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Short Title: PRE Herbicides for Cucurbits

Weed Control Using Preemergence Herbicides in Cucumberand Summer Squash Cultivars

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Abstract

There is limited information on the crop safety and weed control potential of commercially available preemergence (PRE) herbicides when applied under plastic mulch on various cucumber and summer squash cultivars grown in Florida. Two cucumber field trials were conducted at the Gulf Coast Research and Education Center in Wimauma, FL, in fall 2021 and spring 2022 to determine the effects of halosulfuron, pendimethalin, *S*-metolachlor, sulfentrazone, fomesafen, napropamide, oxyfluorfen, and flumioxazin on crop growth and development, yield, and the control of various weed species in the fields. We conducted this trial using three cucumber cultivars: 'Speedway', 'Dominator' and 'Mongoose'. Two summer squash field trials were conducted simultaneously evaluating all the mentioned herbicides except flumioxazin in addition to rimsulfuron on three summer squash cultivars: 'Spineless Beauty', 'Payload' and 'Everglade'. In the cucumber trials, crop damage varied with cultivar and ranged from 3 to 16% in fall 2021. All herbicides caused ≥10% crop injury except oxyfluorfen and flumioxazin at 28 d after transplanting (DATr) in spring 2022. In the summer squash trial, halosulfuron, *S*-metolachor, and flumioxazin were the three most injurious PRE herbicides, causing more than 10% crop injury in seed-grown summer squash with no effect of PRE herbicides in crop injury in transplant-grown summer squash in fall 2021. In spring 2022, crop injury with PRE herbicides varied with cultivar, where pendimethalin and *S*-metolachlor were consistently the most injurious PRE herbicides, causing 14 to 25% injury at 28 DATr. All PRE herbicides caused some damage to cucumber and summer squash with limited differences between cultivars and no effect on overall crop yield.

Nomenclature: Flumioxazin; fomesafen; halosulfuron; napropamide; oxyfluorfen; pendimethalin; rimsulfuron; *S*-metolachlor; sulfentrazone; cucumber, *Cucumis sativus* L.; summer squash, *Cucurbita pepo* L.

Keywords: Alternative fumigants; Florida vegetable production; plasticulture; preemergence herbicides; weed management.

Introduction

Cucumber is one of the important vegetable crops in Florida, with a harvest area of 8,300 ha and an economic value of $102 million. Florida also grows 3,885 ha of squash, including both summer and winter varieties, with an economic value of $45 million (USDA 2023). Field cucumbers and squash are typically cultivated on raised beds covered with plastic mulch in Florida. They can be grown multiple times a year, excluding the extremely hot months like July and August, and the cold months when there is a risk of frost. While cucumber can be grown as a primary crop, most field cucumbers are cultivated as a second crop following the termination of tomato, bell pepper, or eggplant on the same plastic mulch. Despite its economic significance, cucumber production in Florida has declined over the past two decades due to increased imports from Mexico (Huang et al. 2022). Florida primarily grows summer squash including yellow squash, straightneck squash, crookneck squash, and pattypan squash.

Weeds are one of the major production problems faced by Florida cucurbit growers. Although plastic mulch effectively suppresses weeds on the bed, nutsedge species penetrate the plastic mulch, and broadleaf and grassy weed species emerge and grow in the planting holes where they compete directly with the crop. Even at low densities (1 to 3 weeds m^{-2}), common Florida broadleaf weeds such as smooth pigweed or livid amaranth can cause yield reductions of up to 10% in cucumber crops (Berry et al. 2017). Gianessi and Riegner (2007) reported that weeds could lead to yield losses of up to 66% in cucumber fields across the United States, and Sanuel (2021) reported yield reductions ranging from 45 to 90% due to weed interference. Even though there is no published information on yield loss due to weeds in summer squash, the above data indicate that cucurbits tend to be susceptible to competition.

Weed management in Florida cucumber and squash fields traditionally relied on soil fumigation with methyl bromide and hand weeding. After the ban on methyl bromide, alternative fumigants have struggled to provide consistent and effective control (McMillan and Bryan 2001; Vansickle and Nalampang 2002; Gilreath et al. 2004). Herbicides traditionally served as a supplemental weed control tool with soil fumigation in plasticulture production. However, they become the primary weed control method when cucurbits are grown on bare soil, where soil fumigation is not feasible, or when cucurbits are double-cropped with another vegetable in plasticulture production. Approximately 66% of US cucurbit production fields are treated with herbicides, underscoring the role of herbicide in weed control (Gianessi and Riegner 2007).

Almost no preemergence (PRE) herbicides are registered for use under the plastic mulch in cucumber and summer squash. Clomazone and clomazone + ethalfluralin are registered for bare ground production but are not typically recommended for sandy soil with low organic matter which is typical of Florida. Halosulfuron is the only PRE herbicide registered for use under the plastic mulch for cucumber but cannot be used with summer squash. A limited number of registered post-transplant or postemergence herbicide options can be sprayed over the top of both crops with more options available between the rows (Samuel Daramola 2021).

Various published field trials have examined different commercially available PRE herbicides in cucumber (Derr and Monaco 1982; Al-Khatib et al. 1995; Trader et al. 2007; Besancon et al. 2020) and squash (Peachy et al. 2012; Walters et al. 2002). However, these studies did not specifically test the herbicides under plasticulture systems, where they would serve as supplemental weed control tools alongside soil fumigation during bed formation. Culpepper et al. (2009) evaluated multiple PRE herbicide in summer squash varieties in Georgia under low density polyethylene mulch (LDPE) plastic mulch but did not evaluate their use under totally impermeable films (TIF). There is some evidence that crop injury following the use of PRE herbicide may increase under high-barrier films versus low density mulches (Wallace et al. 2017).

It is hypothesized that using PRE herbicides under the plastic mulch, alongside standard soil fumigation, could efficiently manage weeds in Florida's cucumber and summer squash cultivation without inducing notable crop injury or yield reduction. Examining the influence of PRE herbicides on diverse commercially cultivated cucumber and summer squash cultivars could provide Florida growers with alternative tools. Hence, this research aims to evaluate the effect of various PRE herbicides on weed suppression, crop tolerance, growth, and yield across three cucumber and three summer squash cultivars commonly grown in Florida.

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Materials and Method

Experimental Design and Treatment Application

Four field experiments were conducted at the Gulf Coast Research and Education Center in Wimauma, FL (coordinates 27.76°N, 82.22°W) during the fall of 2021 and spring of 2022. Two experiments evaluated preemergence (PRE) herbicides for cucumber and two for summer squash. Fumigation, transplant, and data collection dates were similar for both crops in each season. The experimental site had a Myakka fine sand soil texture, characterized as sandy, siliceous hyperthermic Oxyaqui Alorthod. In fall 2021, the soil had 1.26% organic matter with 92, 3, and 5% sand, silt, and clay, respectively. In spring 2022, the soil had 0.7% organic matter with the same sand, silt, and clay ratio as in fall 2021.

Fields were prepared by disking followed by shaping and compressing the soil to form the raised beds using bed-pressing equipment (Kennco Manufacturing Ruskin, FL). The beds were spaced 1.5 meters apart (center to center), 30.5 cm tall, and 66 cm wide at the top. Each experimental plot consisted of a single raised bed with a linear length of 7.62 meters. The beds were fumigated using 1,3-dichloropropene+chloropicrin (Pic-Clor 60, Soil Chemicals Corporation D/B/A Cardinal Professional Products, Hollister, CA) at 225 kg ha^{-1} with a standard fumigation rig. Dates for fumigation were the same for cucumber and summer squash trials and were July 26 and January 12 for the fall 2021 and spring 2022, respectively.

The experimental design employed a randomized complete block design with four replications and separate experiments for the cucumber and summer squash trials. The treatments were arranged in a 3×10 factorial design, with crop cultivar as the first factor and PRE herbicide as the second factor. PRE herbicides were applied at the recommended rates (Table 1) on the bed top using a CO_2 pressurized backpack sprayer (Bellspray Inc., Opelousa, LA). The herbicides evaluated in this experiment were selected based on known efficacy on problem weeds in the area and preliminary information suggesting the possibility of crop tolerance. The sprayer was equipped with a single 8002 EVS nozzle (Teejet Technologies, Wheaton, IL) at a pressure of 240 kPa and a spray volume of 189 L ha^{-1}. Immediately after treatment application, two drip tapes were buried 2.5 cm beneath the soil surface and the beds were covered with a totally impermeable film (TIF, 1.25 mm thickness, Berry Plastics Corp. in Evansville, IN). Three cultivars of slicing cucumber ('Speedway,' 'Dominator,' and 'Mongoose') and summer squash (‘Spineless Beauty’, ‘Payload’ and ‘Everglade’) were

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transplanted in a single row with 30 cm plant spacing. Both crops were transplanted on September 2, 2021, and February 23, 2022. Each experimental unit consisted of 10 plants. For the summer squash trial in fall 2021, due to a plant shortage, five plants were directly seeded in the field and five plants were transplanted following growth in a greenhouse.

Data Collection

Crop injury on cucumber and summer squash plants was visibly assessed on a scale of 0 to 100%, where 0 indicated no crop injury and 100 represented complete crop death. Injury was evaluated based on yellowing, wilting, and plant tissue death or deformation. The evaluations were conducted 7, 14, and 28 d after transplant (DATr). Additionally, vine length for cucumber and crop height for summer squash were measured using a meter stick (cm) at 14 and 28 DATr. Crop mortality was also recorded at the first harvest and was collected only in spring 2022 for cucumber. Crop mortality data was collected for both seasons for summer squash. Mortality data is the percentage of plants that did not survive from planting to harvest; however, mortality data for summer squash in fall 2021 were the combination of seedling mortality and lack of seed emergence. In the fall of 2021, crop injury and plant height were recorded separately for seed-grown and transplant-grown summer squash.

For weed control evaluations, nutsedge species penetrating the plastic mulch were counted across the entire experimental plot at three-time points: transplant, midseason, and first harvest. Yellow nutsedge (*Cyperus esculentus* L.) and purple nutsedge (*Cyperus rotundus* L.) were two nutsedge species recorded in this study. In the fall 2021 trial, the corresponding dates for transplant, midseason, and first harvest were September 2, September 13, and October 11, respectively. In the spring of 2022, those dates were February 23, March 28, and April 21, respectively. Additionally, the number of broadleaf and grassy weeds growing in the planting holes was noted at the first harvest.

Cucumber and summer squash were harvested manually, with ten plants harvested per experimental plot. In the fall of 2021, cucumbers and summer squash were harvested on four different dates: October 1, October 4, October 7, and October 15. In the spring of 2022, there were six harvesting dates for both crops: April 4, April 7, April 11, April 14, April 18, and April 21. Yield from seed and transplant-grown summer squash was reported separately in the fall of 2021.

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Data Analysis

Data were analyzed using the PROC GLIMMIX procedure in SAS (version 9.4; SAS Institute, Cary, NC). PRE herbicide type, cucumber or summer squash cultivar, dates for data collection (for repeated measured variables) and all interactions containing these three factors were fixed effects in the analysis, whereas block was considered a random effect. The LSMEAN statement was used to determine significant differences between treatment means at the significance level of $P \leq 0.05$. The data from the fall and spring seasons were analyzed separately because they were conducted as separate experiments with different growing weather conditions (Table 2).

Results and Discussion

Cucumber

Vine Length

In fall 2021, vine length varied with cultivars with 'Dominator' and 'Mongoose' having significantly longer vine lengths than 'Speedway' (Table 3). None of the PRE herbicides had a significant effect on vine length. These results align with Webster et al. (2003) who evaluated the effect of halosulfuron on cucumber and squash cultivars and found that cucumber cultivars were more tolerant to halosulfuron than squash and halosulfuron had no effect on cucumber plant biomass or vine length based on the greenhouse studies.

In spring 2022, vine length did not differ between cultivars, whereas the effect of PRE herbicide was significant. Herbicides such as flumioxazin, *S*-metolachlor, sulfentrazone, and fomesafen resulted in a 13 to 28% reduction in vine length compared to the nontreated control (Table 3). The differences between seasons cannot be adequately explained but have increased susceptibility to PRE herbicides has been observed in other crops when the herbicides were applied during the cooler spring temperatures (unpublished data). There was no significant interaction between cultivar and PRE herbicides in both seasons, and as a result, the data are presented for cultivars and PRE herbicides separately. Furthermore, the interaction between the date of vine length measurement, cultivars, and PRE herbicides was insignificant in fall 2021 and spring 2022; therefore, injury data were averaged across the two measurement dates (Table 3).

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Crop Injury

In the fall of 2021, cultivar and PRE herbicide had a significant effect on crop injury. There was a significant PRE herbicide by cultivar interaction; thus, injury data were presented across all PRE herbicide and cultivar combinations (Table 4). Injury data with all combinations ranged between 5 to 16% where the highest crop injury was caused by sulfentrazone in cultivar ‘Mongoose’ and the lowest was caused by oxyfluorfen in cultivar ‘Dominator’. Injury data were averaged across three measurement dates because there was no significant interaction between the date of injury measurement, cultivar, and PRE herbicide. This indicates plants did not recover from herbicide injuries over time.

In spring 2022, there was a significant effect of PRE herbicide whereas the effect cultivar was not significant at 7 DATr (Table 4). There was a significant PRE herbicide by cultivar interaction, and thus, injury data were presented across all PRE herbicide and cultivar combinations. Injuries from all cultivar and PRE herbicide combinations were less than 14%. The highest crop injury resulted from flumioxazin in ‘Dominator’ and *S*-metolachlor in ‘Mongoose’. The lowest crop injury resulted from flumioxazin in ‘Speedway’ and napropamide in ‘Dominator’ (Table 4). At 14 DATr, cultivars and PRE herbicides had significant effect on crop injury. Cultivar ‘Speedway’ had a lower injury of 8% compared to 10% injury with ‘Dominator’ and ‘Mongoose’ (Table 3). This indicates cucumber cultivars differ in their susceptibility to the PRE herbicide application. *S*-metolachlor, sulfentrazone, fomesafen, and flumioxazin were the most injurious herbicides causing 12 to 14% injury. It is noteworthy that flumioxazin is the only herbicide registered for use in cucumber to control row middle weeds out of all the herbicides used in this experiment. At 28 DATr, there was a significant effect of PRE herbicide whereas the effect of cultivar was not significant. Pendimethalin and *S*-metolachlor were the two most injurious PRE herbicides causing 32% and 24% injury respectively (Table 3). *S*-metolachlor consistently caused the highest crop stunting across all measurement dates which had previously been shown to induce 13% and 36% crop stunting in the cucumber cv 'Python' when applied as a PRE herbicide at 700 g ai ha^{-1} and 1400 g ai ha^{-1}, respectively (Besancon et al. 2020). In contrast, Peachey et al. (2012) reported less than 5% crop injury in cucumber cv ‘Speedway’ even with the high rate (2100 g ai ha^{-1}) application of *S*-metolachlor. Bescancon et al. (2020) speculated that the high clay (20%) and organic matter content (2.4%) may have increased *S*-metolachlor adsorption to the soil particles resulting in reduced herbicide uptake by plants and reduced crop injury in the study by Peachey et al (2012). The field site used in our experiment and Bescancon et al.

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(2020) was similar with high sand (>90%) and low organic matter content (<2%). Furthermore, Peachey et al. (2012) also found the cucumber lacks tolerance to other PRE herbicides with injury ranging from 18 to 39% at 14 DATr and 6 to 25% at 28 DATr with fomesafen at 350 g ai ha^{-1}. These injuries percentages increased from 24 to 44% at 14 DATr and 40 to 59% at 28 DATr with higher rate of fomesafen at 700 g a.i./ha. Fomesafen applied at 269 g ai ha^{-1} caused only 15% injury at 28 DATr in our studies. Because there was no significant ($p<0.05$) interaction between cultivar and PRE herbicide with injury data at 14 DATr and 28 DATr, data were separately averaged for cultivars and PRE herbicides. Furthermore, due to significant interaction between cultivars, PRE herbicide and date of injury measurement, injury data were presented by date of injury measurement date spring 2022 (Table 3).

Mortality

In spring 2022, there was a significant effect of cultivar whereas the effect of PRE herbicide was not significant (Table 3). There was no significant interaction observed between herbicide and cucumber cultivars, therefore, mortality data was separately averaged across the cultivar and PRE herbicide. Cultivar 'Speedway' had the lowest mortality of 8% than other cultivars 'Dominator' and 'Mongoose'. The herbicide had no significant effect on mortality, but it is worth noting that plots, where pendimethalin was applied, had a numerically higher mortality rate at 34%.

Yield

In both seasons, cultivars had a significant effect, whereas the effect of PRE herbicide was not significant. No significant interaction was observed between PRE herbicide and cucumber cultivar, so the yield data was averaged across the cultivars and herbicides (Table 3). Even though there was a significant cultivar effect, the yield from each cultivar was inconsistent. For example, 'Speedway' had the highest yields in fall 2021 but lowest in spring 2022. This suggests that overall yield likely varies with environmental conditions. Most importantly, the use of a PRE herbicide in the absence of weed pressure had no effect on yield despite herbicide damage early in the season. Therefore, the use of a PRE herbicide may be beneficial in fields with a history of high weed density. Previous field trials have shown a significant increase in cucumber fruit yield and count with the use of PRE herbicides such as *S*-metolachlor and bensulide (Besancon et al. 2020). However, herbicide selection is critical as Peachey et al. (2012) found that fomesafen at 280 g ai ha^{-1} resulted in little fruit in two out

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of three experiments with the 'Speedway' cultivar. Further research is needed to evaluate the herbicides that caused the least damage in this trial in fields with high weed densities. This would enable us to determine if yield increases associated with weed control are adequate to compensate for the added management costs.

Summer squash

Plant Height

None of the PRE herbicides appear to adversely affect the growth of seed-grown summer squash (Figure 5), although, in the fall of 2021, there was a significant effect of cultivar, PRE herbicide, and interaction between cultivar and PRE herbicide on plant height of seed-grown summer squash (Table 5). Because there was a significant interaction between cultivar and PRE herbicide, plant height data was presented with all cultivar and PRE herbicide combinations. There was no significant effect of cultivar, PRE herbicide, and interaction between cultivar and PRE herbicide on plant height for transplant-grown summer squash (Table 6). Plant height data were averaged separately for cultivar and PRE herbicide due to the lack of significant interaction (Table 6). Because there was no significant interaction ($p>0.05$) observed between the cultivar, PRE herbicide and the date of plant height measurement, plant height data was averaged across two measurement dates for both seed and transplant-grown summer squash.

In spring 2022, there are significant effects of cultivar and PRE herbicide on plant height. Cultivar ‘Payload’ was the tallest cultivar out of the three cultivars evaluated. Flumioxazin and halosulfuron significantly reduced plant height to 40 and 20% respectively compared to the non-treated control (Table 6). Plant height data were averaged separately for cultivar and PRE herbicide due to lack of significant interaction between cultivar and PRE herbicide. Because no significant interaction was observed between the cultivar, PRE herbicide, and the date of plant height measurement, plant height data was averaged across two measurement dates.

Crop Injury

In fall 2021, there was a significant effect of PRE herbicide on crop injury of seed-grown summer squash, whereas the PRE herbicide effect was non-significant for crop injury of transplant-grown summer squash. Halosulfuron, *S*-metolachor, and flumioxazin were the three most injurious PRE herbicides causing more than 10% crop injury in seed-grown

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summer squash (Table 6). Our results are different from Randell et al. (2020), where halosulfuron at 80 g ai ha^{-1} resulted in 2 to 3% crop injury in summer squash var ‘Enterprise’ when applied 14 to 21 d before planting. However, the injury increased to 40% if applied 1 day before planting. PRE herbicides in our study were applied 40 d before planting and were applied along with soil fumigants. In transplant-grown summer squash, all injuries were less than 4% with all PRE herbicides. Cultivar did not have any effect on crop injury. There was no significant ($p>0.05$) interaction between cultivar and PRE herbicide; therefore, data were averaged across cultivar and PRE herbicide separately for both seed and transplant-grown summer squash. In addition, injury data were averaged for two injury data measurement dates because of no significant interaction between cultivar, PRE herbicide and date of injury data measurement.

In spring 2022, there was a significant interaction observed between the cultivar, PRE herbicide, and the date of injury measurement, therefore, the injury data were presented by the date of injury measurement (Table 6). There was no significant effect of cultivar and herbicide on crop injury at 7 DATr. At 14 DATr, PRE herbicide caused significant injuries ranging from 9 to 12% except flumioxazin which caused 18% crop injury. Cultivar ‘Payload’ was significantly more tolerant to PRE herbicide with an average of 8% injury compared to ‘Spineless Beauty’ and ‘Everglade’. As there was no significant interaction between the cultivar and PRE herbicide, injury data were separately averaged for the cultivar and PRE herbicide. There was a significant effect of cultivar and PRE herbicide on crop injury at 28 DATr. Injury data were presented in all cultivar and PRE herbicide combinations because of significant interactions between these two factors. Pendimethalin and *S*-metolachlor consistently had the highest crop injury of 18 to 14% and 14 to 25% respectively in all three cultivars, similar results observed in the cucumber trial in spring 2022 (Table 6). Besancon et al. (2020) reported *S*-metolachlor as a suitable PRE herbicide for summer squash ‘Gold Prize’ where it caused 1 to 4% crop injury when applied at 1400 g ai ha^{-1} which might be an acceptable level of crop injury for cucumber growers unlike, 14 to 25% crop injury in our studies. Besancon et al (2020) also reported less than 17% crop stunting four weeks after planting when *S*-metolachlor was applied at 1400 g ai ha^{-1}. In addition, Grey et al. (2000) observed severe stunting of 31% and 68% in squash varieties such as 'Dixie' and 'Senator' when pendimethalin was applied at rates of 80 g ai ha^{-1} and 560 g ai ha^{-1} respectively, as a PRE herbicide in one of the two seasons studied.

Halosulfuron, sulfentrazone, fomesafen, and oxyfluorfen were four herbicides that caused no crop injury by 28 DATr (Table 5). This agrees with Randell et al. (2020), where halosulfuron appeared to be a safe herbicide for summer squash, unlike our results from fall 2021. This result also supports the fact that halosulfuron is the only herbicide tested that is registered for summer squash.

Crop Mortality

There was no significant effect of cultivar and PRE herbicide on crop mortality in both seasons. Additionally, there was no interaction between cultivar and PRE herbicide; therefore, crop mortality data was averaged across cultivar and PRE herbicide separately in both seasons. There was relatively higher crop mortality in the range of 19 to 39% in fall 2021, whereas all treatments had a crop mortality of less than 10% for all treatments in spring 2022 (Table 4). The high mortality rate in the fall season might be attributed to higher temperatures at the time of planting compared to the spring season (Table 6).

Yield

There was no significant effect of cultivar and PRE herbicide on crop yield in both seasons. Additionally, there was no interaction between cultivar and PRE herbicide; therefore, yield data were separately averaged across cultivar and PRE herbicide in both seasons (Table 6). Studies by Randell et al (2020) reported 0, and 10 to 40% yield loss with the use of halosulfuron at 80 g ai ha^{-1} when applied 21 d before planting (DBP) and 1 to 14 d DBP, respectively. Furthermore, they reported a 4% yield loss with halosulfuron at 160 g ai ha^{-1} when applied 21 DBP. Halosulfuron caused a 25 to 27% yield reduction in our studies even though it was not statistically significant.

Nutsedge Control

In the cucumber trial in the fall of 2021, there was no significant effect of cultivar and PRE herbicide on nutsedge density (Table 7). There was no significant interaction between cultivar, PRE herbicide, and date of nutsedge data collection; therefore, nutsedge data was averaged across the three measurement dates. Furthermore, nutsedge data were separately averaged for cultivar and PRE herbicide because of no significant interaction. It is worth noting that although PRE herbicides did not significantly reduce nutsedge density, all PRE herbicides tended to suppress the nutsedge population by 25 to 40% compared to the non-treated control (Table 7).

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In the cucumber trial in the spring of 2022, there was a significant effect of cultivar and PRE herbicide on nutsedge density (Table 8). There was no significant interaction between cultivar, PRE herbicide, and date of nutsedge data collection therefore, nutsedge data was averaged across the three measurement dates. Furthermore, nutsedge data were presented across all cultivar and PRE herbicide combinations because of a significant interaction between cultivar and PRE herbicide. In spring 2022, the overall weed population was lower compared to the fall of 2021. The highest nutsedge population was of 4 nutsedge m^{-2} in the plots where halosulfuron was applied in the 'Mongoose' cultivar (Table 8).

In the squash trials, there was no significant effect of cultivar and PRE herbicide on the nutsedge population (Table 7). The interaction between cultivar, PRE herbicide, and date of nutsedge data collection was not significant; therefore, nutsedge populations were averaged across three measurement dates. Nutsedge data were averaged for cultivar and PRE herbicide separately because of no significant interaction between cultivar and PRE herbicide. Halosulfuron was the most effective PRE herbicide that caused 83% suppression of nutsedge even though it was not statistically significant (Table 7). In spring 2022, nutsedge counts were minimal therefore, this data was excluded from the analysis.

Previous field trials have evaluated the herbicidal efficacy of PRE herbicides used in our study. *S*-metolachlor at 225 g ai ha^{-1} was able to provide up to 72% nutsedge control when applied as PRE herbicide in a bell pepper-cucumber double cropping system in Florida (Gilreath et al. 2004). The efficacy of *S*-metolachlor against broadleaf and grassy weeds at 700 g ai ha^{-1} as well as against purple nutsedge at 1,366 g ai ha^{-1} has been demonstrated in various field trials (Besançon et al. 2020; Yu et al. 2020). *S*-metolachlor at 2250 g ai ha^{-1} can provide nutsedge control as high as 60% with no interaction with fumigants applied at the time of bed formation (Gilreath et al. 2004). Fomesafen at 710 or 1070 g ai ha^{-1} is another effective herbicide that has shown as herbicidal efficacy as *S*-metolachlor at 280 or 420 g ai ha^{-1} for nutsedge control in Florida plasticulture fields (Miller and Dittmar 2014). However, Boyd (2015) reported that *S*-metolachlor applied at 1070 g ai ha^{-1} or fomesafen at 420 g ai ha^{-1} on the bed top before laying the plastic was not an effective herbicide for reducing nutsedge population compared to the non-treated control. In contrast, other herbicides such as oxyfluorfen and halosulfuron provided consistently better nutsedge control than the nontreated control. Flumioxazin has shown up to 85% yellow nutsedge control when applied as PRE herbicide at 108 g ai ha^{-1} in sweet potato which is half of the rate used in our experiment (Kelly et al. 2006). Further studies are needed to clarify these varying results.

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Weed Control at Planting Hole

The presence of broadleaf and grassy weeds at the planting holes was minimal in all trials in all experimental plots, with most of the weed count being zero. Therefore, the weed data at the planting hole were excluded from the data analysis.

Practical Implications

All PRE herbicides tested caused varying levels of crop injury but there were no adverse effects on crop yield. None of the PRE herbicides controlled nutsedge. Some of the PRE herbicides appear to suppress nutsedge but the differences were not significant in this study. There were cultivar effects and significant interactions between cultivar and PRE herbicide in some instances, but overall, the differences in cultivar susceptibility to PRE herbicides tended to be small. Therefore, crop cultivar selection cannot be used as a method to avoid herbicide injury. Given that none of the PRE herbicides negatively impacted crop yield, we recommend further evaluations in locations with high weed densities to determine if weed control could lead to improved yields even if early-season crop damage occurs.

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Competing Interests

The authors declare none.

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References

Al-Khatib K, Kadir S, Libbey C (1995) Broadleaf weed control with clomazone in pickling cucumber (*Cucumis sativus*). Weed Technol 9:166–172

Berry A, Stall WM, Rathinasabapathi B, Macdonald GE, Charudattan R (2006) Smooth pigweed (*Amaranthus hybridus* L.) and livid amaranth (*Amaranthus lividus*) interference with cucumber (*Cucumis sativus*). Weed Technol 20:227–231

Besançon TE, Wasacz MH, Carr BL (2020) Weed control and crop tolerance with *S*-metolachlor in seeded summer squash and cucumber. Weed Technol 34:849–856.

Boyd NS (2015) Evaluation of preemergence herbicides for purple nutsedge (*Cyperus rotundus*) control in tomato. Weed Technol 29:480–487.

Derr JF, Monaco TJ (1982) Ethalfluralin activity in cucumber (*Cucumis sativus*). Weed Sci 30:498–502

Gianessi LP, Reigner NP (2007) The value of herbicides in U.S. crop production. Weed Technol 21:559–566

Gilreath JP, Noling JW, Santos BM (2004) Methyl bromide alternatives for bell pepper (*Capsicum annuum*) and cucumber (*Cucumis sativus*) rotations. Crop Prot 23:347–351

Grey TL, Bridges DC, NeSmith DS (2000) Tolerance of cucurbits to the herbicides clomazone, ethalfluralin, and pendimenthalin. I. summer squash. HortScience, 35:632–636

Huang KM, Guan Z, Hammami A (2022) The U.S. fresh fruit and vegetable industry: An overview of production and trade. Agriculture 12:1719, https://doi.org/10.3390/agriculture12101719.

McMillan RTJ, Bryan HH (2001) Effect of metam sodium and methyl bromide on root-knot nematode yellow nutsedge, and damp-off on cucumber cv. Dasher II. Pages 266-267

In Proceedings of the Florida State Horticultural Society.

Miller M, Dittmar P (2014) Effect of PRE and POST-directed herbicides for season-long nutsedge (Cyperus spp.) control in bell pepper. Weed Technol 28:518-526

Peachey E, Doohan D, Koch T (2012) Selectivity of fomesafen-based systems for preemergence weed control in cucurbit crops. Crop Prot 40:91–97

Randell TM, Vance JC, Culpepper AS (2020) Broccoli, cabbage, squash and watermelon response to halosulfuron preplant over plastic mulch. Weed Technol 34:202-207

Samuel Daramola O (2021) Weed interference and management in cucumber (*Cucumis sativus* L.). IntechOpen, 10.5772/intechopen.99564

Kelly ST, Shankle MW, Miller DK (2006) Efficacy and tolerance of flumioxazin on sweet potato (*Ipomoea batatas*). Weed Technol 20:334–339

Trader B, Wilson H, Hines T (2007) Halosulfuron helps control several broadleaf weeds in cucumber and pumpkin. Weed Technol 21:966–971

VanSickle JJ, NaLampang S (2002) The impact of the phase-out of methyl bromide on the US vegetable industry. AgEcon Search, 10.22004/ag.econ.15664.

Wallace RD, Culpepper AS, MacRae AW, Sosnoskie LM, Grey TL (2012). Vegetable crop response to EPTC applied preemergence under low-density polyethylene and high-barrier plastic mulch. Weed Technol 26:54-60

Webster TM, Culpepper AS, Johnson WC (2003) Response of squash and cucumber cultivars to halosulfuron. Weed Technol 17:173–176

Yu J, Sharpe SS, Boyd NS (2020) PRE herbicides and POST halosulfuron for purple nutsedge control in tomato grown in plasticulture systems. Weed Technol 34:642–646.

Table 1: Trade name, common name, rate used, and manufacturer information of herbicides used in the cucumber and summer squash field experiment.

Trade name	Common name	Rate used	Manufacturer
		g ai ha^{-1}	
Sandea®	Halosulfuron	52	Canyon Group LLC., c/o Gowan Company, P.O. Box 5569, Yuma, AZ 85364
Prowl®	Pendimethalin	1062	BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709
Dual Magnum®	*S*-metolachlor	1058	Syngenta Crop Protection LLC., P.O. Box 18300, Greensboro, NC 27419
Spartan®	Sulfentrazone	104	FMC Corporation, Walnut Street, Philadelphia, PA 19104
Reflex®	Fomesafen	269	Syngenta Crop Protection LLC., P.O. Box 18300, Greensboro, NC 27419
Devrinol® 2-Xt	Napropamide	1076	UPL NA Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406
Goal® 2XL	Oxyfluorfen	269	Dow AgroSciences LLC., 9330 Zionsville Road, Indianapolis, IN 46268
Chateau®	Flumioxazin[a]	212	Valent USA LLC., P.O. Box 8025, Walnut Creek, CA 94596
Solida®	Rimsulfuron[b]	35	FMC Corporation, Walnut Street, Philadelphia, PA 19104

[a]Flumioxazin was used only for cucumber and [b]rimsulfuron was used only for summer squash.

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Table 2. Monthly weather data for the experimental site (Wimauma, FL) during the trial period collected from the Florida Automatic Weather Network (FAWN).

	Fall 2021			Spring 2022		
	August	September	October	February	March	April
Average air temperature[a] (C)	27	26	24	18	21	22
Minimum air temperature[a] (C)	21	19	15	6	3	8
Maximum air temperature[a] (C)	34	33	34	30	31	31
Average soil temperature[b] (C)	29	28	26	20	23	25
Average rainfall (mm)	117	172	53	17	70	78

[a]Air temperature data was collected 10 m above ground and [b]soil temperature data was collected 10 cm below the soil surface.

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Table 3. Effect of cultivar and preemergence (PRE) herbicide on cucumber growth and yield in the field trial at Gulf Coast Research and Education Center in Wimauma, FL in fall 2021 and spring 2022.

	Vine length[a]				Injury				Mortality[c]		Yield			
	Fall 2021[b]		Spring 2022		Spring 2022				Spring 2022		Fall 2021[d]		Spring 2022[e]	
					14 DATr		28 DATr							
Cultivar	----------cm-----------				-------%------				%		-------------kg ha^{-1}-----------			
Speedway	47	a	26		8	a	14		8	a	19627	b	14547	b
Dominator	53	b	25		10	b	14		24	b	15087	a	15866	a
Mongoose	53	b	28		10	b	13		34	c	14910	a	21973	a
PRE herbicide														
Nontreated control	51		29	b	0	a	0	a	22		17776		23249	
Halosulfuron	51		28	b	8	b	10	b	23		14999		18571	
Pendimethalin	55		31	b	7	b	32	c	34		17014		21415	
S-metolachlor	47		24	a	13	c	24	c	20		15343		12639	
Sulfentrazone	51		24	a	12	c	18	bc	18		17055		14595	
Fomesafen	51		25	a	12	c	15	bc	23		16593		20673	
Napropamide	50		27	b	9	b	12	b	13		15927		14758	
Oxyfluorfen	54		30	b	8	b	7	b	21		17598		16095	
Flumioxazin	51		21	a	14	c	7	b	23		16566		15165	

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Cultivar	0.003	0.083	0.035	0.83	<0.001	<0.001	0.005
PRE herbicide	0.481	<0.001	<0.001	<0.001	0.407	0.763	0.129
Cultivar*PRE herbicide	0.951	0.497	0.688	0.188	0.87	0.595	0.827

Abbreviations: DATr, days after transplant.

[a]Vine length is the average of vine length at two measurement dates because there was no significant interaction (p>0.05) between cultivar, PRE herbicide, and date of vine length measurement.

[b]Mean within the same column followed by the same letter is statistically similar at the 0.05 significance level based upon least square means multiple comparison test.

[c]Mortality refers to the number of plants that did not survive from planting to harvesting. Mortality data was collected once at the first harvest and was collected only in spring 2022.

[d]Yield is the sum of four harvests.

[e]Yield is the sum of six harvests.

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Table 4. Effect of cultivar and preemergence (PRE) herbicide on cucumber injury in the field trial at Gulf Coast Research and Education in Wimuama, FL in fall 2021 and spring 2022.

		Injury			
Cultivar	PRE herbicide	Fall 2021		Spring 2022	
		Average[a]		7 DATr	
		--------------%------------			
Speedway	Nontreated control	0	a[b]	0	a
	Halosulfuron	5	a	4	ab
	Pendimethalin	6	a	5	ab
	S-metolachlor	10	b	6	ab
	Sulfentrazone	5	a	5	ab
	Fomesafen	9	a	9	ab
	Napropamide	10	b	8	ab
	Oxyfluorfen	6	a	5	ab
	Flumioxazin	8	a	3	ab
Dominator	Nontreated control	0	a	0	ab
	Halosulfuron	11	b	5	ab
	Pendimethalin	7	a	3	ab
	S-metolachlor	7	a	8	ab
	Sulfentrazone	6	a	10	b
	Fomesafen	6	a	8	ab
	Napropamide	10	a	3	ab
	Oxyfluorfen	3	a	8	ab
	Flumioxazin	13	b	13	b
Mongoose	Nontreated control	0	a	0	a
	Halosulfuron	11	b	8	ab
	Pendimethalin	11	b	11	b
	S-metolachlor	9	b	13	b
	Sulfentrazone	16	b	0	ab
	Fomesafen	8	a	10	b
	Napropamide	12	b	5	ab
	Oxyfluorfen	11	b	10	b
	Flumioxazin	10	a	8	ab
	Cultivar	0.005		0.12	
	PRE herbicide	<0.001		0.003	
	Cultivar*PRE herbicide	0.045		0.014	

Abbreviations: DATr, days after transplant.

[a]Average injury is the mean of injury data collected at three measurement dates because there was no significant interaction (p>0.05) between cultivar, PRE herbicide, and date of injury measurement.

[b]Mean within the same column followed by the same letter is statistically similar at the 0.05 significance level based upon least square means based upon least square means.

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Table 5. Effect of cultivar and preemergence (PRE) herbicides on summer squash growth in the field trial at Gulf Coast Research and Education Center in Wimauma, FL in fall 2021 and spring 2022.

		Plant height[a]		Injury	
Cultivar	PRE herbicide	Fall 2021		Spring 2022	
		seed		28 DATr	
		cm		%	
Spineless Beauty	Nontreated control	28	b[b]	0	a
	Halosulfuron	25	ab	0	a
	Pendimethalin	24	ab	18	c
	S-metolachlor	26	ab	14	c
	Sulfentrazone	27	b	0	a
	Fomesafen	30	b	0	a
	Napropamide	28	b	8	ab
	Oxyfluorfen	33	b	0	a
	Flumioxazin	31	b	8	ab
Payload	Nontreated control	30	b	0	a
	Halosulfuron	22	ab	0	a
	Pendimethalin	26	ab	21	c
	S-metolachlor	28	ab	25	c
	Sulfentrazone	33	b	0	a
	Fomesafen	29	b	0	a
	Napropamide	30	b	8	ab
	Oxyfluorfen	29	ab	0	a
	Flumioxazin	27	b	0	a
Everglade	Nontreated control	27	ab	0	a
	Halosulfuron	20	a	0	a
	Pendimethalin	30	b	24	c
	S-metolachlor	28	b	25	c
	Sulfentrazone	26	ab	0	a
	Fomesafen	27	ab	0	a
	Napropamide	27	ab	10	b
	Oxyfluorfen	29	b	0	a
	Flumioxazin	23	ab	5	ab
	Cultivar	0.028		0.097	
	PRE herbicide	<0.001		<0.001	
	Cultivar*PRE herbicide	0.044		0.016	

Abbreviations: DATr, days after transplant.

[a]Plant height is the average of two plant heights at two measurement dates because there was no significant interaction (p>0.05) between cultivar, PRE herbicide, and date of plant height measurement.

[b]Mean within the same column followed by the same letter is statistically similar at the 0.05 significance level based upon least square means multiple comparison test.

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Table 6. Effect of cultivar and preemergence (PRE) herbicide on summer squash growth and yield in the field trial at Gulf Coast Research and Education Center in Wimauma, FL in fall 2021 and spring 2022.

	Plant height[a]			Injury						Mortality[c]		Yield		
	Fall 2021	Spring 2022		Fall 2021			Spring 2022			Fall 2021	Spring 2022	Fall 2021[d]		Spring 2022[e]
	transplant			seed		transplant	7 DATr	14 DATr				seed	transplant	
Cultivar	---------cm----------			-------------------------------------%------------------------------------								--------------kg ha^{-1}--------------		
Spineless Beauty	40	18	a[b]	7		2	2	12	b	25	6	15519	16011	17885
Payload	40	20	b	7		1	0	8	a	30	2	17308	14380	14054
Everglade	40	19	ab	9		1	1	10	b	27	4	17841	14991	14226
PRE herbicide														
Nontreated control	41	21	b	2	a	0	0	0	a	33	5	22789	16369	18573
Halosulfuron	38	17	a	13	b	2	1	9	b	20	8	16414	12683	13649
Pendimethalin	40	22	b	7	b	1	1	10	b	24	3	14098	12831	19676
S-metolachlor	41	19	b	12	b	1	1	10	b	39	3	10169	15031	18951
Sulfentrazone	40	19	b	7	b	3	1	11	b	33	3	18395	13393	13609
Fomesafen	41	19	b	4	a	0	1	12	b	29	1	17198	14870	12357
Napropamide	40	18	b	7	b	3	1	9	b	19	2	19065	15552	12053
Oxyfluorfen	42	20	b	6	a	2	2	12	b	24	2	10622	17256	18959
Flumioxazin	41	15	a	11	b	1	2	18	c	25	8	13254	18161	10667
Cultivar	0.895	<0.001		0.427		0.926	0.005	<0.001		0.794	0.244	0.391	0.578	0.321

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PRE herbicide	0.382	<0.001	<0.001	0.188	0.873	<0.001	0.749	0.427	0.784	0.555	0.055
Cultivar*PRE herbicide	0.108	0.438	0.076	0.834	0.958	0.198	0.946	0.5	0.571	0.377	0.94

Abbreviations: DATr, days after transplant.

[a]Plant height is the average of two plant heights at two measurement dates because there was no significant interaction ($p>0.05$) between cultivar, PRE herbicide, and date of plant height measurement.

[b]Mean within the same column followed by the same letter is statistically similar at the 0.05 significance level based upon least square means multiple comparison test.

[c]Mortality refers to the number of plants that did not survive from planting to harvesting in spring 2022, however, mortality data in fall 2021 was the combination of seedling mortality and lack of seed emergence.

[d]Yield is the sum of four harvests.

[e]Yield is the sum of six harvests.

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Table 7. Effect of cultivar and preemergence (PRE) herbicide on nutsedge count in the cucumber and summer squash field trial at Gulf Coast Research and Education Center in fall 2021 in Wimauma, FL.

	Average nutsedge[a]	
	Cucumber trial	Summer squash trial
Cucumber cultivar	-------No. of nutsedge m^{-2}--------	
Speedway	1	-
Dominator	2	-
Mongoose	2	-
Summer squash cultivar		
Spineless Beauty	-	3
Payload	-	4
Everglade	-	4
PRE herbicide		
Nontreated control	4	6
Halosulfuron	2	1
Pendimethalin	1	5
S-metolachlor	1	4
Sulfentrazone	1	3
Fomesafen	1	3
Napropamide	2	4
Oxyfluorfen	2	3
Flumioxazin	1	3
Cultivar	0.311	0.376
PRE herbicide	0.158	0.263
Cultivar* PRE herbicide	0.662	0.448

[a]Average nutsedge is the mean of nutsedge data collected at three nutsedge measurement dates because there was no significant interaction ($p>0.05$) between cultivar, PRE herbicide, and date of nutsedge measurement. Yellow nutsedge (*Cyperus esculentus)* and purple nutsedge (*Cyperus rotundus*) were two nutsedge species recorded in this study.

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Table 8. Effect of cultivar and preemergence (PRE) herbicide on nutsedge count in the cucumber field trial at the Gulf Coast Research and Education Center in Wimauma, FL in spring 2022.

Cultivar	PRE herbicide	Nutsedge[a]	
		No. of nutsedge m^{-2}	
Speedway	Nontreated control	1	b[b]
	Halosulfuron	0	b
	Pendimethalin	0	b
	S-metolachlor	0	b
	Sulfentrazone	0	b
	Fomesafen	0	b
	Napropamide	2	b
	Oxyfluorfen	1	b
	Flumioxazin	0	b
Dominator	Nontreated control	0	b
	Halosulfuron	0	b
	Pendimethalin	2	b
	S-metolachlor	0	b
	Sulfentrazone	1	b
	Fomesafen	0	b
	Napropamide	0	b
	Oxyfluorfen	1	b
	Flumioxazin	0	b
Mongoose	Nontreated control	0	b
	Halosulfuron	4	a
	Pendimethalin	1	b
	S-metolachlor	0	b
	Sulfentrazone	1	b
	Fomesafen	0	b
	Napropamide	3	a
	Oxyfluorfen	1	b
	Flumioxazin	0	b
	Cultivar	0.008	
	PRE herbicide	0.027	
	Cultivar*PRE herbicide	0.014	

[a]Average nutsedge is the mean of nutsedge data collected at three nutsedge measurement dates because there was no significant interaction ($p>0.05$) between cultivar, PRE herbicide, and date of nutsedge measurement. Yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*) were two nutsedge species recorded in this study.

[b]Mean within the same column followed by the same letter is statistically similar at the 0.05 significance level based upon least square means multiple comparison test.

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