Determining Differential Tolerances of Newly Released vs. Traditional Cultivars of Common Ornamental Species to Preemergence Herbicides

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Abstract

Hundreds of new woody ornamental plant cultivars are introduced into the nursery industry each year which have many desirable aesthetic traits. However, in recent years growers have reported a higher level of herbicide sensitivity with certain cultivars compared with older cultivars that have been in the trade for multiple years. The objective of this research was to determine the tolerance of 12 different cultivars of five ornamental species including four cultivars of *Loropetalum chinense* ['Ruby', 'Shang-hi' PP18331 (Purple Diamond®), 'Irodori' USPP 27713 (Jazz Hands®), and 'PIILC-I' (Crimson Fire™), and two cultivars of *Gardenia jasminoides* ('Frostproof' and 'Buttons'), *Lagerstroemia indica* ['JM7' PP34092 (Thunderstruck™ Ruby) and 'Tuscarora'], *Rhododendron* ['Conlet' PP12111 (Autumn Carnival Encore®) and 'Fashion'], and *Ligustrum sinense* Sunshine ('Sunshine' PP20379 and 'Variegatum') to spray-applied applications of dimethenamid-P or isoxaben + prodiamine and granular applications of dimethenamid-P + pendimethalin and indaziflam. While little to no injury was observed in gardenia or crape myrtles, significant injury and differences among cultivars of the same species were observed in azalea, loropetalum, and ligustrum. Results indicate that all new cultivars should be evaluated for herbicide tolerance by growers prior to wide scale application as significant differences in both growth and injury ratings were observed between different cultivars of the same species.

Species used in this study: Ruby Loropetalum (*Loropetalum chinense* (R.Br.) Oliv. 'Ruby'); Purple Diamond® loropetalum *(Loropetalum chinense* 'Shang-hi' PP18331); Jazz Hands loropetalum (*Loropetalum chinense* 'Irodori' USPP 27713); Crimson Fire™ loropetalum *(Loropetalum chinense var. rubrum* 'PIILC-I'); Frostproof gardenia (*Gardenia jasminoides* J.Ellis 'Frostproof'); Buttons gardenia (*Gardenia jasminoides* 'Buttons'); Thunderstruck™ Ruby crape myrtle (*Lagerstroemia* × 'JM7' PP34092); Tuscarora crape myrtle (*Lagerstroemia indica* L. 'Tuscarora'); Autumn Carnival Encore® azalea (*Rhododendron* 'Conlet' PP12111); Fashion azalea (*Rhododendron* × 'Fashion'); Sunshine ligustrum (*Ligustrum sinense* Lour. 'Sunshine' PP20379); Variegated ligustrum (*Ligustrum sinense* 'Variegatum').

Chemicals used in this study: dimethenamid-P (Tower®), (S)-2-chloro-N-(2,4-dimethyl-3-thienyl)-N-(2-methoxy-1-methylethyl)-acetamide; dimethenamid-P+ pendimethalin (FreeHand®) (S)-2-chloro-N-[(1-methyl-2-methoxy)ethyl]-N-(2,4-dimethyl-thien-3-yl)-acetamide + N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenam; indaziflam (Marengo®G) N-[(1R,2S)-2,3-dihydro-2,6-dimethyl-1H-inden-1-yl]-6-[(1RS)-1 fluoroethyl]-1,3,5-triazine-2,4-diamine; prodiamine + isoxaben (Gemini® SC) 2,6-Dinitro-N^1, N^1-dipropyl-4-(trifluoromethyl)benzene-1,3-diamine + 2,6-Dimethoxy-N-[3-(3-methylpentan-3-yl)-1,2-oxazol-5-yl]benzamide.

Index words: cultivars, container production, preemergence herbicides, ornamentals, loropetalum, gardenia, crape myrtle, ligustrum, azalea.

Significance to the Horticulture Industry

The horticultural market has expanded significantly in recent years, highlighting the increasing demand for innovative and visually appealing cultivars. Hundreds of ornamental species are included on herbicide labels as being tolerant for application following established crop safety protocols, but the rapid introduction of a large number of new cultivars creates challenges as each new introduction cannot be tested for every herbicide option. Currently, many labels that list specific genera or species as being tolerant were approved prior to the introduction of many of these new cultivars which could be more sensitive than older more established varieties of the same genus and species. The objective of this research was to compare the tolerance of 12 different cultivars of 5 different ornamental species, including both older, more established cultivars currently included on herbicide labels and newly released cultivars which have not been subjected to extensive evaluation. Results showed that newly released cultivars of *Ligustrum sinense* ('Sunshine') and *Loropetalum chinense* ('Irodori' and 'PILC-I') showed a higher level of injury to sequential applications of commonly used preemergence herbicides compared with older cultivars of the same genus and species. This information provides growers with evidence that small-scale testing should be conducted on all new cultivars prior to large-scale applications, especially when specific cultivars are not included on the tolerant list on product labels.

Introduction

Weed management is an important aspect of nursery production. Weeds can quickly out-compete the ornamentals for light, nutrients, and water, reducing the rate of crop growth as well as salability (Berchielli-Robertson et al. 1990, Norcini and Stamps 1992). Methods currently used for weed management include many different practices ranging from manual weeding, use of mulch (Altland et al. 2016, Bartley et al. 2017, Marble et al. 2019), and strategic fertilizer placement (Saha et al. 2019), but still most

Received for publication December 5, 2023; in revised form March 18, 2024.

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commonly, the use of preemergence herbicides (Case et al. 2005, Yu and Marble 2022). While still costly, preemergence herbicides are much more cost effective than manual weeding or the use of mulch in most scenarios (Case et al. 2005, Gianessi 2013, Merwin et al. 1995) and do not require major changes in production practices as would be required with the use of strategic fertilizer placement or methods such as substrate stratification that have been recently investigated (Khamare et al. 2022).

Currently there are approximately 25 different preemergence herbicides or herbicide combinations registered for use in nursery production (Neal et al. 2017). While these herbicides provide many benefits, there are some drawbacks relating to water quality (Poudyal and Cregg 2019, Wilson et al. 1995) and off target losses resulting from application to spaced containers (Gilliam et al. 1992). However, the most common challenge specifically pertaining to nursery production is crop tolerance due to the vast number of different taxa and cultivars produced by nursery growers. Tolerances of ornamentals widely differ between different crop groups such as ornamental grasses (Neal and Senesac 1991), herbaceous perennials (Derr 1994), tropical species (Boyd et al. 2021), and woody ornamentals (Hood and Klett 1992) and thus, growers and registrants must perform extensive safety testing to ensure nursery species are tolerant to a new herbicide prior to wide scale application or registration. There are currently hundreds of ornamental plants that are listed as tolerant on various herbicide labels, which have been compiled in various crop management guides such as the 2017 Southeast Pest Management Guide for Nursery Crops and Landscape Plants (Neal et al. 2017). While some product labels list tolerant genus, species, and specific cultivars, other labels may only show tolerance at the species level or in some cases to the genus level for certain plants (Neal et al. 2017). For growers, this can create crop safety issues as hundreds of new ornamental plants cultivars are released into the market each year by breeders and seed companies (Brasher 2017) due to differences in tolerances between different species of the same genus, or in some cases, between cultivars of the same species.

Variability in cultivar tolerance to herbicides has been seen in other cropping systems. A wide range of tolerance to both pre- and postemergence herbicides has been previously reported in soybeans [*Glycine max* (L.) Merr.] (Burnside 1972, Chung and Singh 2008), peanuts (*Arachis hypogaea* L.) (Leon and Tillman 2015), cotton (*Gossypium barbadense* L.), and many other crops (Lemerle et al. 1986, Keneni et al. 2012, Samtani et al. 2012, Smith and Schweizer 1983). The actual mechanism resulting in differences in herbicide tolerance or susceptibility is not well understood in all scenarios, but may be due to nontarget site mechanisms (Leon and Tillman 2015), differences in uptake and translocation (Molin and Khan 1996), differences in growth, development, and other physical characteristics or even responses to different environmental conditions (Lemerle and Hinkley 1991, Jensen 1993).

While cultivar tolerances to herbicides have been investigated more thoroughly in field crops, very little work has been conducted in ornamentals in terms of peer-reviewed or public information on many of the most common ornamental taxa. Azaleas (*Azalea* spp.), gardenia (*Gardenia jasminoides*), crape myrtles (*Lagerstroemia indica*), ligustrum (*Ligustrum* spp.), and loropetalum (*Loropetalum chinense*) are some of the most common woody ornamentals grown by the U.S. nursery production industry (Purdue and Hamer 2020) and new cultivars have been released for each within the last several years while many older varieties have been in the trade for decades and were typically the subjects of preemergence herbicide tolerance testing, leading to the registrations of these species. For example, 'Ruby' loropetalum was first introduced in 1989 and has been one of the most widely planted loropetalum cultivars in the southeast (Ruter 2006) while new cultivars such as Purple Diamond® (*Loropetalum chinense* 'Shang-hi' PP18331), Jazz Hands® (*Loropetalum chinense* 'Irodori' USPP 27713), and Crimson Fire™ (*Loropetalum chinense* var. rubrum 'PIILC-I') (Anonymous 2006, Anonymous 2012, Anonymous 2015b) have been released more recently in order to have differences in growth habit and leaf color. Crape myrtles (*Lagerstroemia indica*) are one of the most common deciduous trees in the southeastern U.S. and in the past were predominated with cultivars such as 'Tuscarora', but now more and more growers are producing new varieties such as Thunderstruck™ Ruby, which was patented in 2021 (Anonymous 2021a) and has not been tested for preemergence tolerance to our knowledge. An additional new cultivar that is becoming increasingly popular is 'Sunshine' ligustrum (*Ligustrum sinense* 'Sunshine' PP20379) (Anonymous 2007) which is a more compact-growing variety of ligustrum with bright yellow foliage compared with the standard variegated ligustrum (*Ligustrum sinense* 'Variegatum'), which has been in the trade for several decades. While variegated ligustrum has shown excellent herbicide tolerance and is included on multiple preemergence herbicide labels, many growers are reporting a high level of sensitivity with 'Sunshine'. Newer cultivars of species such as gardenia (*Gardenia jasminoides*) and azaleas are routinely released by breeders, such as the Encore® azaleas (Anonymous 2000), which are released very regularly. It is not known if these new varieties have any differential tolerance to herbicides compared with older cultivars such as 'Frostproof' gardenia or 'Fashion' azaleas (*Rhododendron* × 'Fashion').

In recent years, we have received several reports of growers observing phytotoxicity on newer cultivars of common ornamental species when using preemergence herbicides that are labeled as tolerant at the genus or species level or in certain instances, in cases where most of the cultivars they grew of a particular species showed tolerance but one or more cultivars showed significant or even severe injury (Marble, personal communication). Therefore, the objective of this study was to evaluate the safety of four commonly used granular preemergence herbicides on 12 cultivars of 5 common ornamental species commonly produced by Florida growers utilizing both old "industry standard" cultivars that have been previously tested alongside newly released cultivars where little to no safety testing has been done.

Materials and Methods

Experiments were conducted in the spring and summer of 2023 at the Mid-Florida Research and Education Center

Table 1. Response of *Gardenia jasminoides* 'Frostproof' and 'Buttons' to sequential over-the-top applications of selected preemergence herbicides. Results pooled over two experimental runs conducted in 2023.

Herbicide	Rate[y] kg ai ha^{-1}	Rate[y] lb. ai A^{-1}	Phytotoxicity ratings (0 to 10)[z] 2 WAT[x]	4 WAT	8 WAT	2 WAT2[w]	4 WAT2	8 WAT2
			Gardenia jasminoides 'Frostproof'					
Dimethenamid-P	3.37	3.01	0.0 A[v]	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Indaziflam	0.1	0.09	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Control	0	0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
			Gardenia jasminoides 'Buttons'					
Dimethenamid-P	3.37	3.01	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Indaziflam	0.1	0.09	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Control	0	0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A

[z]Phytotoxicity ratings were taken on a scale of 0 to 10 based on overall health and marketability of the plants during the experiment where 0 = no injury and 10 = dead plant.

[y]Rate is expressed in amount of active ingredient applied on a per hectare or per acre basis. Rates tested represented approximately 2× the manufacturer label rate.

[x]The first application was applied on 4/5/2023 in experimental run 1 and 4/12/2023 in experimental run 2.

[w]The second application was applied on 5/29/2023 in experimental run 1 and 6/7/2023 in experimental run 2.

[v]Means within a column and cultivar followed by the same letter are not significantly different according to Tukey's HSD test ($P \leq 0.05$).

in Apopka, Florida. Twelve ornamental cultivars from 5 species were selected to evaluate their tolerance to common preemergence herbicides based upon their wide scale use in the industry and based upon grower interest and reports of differences in tolerance to preemergence herbicides. Plant species selected included four loropetalum cultivars and two cultivars of gardenia, crape myrtle, ligustrum, and azaleas. Due to availability constraints with some of the cultivars, different initial liner sizes and final pot sizes after transplanting differed. Initial and final container sizes utilized for the 12 cultivars were as follows: *Loropetalum chinense* (loropetalum) 'Ruby' [3.8 L (1 gal) to 11.3 L (3 gal)], 'Purple Diamond®' [3.0 L (trade gal 7.7 L (2 gal)], 'Jazz Hands®' and 'Crimson Fire™' [both 5 cm (2 in) to 3.8 L (1 gal)], *Gardenia jasminoides* (gardenia) 'Frostproof' [both 3.8 L (1 gal) to 11.3 L (3 gal)], *Lagerstroemia indica* (crape myrtle) 'Tuscarora' and Thunderstruck™ Ruby 'JM7' PP34092 [both 5 cm (2 in.) to 3.8 L (1 gal)], *Rhododendron* × 'Fashion' and *Rhododendron* 'Conlet' (azaleas) [both 3.0 L (trade gal) to 7.6 L (2 gal)], and *Ligustrum sinense* (ligustrum) 'Variegatum' [0.9 L (1 qt) to 8.5 L (2.3 gal)] and 'Sunshine' [3.0 L (trade gal) to 8.5 L (2.3 gal)]. In all cases, plants were potted using a pine bark: sand (8:1 by volume) substrate that had been previously amended with a controlled release fertilizer containing a micronutrient blend (17-5-11, 12-14 month) (Osmocote® Blend, ICL Specialty Fertilizers, Dublin, OH) at 8.9 kg·m^{-3} (15 lb·yd^{-3}). Following potting, all plants were placed on a full sun container nursery pad and received a total of 1.3 cm (0.5 in) of overhead irrigation per day via two daily cycles [each at 0.7 cm (0.25 in)]. All species were then lightly pruned using hand shears so that each individual cultivar was relatively similar in size prior to study initiation.

Herbicides were selected based upon grower interest and are some of the most common active ingredients used in container nursery production in Florida and included indaziflam (Marengo®G, Bayer Environmental Sciences, Research Triangle Park, NC) (granular formulation), dimethenamid-P (Tower® 6.0 EC, BASF Corp., Research Triangle Park, NC) (emulsifiable concentrate spray-applied formulation), dimethenamid-P + pendimethalin (FreeHand®, BASF Corp., Research Triangle Park, NC) (granular formulation), and prodiamine + isoxaben (Gemini® SC, Everiss NA, Inc. Dublin, OH) (suspension concentrate spray-applied formulation). As plant numbers were limited, each product was only evaluated at one rate and we chose to evaluate safety of each product at approximately 2× the recommended label rate to create a worst case scenario ensure each cultivar would tolerate a label rate of product. For experimental round 1, all plants were potted March 29 to 31st and spray-applied herbicide treatments (isoxaben + prodiamine and dimethenamid-P, Table 1) were applied on April 5 [27 C (81 F), 60% relative humidity, no wind, clear skies] using a CO_2 backpack sprayer calibrated to deliver 467 L·ha^{-1} (50 gal·A^{-1}) using an 8006 flat fan nozzle (TeeJet Technologies, Wheaton, IL). Granular treatments (indaziflam and dimethenamid-P + pendimethalin) were applied using a hand-shaker jar with a pre-measured amount of each herbicide and applied over plant foliage, making as many passes as possible. All plant foliage was dry at the time of application and remained dry for approximately 6 hours until irrigation was resumed. Following treatment, plants were grouped by species and cultivar in a completely randomized design with 6 single pot replications for each herbicide treatment and cultivar. A second herbicide application was applied approximately 8 wk later following the same methodology on May 29 [27 C, (81 F, 49% relative humidity, winds 4.8 kph (3 mph), clear skies]. This same methodology was used for experimental run 2 with treatments first being applied on April 12 [24 C, (75 F), 61% relative humidity, calm winds, cloudy skies] and the second

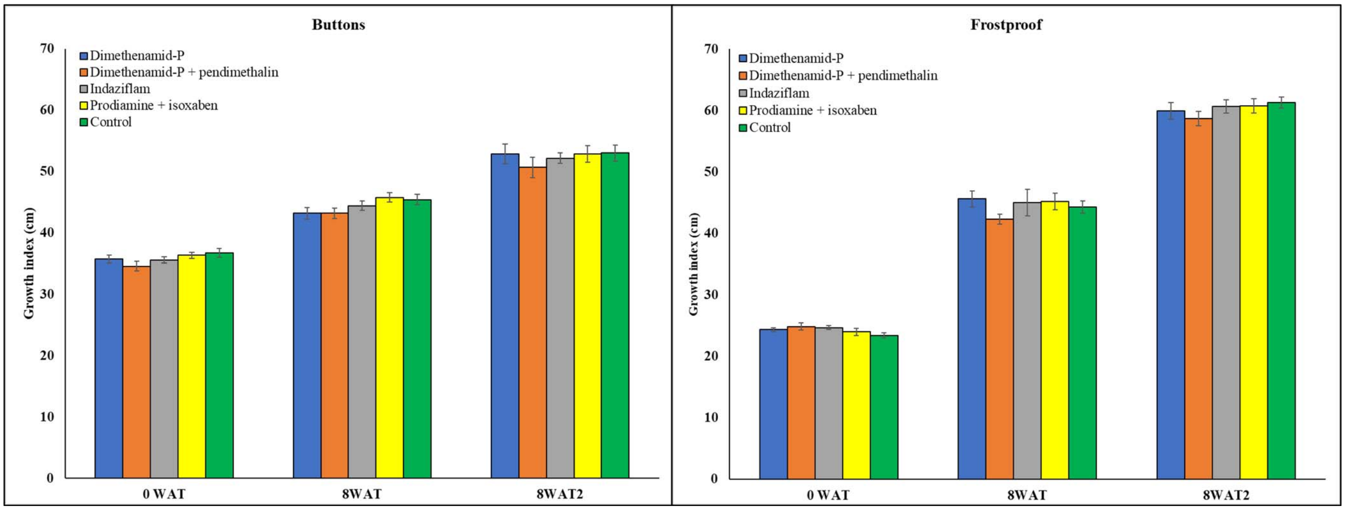

Fig. 1. Growth index [(plant height + width + perpendicular width)/3] of *Gardenia jasminoides* 'Buttons' and 'Frostproof' at 0 and 8 weeks after treatment (0 and 8 WAT) and at 8 weeks after a second treatment (8 WAT2) of preemergence herbicides including dimethenamid-P, dimethenamid-P + pendimethalin, indaziflam, and prodiamine + isoxaben applied at 2× the manufacturer's recommended label rate. Results were pooled over two experimental runs. Mean growth index and standard errors are shown.

application on June 7 [29 C, (85 F), 63% relative humidity, calm winds, clear skies].

Data collected included visual injury ratings on a scale of 0 to 10 where 0 = no injury and 10 = dead plant at 2, 4, and 8 weeks after the first treatment (WAT) and second treatment (WAT2). Plant growth was assessed by taking plant growth index measurements [(plant height + plant width1 + plant width 2)/3] at the time of potting (initial), before the second treatment was applied at 8 WAT, and at the conclusion of the study at 8 WAT2. All data were subjected to analysis of variance using JMP® Pro software (ver. 16, SAS Institute, Cary, NC) and post hoc means comparisons were made using Tukey's honest significance differences test (HSD) ($P \leq 0.05$) in order to make all possible treatment comparisons. Each species was analyzed separately and conducted as separate experiments but results for cultivars within each species are discussed concurrently.

Results and Discussion

Gardenia jasminoides. No injury of any kind was observed in either 'Frostproof' or 'Button's gardenia throughout the trial (Table 1). Further, growth index measurements taken at 8 WAT and 8 WAT2 showed no differences in gardenia growth regardless of herbicide treatment, and all plants were similar in size to the non-treated control at all evaluation periods (Fig. 1). Having low to no injury was somewhat expected in gardenia as it tends to tolerate over-the-top applications of preemergence herbicides well and is currently included as a tolerant species on approximately 20 different preemergence herbicide labels (Neal et al. 2017). Additionally, results are similar to previous reports where minimal to no injury were noted with these cultivars following applications of dimethenamid-P or dimethenamid-P + pendimethalin at rates similar to those evaluated here (Anonymous 2023).

Loropetalum chinense. While there was very minimal to no injury observed in 'Ruby' or Purple Diamond®, injury was observed in both Jazz Hands® and Crimson Fire® loropetalum in all herbicide treatments beginning with the first application (Table 2). In Jazz Hands®, injury consisted of some stunting and general chlorosis beginning at 2 WAT but some recovery was observed at 4 WAT with injury decreasing from ~2.6 to 3.7 down to 1.0 to 1.7. Injury was again observed at 8 WAT but mean ratings were all below 3.0. While injury was observed in all herbicide-treated plants at this time, no differences between herbicides were observed. Injury increased in all treatments following the second application with the Tower and FreeHand treatments resulting in the highest injury compared with the non-treated plants. Injury generally increased in both dimethenamid-P herbicide treatments (Tower and FreeHand) throughout the remainder of the trial, but some recovery was noted in plants treated with indaziflam or prodiamine + isoxaben. A high level of injury was also observed in Crimson Fire™, with plants displaying similar symptoms including chlorosis, stunting, and minor tip burn on young tender foliage, but in contrast to Jazz Hands® where injury was mostly observed in dimethenamid-P-treated plants, injury tended to be highest in Crimson Fire™ following applications of dimethenamid-P + pendimethalin or prodiamine + isoxaben, especially at trial conclusion at 8 WAT2.

With regards to growth index, no differences in growth index were observed in Purple Diamond® following the first application (Fig. 2). However, at 8 WAT, 'Ruby' treated with dimethenamid-P + pendimethalin or prodiamine + isoxaben were slightly smaller than the non-treated control plants. At the conclusion of the trial, prodiamine + isoxaben was the only treatment to cause any growth reduction in Purple Diamond® while both dimethenamid-P treatments and prodiamine + isoxaben reduced growth of 'Ruby' by 20 to 40% in comparison with non-treated plants. Significant growth reductions were also noted in both Jazz Hands® and Crimson Fire™, which was expected based upon the higher levels of injury that were observed. In JazzHands®, dimethenamid-P and dimethenamid-P + pendimethalin reduced growth by over 50% while

Table 2. Response of *Loropetalum chinense* 'Ruby', 'Shang-hi' PP18331, 'Irodori' USPP 27713, and var. rubrum 'PIILC-I' to sequential over-the-top applications of selected preemergence herbicides. Results pooled over two experimental runs conducted in 2023.

Herbicide	Rate[y] kg ai ha^{-1}	Rate[y] lb. ai A^{-1}	Phytotoxicity ratings (0 to 10)[z] 2 WAT[x]	4 WAT	8 WAT	2 WAT2[w]	4 WAT2	8 WAT2
			Loropetalum chinense 'Ruby'					
Dimethenamid-P	3.37	3.01	0.0 A[v]	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Indaziflam	0.1	0.09	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Control	0	0	0.0 A	0.2 A	0.0 A	0.0 A	0.0 A	0.0 A
			Loropetalum chinense 'Shang-hi' PP18331 (Purple Diamond®)					
Dimethenamid-P	3.37	3.01	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.0 A	0.0 A	0.0 A	0.0 A	0.2 A	0.0 A
Indaziflam	0.1	0.09	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.0 A	0.0 A	0.0 A	0.0 A	0.2 A	0.0 A
Control	0	0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
			Loropetalum chinense 'Irodori' USPP 27713 (JazzHands®)					
Dimethenamid-P	3.37	3.01	2.8 A	1.2 A	2.4 A	3.7 A	4.7 A	6.5 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	2.6 A	1.1 A	2.3 A	2.9 A	4.5 A	4.3 AB
Indaziflam	0.1	0.09	3.7 A	1.7 A	1.7 A	1.3 AB	4.0 AB	2.2 B
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	2.8 A	1.0 A	1.6 A	1.4 AB	3.3 AB	3.0 AB
Control	0	0	0.0 B	0.0 A	0.0 A	0.0 B	0.0 B	0.9 B
			Loropetalum chinense var. rubrum 'PIILC-I' (Crimson Fire®)					
Dimethenamid-P	3.37	3.01	1.1 AB	0.7 A	2.0 AB	2.1 AB	0.8 AB	3.3 AB
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	2.3 A	1.3 A	2.5 AB	3.2 A	3.8 A	6.8 A
Indaziflam	0.1	0.09	0.8 B	1.1 A	3.3 A	0.7 BC	0.8 AB	0.8 B
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.8 B	1.6 A	2.7 AB	2.3 AB	2.5 AB	6.9 A
Control	0	0	0.0 B	0.0 A	0.0 B	0.0 C	0.0 B	0.8 B

[z]Phytotoxicity ratings were taken on a scale of 0 to 10 based on overall health and marketability of the plants during the experiment where 0 = no injury and 10 = dead plant.

[y]Rate is expressed in amount of active ingredient applied on a per hectare or per acre basis. Rates tested represented approximately 2× the manufacturer label rate.

[x]The first application was applied on 4/5/2023 in experimental run 1 and 4/12/2023 in experimental run 2.

[w]The second application was applied on 5/29/2023 in experimental run 1 and 6/7/2023 in experimental run 2.

[v]Means within a column and cultivar followed by the same letter are not significantly different according to Tukey's HSD test ($P \leq 0.05$).

dimethenamid-P and prodiamine + isoxaben reduced growth of Crimson Fire™ similarly.

Injury to loropetalum following two back-to-back applications of dimethenamid-P containing herbicides would be expected as both Tower and FreeHand labels state to not apply sequential applications and to separate applications by at least 16 weeks, or a duration twice as long as was done in this study (Anonymous 2015a, 2017). Further, some slight stunting has been previously observed in 'Ruby' following back-to-back applications of dimethenamid-P at higher rates as were evaluated here (Anonymous 2023). However, three cultivars including 'Ruby', Purple Diamond®, and Crimson Fire™ were all stunted following two applications of isoxaben + prodiamine, which is generally considered one of the safer liquid preemergence herbicide combinations and is widely used in the nursery industry. There are currently four different loropetalum cultivars included as tolerant on the Gemini 3.7 SC herbicide label, including 'Ruby', but very high rates were evaluated here representing twice the highest standard label rate and the annual maximum amount of active ingredient (Anonymous 2023). While all herbicides caused injury, the only herbicide which caused no significant growth reduction in any cultivar was indaziflam, which of the cultivars evaluated in this study, only lists 'Ruby' as a tolerant cultivar.

While results differed by cultivar, Jazz Hands® and Crimson Fire™ both experienced a greater degree of injury and growth reduction in comparison with Purple Diamond® and 'Ruby'. While this could have been due to genetic variability alone, Jazz Hands® and Crimson Fire™ were also both smaller in size at the time of treatment (Fig. 2), being potted into 3.8 l (1 gal) pots compared with 11.3 l (3 gal)] and 7.7 L (2 gal) for 'Ruby' and Purple Diamond®, respectively. While there are few detailed studies evaluating crop stage or size impacts on the herbicide tolerance of ornamental species, studies have shown that plants such as *Hydrangea paniculata* Siebold are more sensitive to oryzalin and oxyfluorfen when exposed at early growth stages (young plants) (Poudyal et al. 2020). Studies in other agricultural sectors have shown that as crop size increases, herbicide tolerance may increase as well, depending upon the crop and herbicide (McCown et al. 2018, Polter et al. 2004,Wall, 1997, Young et al. 2003). Consequently, many nursery preemergence herbicide labels may state precautions against applications to very small plants or plants less than 13 cm (5 inches) in height (Anonymous 2021b). For loropetalum and other common ornamentals, additional research is warranted to evaluate how crop growth stage and crop size affect herbicide tolerance and key marketability aspects (flowering, leaf color, etc.) throughout the production cycle.

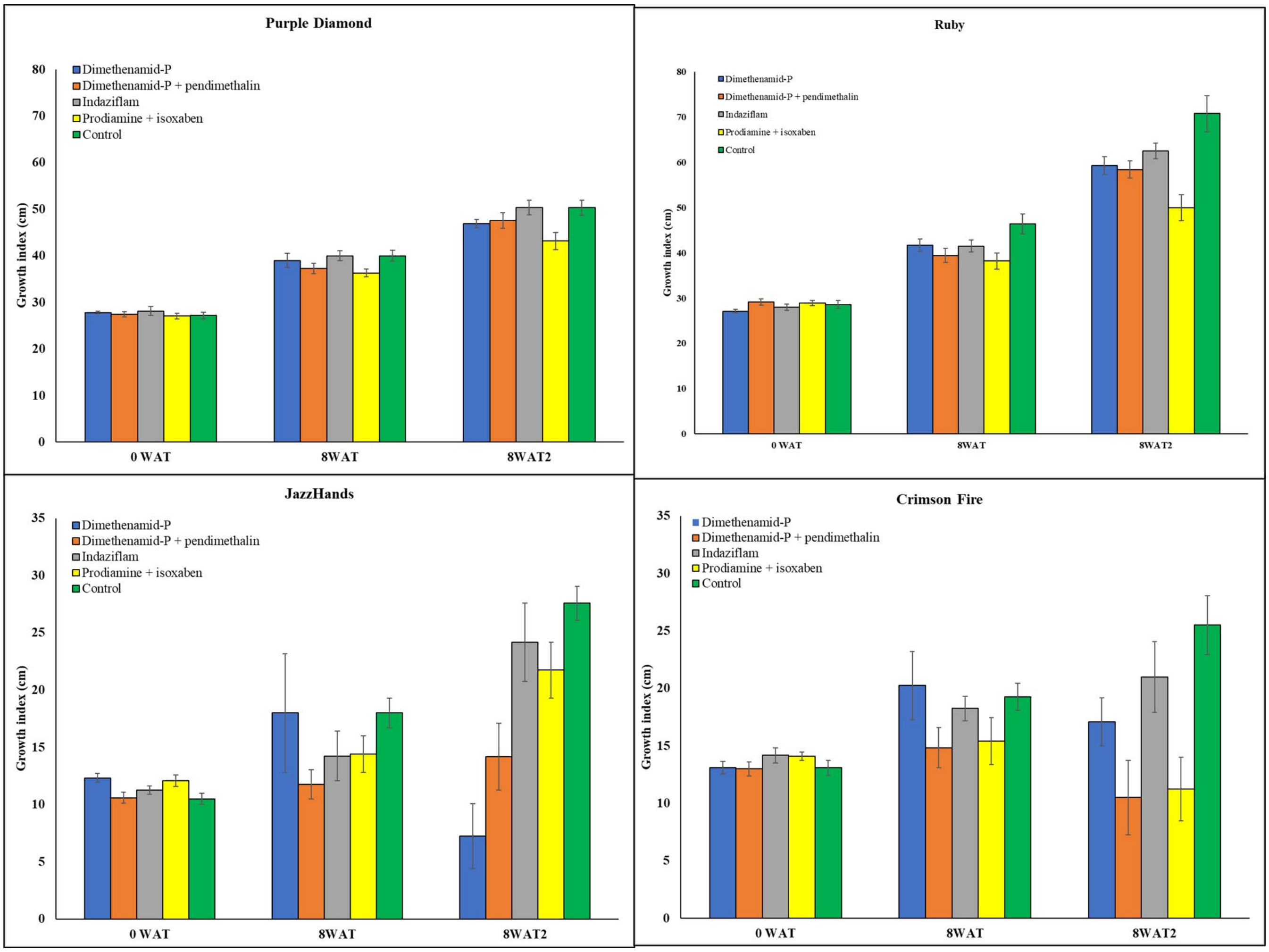

Fig. 2. Growth index [(plant height + width + perpendicular width)/3] of *Loropetalum chinense* 'Shang-hi' PP18331 (Purple Diamond®), 'Ruby', 'Irodori' PP 27713 (JazzHands®), and 'PIILC-I' (Crimson Fire®) at 0 and 8 weeks after treatment (0 and 8 WAT) and at 8 weeks after a second treatment (8 WAT2) of preemergence herbicides including dimethenamid-P, dimethenamid-P + pendimethalin, indaziflam, and prodiamine + isoxaben applied at 2× the manufacturer's recommended label rate. Results were pooled over two experimental runs. Mean growth index and standard errors are shown.

Lagerstroemia indica. Very minor injury was noted in Thunderstruck™ Ruby crape myrtle in all herbicide treatments following both the first and second applications which consisted of some leaf burning but injury ratings never exceeded 0.9 and all plants would have been considered highly marketable (Table 3). Similarly, only very minor leaf injury was noted on a few 'Tuscarora' plants following the first application but no injury following the second, and ratings never exceeded 0.3 in any treatment. Growth data followed the same trend and no differences in growth were observed between treated and non-treated plants in either cultivar (Fig. 3). Similar to gardenia, crape myrtles tend to be fairly tolerant to a wide range of preemergence herbicides both in container production and when field planted, with *L. indica* being listed as a tolerant species on approximately 20 different preemergence herbicide labels (Neal et al. 2017). Results from this trial are in agreement with previous assessments in that both cultivars showed a high degree of tolerance to all herbicides evaluated.

Rhododendron (azalea). Very little to no injury was observed in either Autumn Carnival® or 'Fashion' azaleas following the first application or at early evaluation periods following the second application (Table 4). For Autumn Carnival®, no treatment differences were observed throughout 2WAT2 and for 'Fashion', the only treatment which had significantly higher injury than the non-treated control were plants treated with prodiamine + isoxaben at 4 WAT (mean rating of 2.3) and these plants recovered fully by 8 WAT. Throughout the remainder of the experiments, 'Fashion' showed little to no injury with only some minor leaf chlorosis showing at times but was not consistent nor increased in any herbicide treatment. However, Autumn Carnival® injury ratings significantly increased in all treatments beginning at 4WAT2, characterized by defoliation and some leaf spotting. At this time, plants treated with dimethenamid-P and prodiamine + isoxaben had mean injury ratings higher than 4.0 while plants treated with dimethenamid-P + pendimethalin and indaziflam had mean injury ratings over 3.0. Injury increased again in all treatments at 8 WAT2, with severe defoliation and leaf spotting displaying on most of the foliage, including the non-treated control.

As non-treated control plants started to be affected, albeit to a lesser extent, leaf samples from multiple plants across all treatments were submitted to the University of

Table 3. Response of *Lagerstroemia* × 'JM7' PP34092 and 'Tuscarora' to sequential over-the-top applications of selected preemergence herbicides. Results pooled over two experimental runs conducted in 2023.

Herbicide	Rate[y] kg ai ha^{-1}	Rate[y] lb. ai A^{-1}	Phytotoxicity ratings (0 to 10)[z] 2 WAT[x]	4 WAT	8 WAT	2 WAT2[w]	4 WAT2	8 WAT2
			Lagerstroemia × 'JM7' PP34092 (Thunderstruck Ruby™)					
Dimethenamid-P	3.37	3.01	0.3 A[v]	0.2 A	0.2 A	0.0 A	0.2 A	0.9 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.0 A	0.3 A	0.3 A	0.0 A	0.2 A	0.3 A
Indaziflam	0.1	0.09	0.0 A	0.0 A	0.2 A	0.0 A	0.3 A	0.5 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.2 A	0.0 A	0.3 A	0.0 A	0.2 A	0.5 A
Control	0	0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.2 A
			Lagerstroemia indica × 'Tuscarora'					
Dimethenamid-P	3.37	3.01	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.0 A	0.0 A	0.3 A	0.0 A	0.0 A	0.0 A
Indaziflam	0.1	0.09	0.2 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.2 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Control	0	0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A

[z]Phytotoxicity ratings were taken on a scale of 0 to 10 based on overall health and marketability of the plants during the experiment where 0 = no injury and 10 = dead plant.

[y]Rate is expressed in amount of active ingredient applied on a per hectare or per acre basis. Rates tested represented approximately 2× the manufacturer label rate.

[x]The first application was applied on 4/5/2023 in experimental run 1 and 4/12/2023 in experimental run 2.

[w]The second application was applied on 5/29/2023 in experimental run 1 and 6/7/2023 in experimental run 2.

[v]Means within a column and cultivar followed by the same letter are not significantly different according to Tukey's HSD test ($P \leq 0.05$).

Florida Plant Pathology Diagnostic Clinic in Gainesville for analysis. Results revealed that plants were infected with both Pestalotia leaf spot [*Pestalotia rhododendri* (D. Sacc.) Guba (1929)] as well as anthracnose (*Colletotrichum* spp.). Both fungal pathogens are often stress related (Maharachchikumbura et al. 2011) and while no previous reports of increased severity following applications of herbicides evaluated here were found, in general, both pathogens have shown increases in severity when accompanied by herbicide related stress or injury (Duke et al. 2007, Johal and Huber 2009, Kao et al. 2019). While no plants died and no differences in growth index were observed at trial conclusion with either cultivar (Fig. 4), the severity of both fungal pathogens increased in herbicide-treated plants, being highest in plants treated with dimethenamid alone by the conclusion of the trial. As no other significant visual injury was observed, future work should evaluate the use of preemergence herbicides and what, if any, increase in susceptibility different ornamental taxa may have to different causal pathogens in the absence of a preventative fungicide program or other biotic/abiotic stresses.

Ligustrum sinense. No significant injury was noted in 'Variegatum' throughout the trial and injury was only recorded in two instances, once in dimethenamid-P treated plants and once in prodiamine + isoxaben treated plants, both at 4 WAT2 (Table 5). Injury was very minor (some discoloration of new growth) and mean ratings never

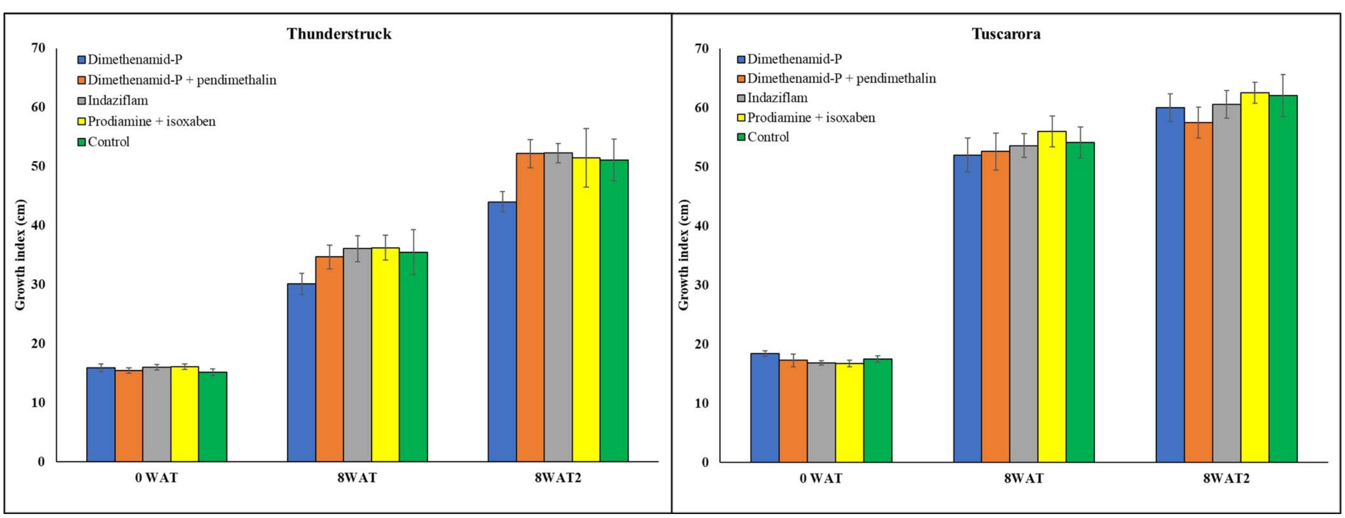

Fig. 3. Growth index [(plant height + width + perpendicular width)/3] of *Lagerstroemia indica* 'JM7' PP34092 (Thunderstruck® Ruby) and 'Tuscarora' at 0 and 8 weeks after treatment (0 and 8 WAT) and at 8 weeks after a second treatment (8 WAT2) of preemergence herbicides including dimethenamid-P, dimethenamid-P + pendimethalin, indaziflam, and prodiamine + isoxaben applied at 2× the manufacturer's recommended label rate. Results were pooled over two experimental runs. Mean growth index and standard errors are shown.

Table 4. **Response of *Rhododendron* 'Conlet' PP12111 and × 'Fashion' to sequential over-the-top applications of selected preemergence herbicides. Results pooled over two experimental runs conducted in 2023.**

Herbicide	Rate[y] kg ai ha^{-1}	Rate[y] lb. ai A^{-1}	Phytotoxicity ratings (0 to 10)[z] 2 WAT[x]	4 WAT	8 WAT	2 WAT2[w]	4 WAT2	8 WAT2
			Rhododendron 'Conlet' PP12111 (Autumn Carnival Encore®)					
Dimethenamid-P	3.37	3.01	0.8 A[v]	0.7 A	1.0 A	1.3 A	4.8 A	5.6 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.3 A	0.0 A	1.1 A	0.3 A	3.1 AB	3.8 AB
Indaziflam	0.1	0.09	0.5 A	0.0 A	0.3 A	0.8 A	3.2 AB	4.6 AB
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.8 A	0.5 A	0.4 A	1.8 A	4.2 A	4.2 AB
Control	0	0	0.0 A	0.6 A	0.0 A	1.3 A	1.0 B	2.5 B
			Rhododendron × 'Fashion'					
Dimethenamid-P	3.37	3.01	0.3 A	0.0 B	0.5 A	0.0 A	0.0 A	0.0 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.0 A	0.0 B	0.0 B	0.0 A	0.0 A	0.2 A
Indaziflam	0.1	0.09	0.0 A	0.0 B	0.0 B	0.0 A	0.0 A	0.3 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.0 A	2.3 A	0.0 B	0.2 A	0.0 A	0.3 A
Control	0	0	0.0 A	0.0 B	0.0 B	0.0 A	0.0 A	0.0 A

[z]Phytotoxicity ratings were taken on a scale of 0 to 10 based on overall health and marketability of the plants during the experiment where 0 = no injury and 10 = dead plant.

[y]Rate is expressed in amount of active ingredient applied on a per hectare or per acre basis. Rates tested represented approximately 2× the manufacturer label rate.

[x]The first application was applied on 4/5/2023 in experimental run 1 and 4/12/2023 in experimental run 2.

[w]The second application was applied on 5/29/2023 in experimental run 1 and 6/7/2023 in experimental run 2.

[v]Means within a column and cultivar followed by the same letter are not significantly different according to Tukey's HSD test ($P \leq 0.05$).

exceeded 0.2, indicating that all plants were highly marketable. While injury was initially low in 'Sunshine' at 2 WAT, injury increased in most treatments at 4 WAT, with the highest injury being observed in plants treated with prodiamine + isoxaben (rating of 2.5) and dimethenamid-P + pendimethalin (rating of 1.0). Injury then slightly increased in all herbicide treatments at 8 WAT2 but were markedly higher at 2 WAT2 following the second application. At this time, the highest injury was observed in plants treated with prodiamine + isoxaben and on average, plants receiving this treatment were not marketable, primarily due to leaf drop and stunting. Similar albeit much less severe symptoms were noted in other herbicide-treated plants at this time but were not statistically different from non-treated plants. Injury increased again in all treatments at 4WAT2 and by 8 WAT2, all plants, including non-treated plants were showing the same type of injury. No causal agents were found and no arthropod pests were found, but it was clear that after 16 weeks in production, all plants were experiencing stress, most likely an abiotic stress which could not be diagnosed.

Similar to injury ratings, growth data showed no effects of herbicide on 'Variegata' growth, and all plants were similar in size to the non-treated control by trial conclusion (Fig. 5). Growth in 'Sunshine' was highly variable, especially at the later evaluation dates and declined in all treatments from 8

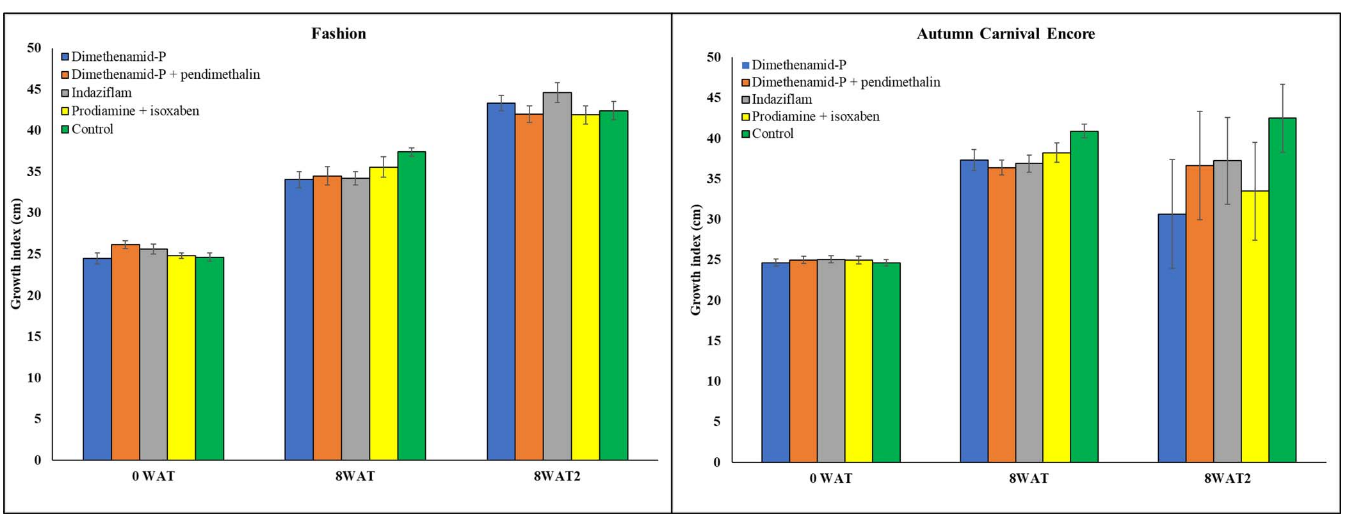

Fig. 4. **Growth index [(plant height + width + perpendicular width)/3] of *Rhododendron* × 'Fashion' and 'Conlet' PP1211 (Autumn Carnival Encore®) at 0 and 8 weeks after treatment (0 and 8 WAT) and at 8 weeks after a second treatment (8 WAT2) of preemergence herbicides including dimethenamid-P, dimethenamid-P + pendimethalin, indaziflam, and prodiamine + isoxaben applied at 2× the manufacturer's recommended label rate. Results were pooled over two experimental runs. Mean growth index and standard errors are shown.**

Table 5. **Response of *Ligustrum sinense* 'Sunshine' PP20379 and 'Variegatum' to sequential over-the-top applications of selected preemergence herbicides. Results pooled over two experimental runs conducted in 2023.**

Herbicide	Rate[y] kg ai ha^{-1}	Rate[y] lb. ai A^{-1}	Phytotoxicity ratings (0 to 10)[z] 2 WAT[x]	4 WAT	8 WAT	2 WAT2[w]	4 WAT2	8 WAT2
			Ligustrum sinense 'Sunshine'					
Dimethenamid-P	3.37	3.01	0.0 A[v]	0.3 B	1.4 A	1.4 B	3.3 AB	4.8 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.3 A	1.0 AB	2.0 A	1.6 B	1.0 B	4.7 A
Indaziflam	0.1	0.09	0.0 A	0.0 B	1.0 A	0.5 B	1.6 B	4.5 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.0 A	2.5 A	1.7 A	5.4 A	6.6 A	9.0 A
Control	0	0	0.0 A	0.0 B	0.0 A	0.0 B	1.8 B	4.5 A
			Ligustrum sinense 'Variegatum'					
Dimethenamid-P	3.37	3.01	0.0 A	0.0 A	0.0 A	0.0 A	0.1 A	0.0 A
Dimethenamid-P + pendimethalin	3.35 + 4.47	3.0 + 4.0	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Indaziflam	0.1	0.09	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A
Prodiamine + Isoxaben	3.36 + 2.24	3.0 + 2.0	0.0 A	0.0 A	0.0 A	0.0 A	0.2 A	0.0 A
Control	0	0	0.5 A	0.0 A	0.0 A	0.0 A	0.0 A	0.0 A

[z]Phytotoxicity ratings were taken on a scale of 0 to 10 based on overall health and marketability of the plants during the experiment where 0 = no injury and 10 = dead plant.

[y]Rate is expressed in amount of active ingredient applied on a per hectare or per acre basis. Rates tested represented approximately 2× the manufacturer label rate.

[x]The first application was applied on 4/5/2023 in experimental run 1 and 4/12/2023 in experimental run 2.

[w]The second application was applied on 5/29/2023 in experimental run 1 and 6/7/2023 in experimental run 2.

[v]Means within a column and cultivar followed by the same letter are not significantly different according to Tukey's HSD test ($P \leq 0.05$).

WAT to 8 WAT2, indicating abiotic or possibly other stress as discussed above, and no clear trends relating to herbicide effects on growth were observed with growth index measurements. Despite the fact that 'Sunshine' ligustrum declined at later evaluation dates based on both injury ratings and growth data, early data throughout the first 10 weeks of the trial clearly showed however that 'Sunshine' was much more sensitive to preemergence herbicides compared with 'Variegata'. As this is a newer cultivar, production guides or techniques have not been widely published but some growers have reported far more issues with 'Sunshine' compared with other *Ligustrum* spp., at least in regards to herbicide tolerance (Marble, personal communication). Data from this study supports these reports in that a high degree of injury was observed, and further screening is warranted in order to find tolerant options for this cultivar during production.

Results from these experiments indicate that cultivar tolerance to preemergence herbicides could widely differ between different ornamental genera. While no differences were observed in gardenia or crape myrtles, significant injury or growth differences were observed in cultivars of loropetalum, azaleas, and Ligustrum, while other cultivars of these species were largely unaffected. In the case of loropetalum, 'Ruby' and Purple Diamond® were largely unaffected by any preemergence herbicide evaluated while significant injury was noted on both Jazz Hands® and Crimson Fire™, most notably in plants treated with dimethenamid-P. A higher degree of injury in loropetalum

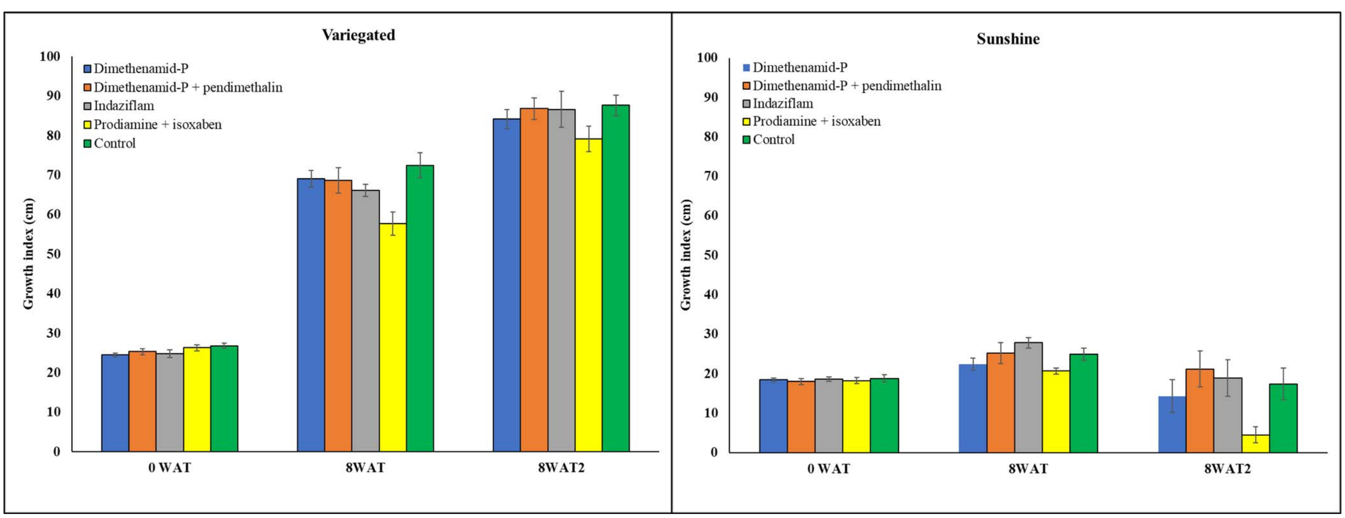

Fig. 5. **Growth index [(plant height + width + perpendicular width)/3] of *Ligustrum sinense* 'Variegatum' (Variegated) and 'Sunshine' at 0 and 8 weeks after treatment (0 and 8 WAT) and at 8 weeks after a second treatment (8 WAT2) of preemergence herbicides including dimethenamid-P, dimethenamid-P + pendimethalin, indaziflam, and prodiamine + isoxaben applied at 2× the manufacturer's recommended label rate. Results were pooled over two experimental runs. Mean growth index and standard errors are shown.**

Table 6. **Species and cultivars listed tolerant to over-the-top applications of five selected preemergence herbicides registered for use in nursery container plant production.**

Herbicide (Trade name)[y]	Species and cultivars included on selected herbicide labels[z]				
	Gardenia jasminoides	***Loropetalum chinense***	***Lagerstroemia indica***	***Rhododendron spp.***	***Ligustrum sinense***
Dimethenamid-P (Tower® EC)		*Loropetalum* spp.	*Lagerstroemia* spp.	*Rhododendron* spp.	*Ligustrum* spp. including Variegatum
Dimethenamid-P + pendimethalin (Freehand® G)	*Gardenia jasminoides*	*Loropetalum chinense*	*Lagerstroemia indica*	*Rhododendron* spp.	*Ligustrum* spp.
Indaziflam (Marengo® G)		Burgundy, Ruby, Plum Purple, Rubra	Burgundy Cotton, Pocomoke Pink, Sarah's Favorite, Siren Red	Autumn Debutante	
Prodiamine + isoxaben (Gemini® SC)	Mystery, August Beauty, Miniature	Ruby, Sizzling Pink, Razzleberri	Tuscarora, Burgundy Cotton	Fashion, Wakeiebisu, George Tabor, Delaware Valley, Girard Roberta, Girard Crimson, Golden Flare Exbury, Helmut Vogel, Hershey Red, Inga, Iren Koster, President Clay	Variegatum

[z]Genus, species, or cultivar included on selected preemergence herbicides as tolerant to over-the-top applications of labeled rates during container production (Anonymous 2015a, 2017, 2021b, 2023).

[y]G = EC = emulsifiable concentrate formulation, G = granular formulation, and SC = suspension concentration formulation.

following two back-to-back applications with dimethenamid-P, especially at a 2× label rate, would not be unexpected as both labels warn against sequential applications (Anonymous 2015a, 2017). While direct comparisons could not be made between all four cultivars due to size differences of the initial liner plants, multiple studies showed safety to 'Ruby' when treated with dimethenamid-P or dimethenamid-P + pendimethalin at the liner stage, similar to the size of Jazz Hands® or Crimson Fire™ (Anonymous 2023). Of the herbicides evaluated in the present study, 'Ruby' is the only cultivar specifically listed on any of the herbicide labels with both dimethenamid-P products being labeled for use in *Loropetalum* spp. or *Loropetalum chinense*, while indaziflam and prodiamine + isoxaben being labeled only for 'Ruby' and certain other cultivars not evaluated here (Table 6). As more and more loropetalum varieties are released, it would be recommended that growers test all new cultivars for tolerance prior to wide scale application.

Results in both azaleas and ligustrum species were confounded by biotic and likely abiotic problems, resulting in overall plant health decline by the conclusion of the experiments. However, injury data collected at early evaluation periods clearly showed differences in tolerance within the ligustrum cultivars with 'Sunshine' showing significant injury following two applications of prodiamine + isoxaben. As 'Sunshine' is a relatively new cultivar release, it is not currently included as a tolerant cultivar on any of the herbicides evaluated in this study (Table 6). Many labels however indicate that the product can be applied to the genus *Ligustrum* or specifically include *Ligustrum sinense* with 'Variegatum' listed as a tolerant cultivar. As 'Sunshine' becomes more popular and widely used, targeted safety trials with this cultivar are warranted to find herbicide options which can include 'Sunshine' as a tolerant plant.

Differences in azalea cultivars were much less pronounced and deserve further evaluation as Autumn Carnival® did show a slightly higher tendency to be injured compared with 'Fashion'. Of the five herbicides evaluated here, two (dimethenamid-P and dimethenamid-P + pendimethalin) list *Rhododendron* as a tolerant genus while indaziflam and prodiamine + isoxaben list one or more *Rhododendron* cultivars as being tolerant, but only prodiamine + isoxaben specifically lists 'Fashion'. There are currently over 30 Encore® cultivars available in the trade and while growers typically report a good level of tolerance to commonly used preemergence herbicides, cultivar differences may exist and warrant further investigation.

This study was to our knowledge, the first comparison of herbicide tolerance among multiple cultivars of several commonly grown ornamental species, and results showed significant variability among many of the cultivars. As exact environmental conditions cannot be replicated from site to site, and considering the high value of ornamental plants, it would be recommended to evaluate the tolerance of ornamental plants to new preemergence herbicides prior to wide-scale applications even when species are listed as tolerant. Most ornamental herbicide labels including wording stating that all cultivars or varieties have not been tested and to monitor for crop tolerance prior to large applications; results from this study clearly demonstrate that this should be a widely adopted practice even if crops are labeled as tolerant at the genus or species level.

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