[w]	70.8[w]
Wild type—Expt. 3	155	59	98.0	82[u]	7.0[u]

[z]Did not fruit, data could not be collected.
[y]Germination data were collected for 60 d and then seeds were tested for post germination viability to determine seed dormancy.
[x]Insufficient seed for complete analysis and only pregermination viability tests were conducted (germination data not available).
[w]Data not available.
[v]Germination data were collected for 252 d. Postgermination viability tests were not performed.
[u]Germination data were collected for 168 d and then seeds were tested for postgermination viability to determine seed dormancy.

ranging anywhere from 67% to 100% compared with 85% to 98% for wild-type seeds (Table 3). Germination was substantially delayed, with the onset typically occurring between 60 and 77 d and extending to at least 168 d at 25/15 °C (Table 3). Seed germination of selections ranged from 12.5% to 31.8% after 60 d, with post germination viability tests confirming that most of the nongerminating seeds were still dormant. Total seed viability (germination + dormancy) of selections ranged from 79.3% to 87.0%. Total viability of wild-type seeds was 78% in Expt. 2 and 89% in Expt. 3.

DNA nuclear content and inferred ploidy. Nuclear DNA content ranged from 4.09 to 4.54 among selections compared with 4.07 and 4.52 for the wild-type heavenly bamboo (Table 4). This indicated that all selections studied were diploid and that polyploidy does not seem to be the cause of the female infertility observed in some of the heavenly bamboo selections.

Potential noninvasiveness. Based on results from Expt. 1, we identified three selections ('Firepower', 'Gulf Stream', and 'Harbour Dwarf' heavenly bamboo) that performed well in the landscape and had little if any fruit. These were formally submitted to the IFAS ITP that concluded they were noninvasive (UF/IFAS, 2021) and can be recommended for use in Florida (Knox and Wilson, 2015, 2016). A fourth selection, 'Jaytee', performed well and produced no fruit in southern Florida and 42 fruit in northern Florida. The ITP assessment concluded 'Jaytee' to be noninvasive in southern Florida but to use with caution (due to its presence of fruit in northern Florida). Based on results from Expt. 2, we identified four more selections ('AKA', 'Firestorm', 'Firehouse', and 'Monfar') that performed well with limited or absent fruit production in Florida. We believe these selections merit consideration for noninvasive status and have formally submitted a request for their ITP assessment. Last, based on the results from Expt. 3, we identified an additional four selections ('Lemon-Lime', 'SEIKA', 'Murasaki', and 'Greray') that merit noninvasive consideration based on their worthy performance and absence of fruit.

Table 4. Nuclear DNA content and inferred ploidy level of 26 heavenly bamboo selections. Plants were assigned to fruiting categories where 0 = no fruiting, 1 = low fruiting, 2 = moderate fruiting, or 3 = heavy fruiting during the timeframe of the study.

Selection	Fruiting category (0–3 scale)	Ploidy level	Nuclear DNA content ± SD (pg/2C)
AKA Blush Pink	0	2*x*	4.29 ± 0.11
Alba	2	2*x*	4.25 ± 0.13
Chime	0	2*x*	4.14 ± 0.15
Compacta	3	2*x*	—[z]
Emerald Sea	1	2*x*	4.19 ± 0.05
Filamentosa	0	—[y]	—[y]
Firehouse	0	2*x*	4.22 ± 0.15
Firepower	0	2*x*	4.24 ± 0.06
Firestorm	0	2*x*	4.28 ± 0.09
Greray Sunray	0	2*x*	4.37 ± 0.02
Gulf Stream	1	2*x*	4.14 ± 0.10
Harbour Dwarf	1	2*x*	4.18 ± 0.16
Jaytee Harbor Belle	1	2*x*	—[z]
Lemon-Lime	0	2*x*	4.09 ± 0.06
Lowboy	3	2*x*	4.21 ± 0.01
Monfar Sienna Sunrise	1	2*x*	4.33 ± 0.19
Monum Plum Passion	3	2*x*	—[z]
Moon Bay	0	2*x*	—[z]
Moyer's Red	2	2*x*	4.54 ± 0.13
Murasaki Flirt	1	2*x*	4.32 ± 0.12
Royal Princess	1	2*x*	—[z]
SEIKA Obsession	0	2*x*	4.11 ± 0.11
Twilight	1	2*x*	4.22 ± 0.07
Twisted Leaf	1	2*x*	4.11 ± 0.02
Umpqua Chief	2	2*x*	—[z]
Wild type—Expt. 2	3	2*x*	4.52 ± 0.13
Wild type—Expt. 3	3	2*x*	4.07 ± 0.02

[z]Data not available.
[y]Insufficient tissue for analysis.

Discussion

Of the 26 selections we evaluated, 5 were categorized as dwarf-sized, 10 as medium-sized, and 11 as large-sized plants. This information can be useful when selecting plants for different areas of landscapes and gardens. Overall, most of the selections performed fair to excellent from northern through southern parts of the state despite full-sun conditions and Florida's hot and humid summers. Results of this statewide study reveal heavenly bamboo's adaptability to varying soils and temperature extremes, requiring minimal input.

Fruiting varied widely among selections where 44% (11) did not fruit and 32% (8) had very limited fruit production. Of the 19 low to no fruiting selections, 63% (12) also performed well in our landscape statewide trials and warrant consideration as safe alternatives to the wild-type heavenly bamboo. Other anecdotal extension information of heavenly bamboo fruiting is somewhat consistent with our findings with some exceptions. Namely, Kluepfel and Polomski (2018) reported 'Firepower', 'Gulfstream', 'Nana'/'Nana Atropurpurpea', 'SEIKA', 'Woods Dwarf', 'Monfar', 'Lemon-Lime', 'Murasaki', and 'AKA' to be fruitless; whereas, 'Alba', 'Compacta', 'Jaytee', 'Harbour Dwarf', 'Leucocarpa', 'Moon Bay', 'Moyer's Red', and 'Monum' were reported to fruit abundantly. Of the same selections that we evaluated in replicated field trials, we found 'Gulf Stream' to have 141 fruit only in northern Florida, 'Jaytee' to have only 2 to 3 fruit, 'Monfar' to have 4 to 80 fruit, and 'Murasaki' to have 1 fruit solely in northern Florida. As such, we classified these as low fruiting. We did not observe fruit on 'Moon Bay', considered 'Moyer's Red' to be a moderate fruiter, and 'Monum' to be a heavy fruiter. This emphasizes the value of replicated trials in different geographic conditions. In addition, the greater fruit production in northern Florida compared with southern Florida emphasizes the importance of distinguishing plants as invasive in northern, central, or southern Florida, as exemplified by the *IFAS Assessment of Non-native Plants in Natural Areas* (UF/IFAS, 2021).

Both the wild-type and fruiting heavenly bamboo selections produced viable seed. Our germination results are consistent with others who found heavenly bamboo to have a morphophysiological dormancy (Dirr and Heuser, 2006; Rhie et al., 2016). Baskin and Baskin (2014) describe this as a combination of morphological dormancy (seeds have an embryo that is undifferentiated or underdeveloped at harvest and requires time for further development before germination) and physiological dormancy (seed have a low embryo ability to rupture their seed coverings). Of interest to note, horticultural observations by Rhie et al. (2016) found that heavenly bamboo seeds 1) imbibe normally (physical dormancy is lacking), 2) can be treated with 1000 $mg{\cdot}L^{-1}$ gibberellic acid (GA_3) as a substitute for warm stratification at 25/15 or 20 °C, and 3) do not have a light or dark preference for germination. They further characterize the morphophysiological dormancy as "simple nondeep" due to their requirement of warm stratification (25/15 °C) for embryo growth with no requirement for cold stratification. Under natural conditions, we have observed heavenly bamboo fruiting to occur in fall, persist through early winter in leaf litter, undergo natural warm stratification in summer months, and then eventually germinate.

Regardless of their capacity to fruit, both cultivated and wild-type forms of the heavenly bamboo we evaluated were diploid (Table 4). Similarly, all 40 selections sampled from the JC Raulston Arboretum were found to be diploid (Knox et al., 2007; Raulston, 1984). Thus, polyploidy does not appear to be the cause of nonfruiting. In nature, polyploidy may confer advantages that could facilitate invasive potential, such as faster growth and herbivore resistance (Leonhardt, 2019; Levin, 1983), and as such, polyploidy is one of the dataset variables used in invasive plant modeling (Barbier et al., 2011). Ploidy manipulation is a commonly used genetic approach to produce triploids that are often highly male- and female-sterile (Czarnecki and Deng, 2020; Wang et al., 2016). Using such an interploid hybridization system requires tetraploids that are either selected among existing cultivars or induced from diploids by chromosome doubling (Datta et al., 2020; Fetouh et al., 2020; Vining et al., 2012). In addition to sometimes lengthy and expensive planned breeding programs to induce sterility in invasive ornamentals, naturally occurring whole plant mutations can be sources of novel and nonfruiting variants. The driving factors behind the sterility of some heavenly bamboo selections remain complex.

Disagreement remains about what level of fecundity in cultivars can be tolerated without posing a risk to the environment. Bufford and Daehler (2014) caution that horticultural selection for sterility (i.e., induced through transgenic techniques, through interspecific hybridization, or through chemically induced polyploidy to create triploid plants) can yield low-risk sterile cultivars of popular ornamentals provided that further hybridization or allopolyploidy does not restore fertility and vegetative spread is limited. Knight et al. (2011) ask how much of a reduction in seed production or seed viability is necessary to create a cultivar that will not be invasive in natural areas, and emphasize that reduced seed production may be insufficient to eliminate the invasive potential of a species. Some examples of policy regulating the use of noninvasive cultivars does exist. For instance, the Oregon Department of Agriculture (ODA) approved seedless cultivars of a noxious weed, butterfly bush, for propagation, transportation, and sale provided they produce less than 2% viable seeds (ODA, 2021). As another example, cultivar exemptions of the noxious weed chinese privet (*Ligustrum sinense*) have been made for cultivars Variegatum and Sunshine (FDACS, 2021). Wilson et al. (2014b) caution that 'Variegatum' chinese privet can revert back to its green form and begin fruiting within 72 weeks. Last, specific nonfruiting cultivars of mexican petunia such as R10-102 (Mayan Purple), R10-105-Q54 (Mayan Pink), and R10-108 (Mayan White) were approved for use in Florida, but with cautionary restrictions due to their risk of vegetative spread (UF/IFAS, 2021). Recently, Datta et al. (2020) reviewed the biological basis of sterility and methods used to generate and confirm sterile cultivars. Noteworthy are questions they put forward when considering the risk of cultivar invasions, including what the trait differences are between the proposed safe alternatives and corresponding invasive species, how this translates into a difference in invasion risk and regulation, and whether these differences are spatially and temporally stable.

It can be argued that saturating the market with low to no-fruiting cultivars as an alternative to a nonregulated (not listed by FDACS) invasive wild-type species can significantly help prevent further spread. However, consumer education distinguishing recommended and nonrecommended cultivars is lacking (Knox et al., 2018a). Moreover, although significant strides have been made toward promotion of noninvasive plant use, there is little information available on what economically feasible alternatives are suitable and easy to purchase (Stack et al., 2007). Knox et al. (2018a, 2018b, 2018c) published native and non-native alternative lists to common invasive ornamentals; however, only a limited number of sterile noninvasive cultivars have been released and they are largely unknown on a national scale. Sterile noninvasive cultivars are typically not labeled as such in retail markets, despite research that shows informed labeling may increase a consumer's willingness to buy plants (Yue et al., 2011).

In a survey distributed to southeastern U.S. nurseries, 40% of respondents indicated they would be extremely likely to sell sterile cultivars of heavenly bamboo (Bechtloff et al., 2019). Noninvasive cultivars may be a desirable replacement of the invasive wild-type forms, but much confusion remains in distinguishing their differences, and the voluntary or involuntary regulation of existing invasive inventory is complicated (Niemiera and Von Holle, 2009). Drew et al. (2010) points out that the plant availability market is largely driven by consumers who need access to reliable information about the plants they are buying and even suggests the possibility of incentivizing plant producers in their decisions to make appropriate choices. In line with consumer involvement in making the right plant choices, Dehnen-Schmutz and Conroy (2018) go a step further and suggest using a citizen's science approach in which gardeners are asked to report ornamental plants that are spreading and difficult to control in their landscapes.

In summary, we have evaluated heavenly bamboo selections at multiple sites in northern, central, and southern Florida over a period of nearly 2 decades, with nearly three-fourths of these selections exhibiting little to no fruiting when compared with the wild-type form. Characteristics typical of these selections, such as plant form, leaf morphology and color, and flowering and fruiting responses, were consistent over time, with no observations of trait reversion. Thus, these selections having no or little potential to produce fruit (seeds) can serve as viable alternatives to replace the wild-type heavenly bamboo. Promotion of wide use of these noninvasive alternatives can help reduce or eliminate the sales of those cultivars that fruit. All nonfruiting heavenly bamboo cultivars are most likely diploids. Our study suggests that selection of mutations and other traditional breeding approaches may lead to the development of noninvasive cultivars. It cannot be overstated that the processes of noninvasive cultivar development that use forms of genetic mutation and traditional breeding are complex and warrant rigorous scrutiny and screening before introduction.

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