Varietal Tolerance of Cucurbitaceous Crops with *S*-metolachlor Applied Postemergence

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ABSTRACT. Cucurbit crops comprise ~25% of the vegetable acreage in the mid-Atlantic and Northeastern United States. However, options for postemergence weed control in these crops are limited. Overlapping herbicides is a technique that involves sequential applications of soil-applied residual herbicides to lengthen herbicidal activity before the first herbicide dissipates. Residual herbicides such as *S*-metolachlor will not control emerged weeds, but weed control efficacy may be extended if these herbicides are applied after crop emergence, but before weed emergence occurs. Currently *S*-metolachlor is not labeled for broadcast applications over cucurbit crops. Greenhouse studies were conducted to evaluate pumpkin, cucumber, and summer squash variety response to varying *S*-metolachlor rates. *S*-metolachlor was applied at 1.42 and 2.85 lb/acre at the two-leaf stage of pumpkin and 0.71, 1.42, 2.85, and 5.7 lb/acre at the two-leaf stage of cucumber and summer squash. Cucumber showed a greater response to *S*-metolachlor with up to 67% injury observed at 5.70 lb/acre. *S*-metolachlor applications to pumpkin and summer squash resulted in less than 6% injury, regardless of application rate or crop variety. *S*-metolachlor applied at 2.85 lb/acre reduced pumpkin and cucumber dry weight 6% and 19%, respectively, but did not reduce squash dry weight. *S*-metolachlor reduced cucumber dry weight 78% for all varieties. Pumpkin varieties 'Munchkin' and 'Baby Bear' exhibited a 23% difference in dry weight, but no other differences were observed among other varieties because of *S*-metolachlor applications. Summer squash varieties 'Respect' and 'Golden Glory' exhibited a 31% difference in dry weight, but no other differences were observed among other varieties. Results show that pumpkin and summer squash demonstrated good crop safety when *S*-metolachlor was applied as a broadcast treatment after crop emergence. However, caution should be urged when applying this herbicide to cucumber.

Cucurbits (Cucurbitaceae), including cucumber (*Cucumis sativus* L.), pumpkin (*Cucurbita pepo* var. *pepo* L., *Cucurbita maxima* L., others), and squash (*Cucurbita pepo* subsp. *pepo* L.), are economically important vegetable crops in the mid-Atlantic and Northeast regions of the United States. In 2018, 37,500 acres of cucurbits, valued at \$106.9 million, were harvested, corresponding to 25% of the greater area's vegetable production acreage [US Department of Agriculture–National Agricultural Statistics Service (USDA-NASS 2022)]. New York is one of the top 10 states for both pumpkin and squash acreage (9200) and value (\$33.4 million) (USDA-NASS 2022). In 2021, slicing cucumber and summer squash production in New Jersey accounted for 1800 acres each and generated ~\$22.2 million (Eklund 2022).

Significant yield reductions can occur when weeds are not controlled in cucurbit crops (Adkins et al. 2010; Gilbert et al. 2008; Monks and Schultheis 1998; Terry et al. 1997). For example, season-long weed interference can reduce cucumber yield 45% to 98% depending on annual weather conditions, species, and planting density (Friesen 1978; McGowen et al. 2018; Weaver 1984). Mallet and Ashley (1988) found a 49% reduction of summer squash fruit yield when common lambsquarters (*Chenopodium album*), common ragweed (*Ambrosia artemisiifolia*), and quackgrass (*Elymus repens*) were allowed to compete for 12 weeks as compared with a complete absence of competition. Besançon et al. (2020) reported similar results with 52% and 85% fruit yield reduction for summer squash and cucumber, respectively, when competing with natural mixed populations of common lambsquarters, smooth pigweed (*Amaranthus hybridus*), hairy galinsoga (*Galinsoga quadriradiata*), large crabgrass (*Digitaria sanguinalis*), and American black nightshade (*Solanum americanum*) as compared with a manually weeded control. In the absence of effective weed control, yields of 'Magic Wand' pumpkins were reduced by up to 95% (Walters and Young 2022). In addition, weeds can serve as alternate hosts for pathogens, especially viruses, which can adversely affect crop growth and yield (Aguiar et al. 2018; Kavalappara et al. 2022; Webster et al. 2015). Weed infestations can also interfere with harvesting, both hand harvesting and machine harvests. However, the level of yield loss has not been quantified for most cucurbit crops.

The utility of mechanical cultivation for weed control is limited due to the vining nature of cucurbit crops (Gilreath and Everett 1983). Hand weeding, while effective, is costly and dependent on the availability of labor (Taylor et al. 2012). Soil-applied residual herbicides used at planting before weed emergence (i.e., preemergence [PRE]) are a critical management tool to limit early-season weed competition due to lack of safe and effective postemergence (POST) herbicides labeled for application after transplant or after crop emergence. Across cucurbit crops, clomazone [Weed Science Society of America (WSSA) group 13 deoxy-D-xylulose phosphate synthase inhibitor], ethalfluralin (WSSA group 3 microtubule assembly inhibitor), halosulfuron-methyl [WSSA group 2 acetolactate synthase (ALS) inhibitor], and fomesafen [WSSA group 14 protoporphyrinogen oxidase (PPO) inhibitor] are the most frequently applied PRE herbicides. However, because of the regional occurrence of weed species that have evolved resistance to ALS- and PPO-inhibiting herbicides (Boyd et al. 2022), it is recommended that growers mix and rotate herbicides with different mechanisms of action to manage further development and spread (Norsworthy et al. 2012). To successfully achieve this across cucurbit crops, new active ingredients will need to be evaluated for performance and safety and current labels will need to be expanded.

S-metolachlor is a very long chain fatty acid biosynthesis-inhibiting, soil-applied herbicide (WSSA Group 15) that provides residual and selective control of many annual monocotyledonous weeds as well as some small seeded dicotyledonous weeds, including pigweeds, hairy galinsoga, or eastern black nightshade (*Solanum ptychanthum*) (Bean et al. 2023; Shaner 2014). *S*-metolachlor is also effective at suppressing yellow nutsedge (*Cyperus esculentus*), the most troublesome weed species in cucurbit crops (Meyers and Shankle 2017; Van Wychen 2019). The *S*-metolachlor section 3 label allows for a variety of use patterns (i.e., PRE, POST, incorporated preplant) across multiple crops, including POST interrow applications in pumpkin (Syngenta 2023). The minimum weed-free period (when the crop must be kept weed-free to prevent yield losses to weed competition) in cucurbit crops has been estimated as the first 4 to 6 weeks after planting, until extensive vining occurs (Friesen, 1978; McGowen et al. 2018; Weaver 1984). Delayed PRE application of *S*-metolachlor after crop transplanting can provide residual weed control during the entire critical weed-free period, especially as *S*-metolachlor generally provides 10 to 14 weeks of residual weed control (Shaner 2014). *S*-metolachlor (Dual Magnum; Syngenta Crop Protection, Greensboro, NC, USA) received a section 24(c) special local need label in Massachusetts for use on cucumber as a POST application at 0.64 to 1.27 lb/acre after crop reached the one to two true leaves stage (Syngenta 2018). In addition to the cucumber POST application, the New York label allows a similar use on summer squash having at least four true leaves (Syngenta 2016). Unfortunately, these special local need labels are not available for other states in the northeastern United States.

The approval of additional 24(c) labels, or else expansion of the national label, will require additional information about the safety of *S*-metolachlor across cucurbit crops. Currently, literature is limited and sometimes contradictory. Bean et al. (2023) reported that *S*-metolachlor was relatively safe and effective, relative to registered products, in both seeded and transplanted cantaloupe and honeydew melons, particularly when applied POST, across a range of production conditions in California. Stunting, when it was observed, did not result in yield reductions under the conditions of the trials. Ferebee et al. (2019) found that pumpkin treated with *S*-metolachlor POST directly over the tops of rows were the best yielding plots (4356 fruits/acre). Sosnoskie et al. (2008) found that *S*-metolachlor PRE at 0.45 to 0.89 lb/acre decreased summer squash yield up to 20%, whereas POST application 3 weeks after planting (WAP) at 0.45 lb/acre did not reduce yield. Peachey et al. (2012) reported that cucumber and summer squash emergence, as well as marketable yield, were not reduced with *S*-metolachlor applied PRE alone at 0.98 or 1.87 lb/acre. Besançon et al. (2020) reported excellent tolerance of ‘Gold Prize’ summer squash to *S*-metolachlor at 1.25 lb/acre applied POST at the second- to third-leaf crop stage with 3% stunting noted 4 WAP. Conversely, a similar *S*-metolachlor POST application on ‘Python’ cucumber caused 17% stunting 4 WAP and reduced marketable yield 39% compared with a clomazone plus ethalfluralin standard. To increase our understanding of cucurbit tolerance to *S*-metolachlor, applied early POST, greenhouse studies were conducted in Delaware, New Jersey, and New York to evaluate crop tolerance and biomass accumulation of five cultivars of pumpkin, summer squash, and cucumber in response to various rates of *S*-metolachlor applied POST after plants have reached the two-leaf stage.

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Materials and methods

Pumpkin trials. A greenhouse trial was conducted in the winter of 2018 at the University of Delaware Carvel Research and Education Center in Georgetown, DE, USA. Pumpkin seeds were planted in a sterilized (1:1) mix of Pro-Mix BX Mycorrhizae (Premier Tech Horticulture, Quebec, Canada) and a Rosedale loamy sand (loamy, siliceous, semiactive, mesic, Arenic Hapludults) obtained from an adjacent field with 1.1% organic matter and pH of 6.0. The experimental design was a two-factor factorial consisting of pumpkin cultivar and *S*-metolachlor rate. Pumpkin cultivars included Baby Bear, Champion, Gladiator, Munchkin, Prankster, and Solid Gold. Cultivars were chosen to represent a range of genetic backgrounds, fruit sizes, and breeding sources. *S*-metolachlor rates consisted of 1.42 and 2.86 lb/acre applied POST when plants reached the two-leaf stage. A nontreated control (NTC) was also included for comparison. Each variety by rate combination was replicated four times and the study was repeated twice.

Plants were seeded at a 1-inch depth, into 4-inch-diameter pots. Plants were thinned to two plants per pot before *S*-metolachlor applications. A high-pressure sodium 2000K lamp was placed above each bench to provide 16-h light period with a photosynthetic photon flux density of 640 $\mu mol \cdot m^{-2} \cdot s^{-1}$ followed by an 8-h dark period. Mean greenhouse temperature was 20 °C during the first run and 22 °C during the second run. Pots were surface irrigated once per day, although supplemental water was provided when needed. Herbicides were applied with a moving nozzle cabinet sprayer equipped with an 8003VS flat-fan nozzle (Teejet, Glendale Heights, IL, USA) calibrated to deliver 25 gal/acre at 25 psi. No insecticides or fungicides were applied during the trial.

Cucumber and squash trials. Greenhouse trials were initiated in Jan 2020 at the Rutgers University Philip E. Marucci Center for Blueberry and Cranberry Research and Extension in Chatsworth, NJ, USA, and in Jul 2022 at Cornell AgriTech in Geneva, NY, USA. In New Jersey, cucumber and squash seeds were planted into a sterilized 1:1 (v/v) mix of SunGro Canadian sphagnum peatmoss (Sun Gro

Horticulture Distribution Inc., Agawam, MA, USA) and pre-sieved Woodmansie sand (coarse-loamy, siliceous, semiactive, mesic Typic Hapludults) obtained from a local gravel pit with 3.9% organic matter content and pH of 4.4. In New York, seeds were planted into a 1:1 (v/v) mix of Lambert LM-111 Canadian sphagnum peatmoss (Lambert Peat Moss, Rivière-Ouelle, QC, Canada) and pre-sieved Honeyoye loam (fine-loamy, mixed, semiactive, mesic Glossic Hapludalfs) with 2.5% organic matter and a pH of 6.3.

Trials were conducted as a two-factor factorial arranged in a randomized complete block design with four replications for each variety by rate combination. Three experimental runs were conducted for each crop species and included two runs in New Jersey and one in New York. The main factors consisted of five cultivars for each crop species and five rates of *S*-metolachlor. Cultivars were chosen to represent a range of genetic background, fruit sizes, and breeding sources. Summer squash cultivars were Goldprize, Multipik, Sunburst, Respect, and Golden Glory; cucumber cultivars included Python, Bristol, Diamondback, Deli King, and Supremo. Seeds were planted at a depth of 2.5 cm below the soil surface in 15-cm-diameter pots. Following emergence, seedlings were thinned to a single plant per pot. Plants were irrigated as needed and fertilized weekly with 250 ppm of 20–20–20 fertilizer beginning 1 week after emergence. In both states, high-pressure sodium 2000K lamps were used to provide a 16-h light period with a photosynthetic photon flux density of 640 $\mu mol \cdot m^{-2} \cdot s^{-1}$ followed by an 8-h dark period. For both locations, greenhouse temperatures were maintained at 25 °C with a fluctuation of 10 °C. No insecticides or fungicides were applied during the trial at either location. *S*-metolachlor (Dual Magnum; Syngenta Crop Protection, Greensboro, NC, USA) was applied POST at 0.71, 1.42, 2.85, and 5.70 lb/acre when seedlings reached the two-leaf stage. An NTC was also included for comparison. In New Jersey, herbicides were applied in water with a carbon dioxide (CO_2)-pressurized backpack sprayer equipped with 8004VS flat-fan nozzles (TeeJet, Glendale Heights, IL, USA) calibrated to deliver 20 gal/acre at 15 PSI. In New York, treatments were made using a cabinet sprayer equipped with a single 8002VS flat-fan nozzle calibrated to deliver 20 gal/acre at 15 psi. No insecticides or fungicides were applied during the trial.

Data collection and analysis. Crop tolerance to *S*-metolachlor was rated 1 and 2 WAT for pumpkin, 3 WAT and 4 WAT for summer squash, and 4 WAT for cucumber. Pumpkin was not rated beyond 2 WAT because of the lack of visible injury, whereas herbicide phytotoxicity culminated 3 to 4 WAT for squash and cucumber. Tolerance was assessed on a scale of 0% (no injury or growth reduction compared with the NTC) to 100% (plant death) (Frans et al. 1986) by scoring seedlings for general stunting (Fig. 1A) as well as leaf injury expressed as a composite rating of leaf necrosis (Fig. 1B), chlorosis (Fig. 1C), and cupping (Fig. 1D). Pumpkin height was assessed 2 WAT by measuring vines from the aboveground base to the apical meristem. For squash and cucumber, leaf area was evaluated 4 WAT. In New Jersey, the surface area of the third-emerged leaf of each plant was analyzed using a Leaf-IT leaf area meter (Schrader et al. 2017). In New York, leaf area was assessed for each plant using a CID Bio-Science CI-202 portable leaf area meter. For all crops, the total aboveground vegetation was collected at the end of the experiments, placed in paper bags, and dried at 66 °C for 4 d, after which dry weight was measured.

All statistical analyses were conducted using the generalized linear mixed model (GLIMMIX) procedure in SAS software (version 9.4; SAS Institute, Cary, NC, USA). Cucurbit cultivars, *S*-metolachlor treatments, and interactions between these two factors were considered fixed effects, whereas runs and replication nested within runs were designated as random factors in the model. Because of unequal variance, percent crop injury data were converted using the arcsine square root transformation before the analysis of variance and backtransformed for presentation purposes (Grafen and Hails 2002). To minimize the effect of the genetic background of each cucurbit crop cultivar on height, leaf area, and dry biomass, these data were expressed as percentage of the NTC before statistical analysis. When main effect interactions were not significant, data were pooled appropriately and noted below. Mean comparisons for the fixed effects were performed using Tukey's honestly significant difference test when F values were statistically significant ($P \leq 0.05$).

Results and discussion

Pumpkin. The two-way interaction of pumpkin cultivar by *S*-metolachlor rate was significant ($P < 0.05$) for seedling injury 1 WAT (Table 1). Thus, pumpkin injury data were analyzed by cultivar. Observed pumpkin injury was less than 7% and consisted exclusively of leaf necrosis 1 week after POST applications of *S*-metolachlor (Table 2) and no injury was noted at 2 WAT (data not shown). Significant ($P < 0.05$) leaf necrosis, relative to the NTC, was only observed for 'Champion' (6%) at the 1.42 lb/acre rate. At the 2.85 lb/acre *S*-metolachlor rate, 'Champion', 'Baby Bear', 'Solid Gold', and 'Munchkin' exhibited ($P < 0.05$) greater leaf necrosis ranging from 2% to 6% as compared with the NTC. 'Gladiator' and 'Prankster' were the least sensitive cultivars with leaf necrosis not exceeding 1%, regardless of *S*-metolachlor rate. A comparison of cultivars within each *S*-metolachlor rate indicated that Champion exhibited significantly ($P < 0.05$) more leaf burning than Gladiator, Munchkin, and Prankster at the 1.42 lb/acre rate and Gladiator and Prankster at the 2.85 lb/acre rate.

The main effects of *S*-metolachlor rate and cultivar significantly ($P < 0.05$) affected seedling dry weight (Table 3). Averaged across cultivars, *S*-metolachlor applied POST reduced pumpkin weight by 6% at the 2.85 lb/acre rate compared with the NTC; no significant ($P > 0.05$) dry weight reduction was noted at the 1.42 lb/acre rate. The adverse effect of *S*-metolachlor on 'Munchkin' growth was also noted for dry weight, which was 23% reduced compared with 'Baby Bear'. The development of Champion, Gladiator, and Solid Gold cultivars was not significantly ($P < 0.05$) affected by *S*-metolachlor POST applications. Averaged over *S*-metolachlor rates, heights of 'Munchkin' and 'Prankster' were reduced at least 12% and 7% compared with 'Gladiator' and 'Baby Bear'.

Currently, *S*-metolachlor label restrictions require that the herbicide be applied only between rows of pumpkin while leaving a 30-cm wide nontreated area directly over the row to minimize the risk of injury to the pumpkin crop such as stand loss, delayed maturity, and

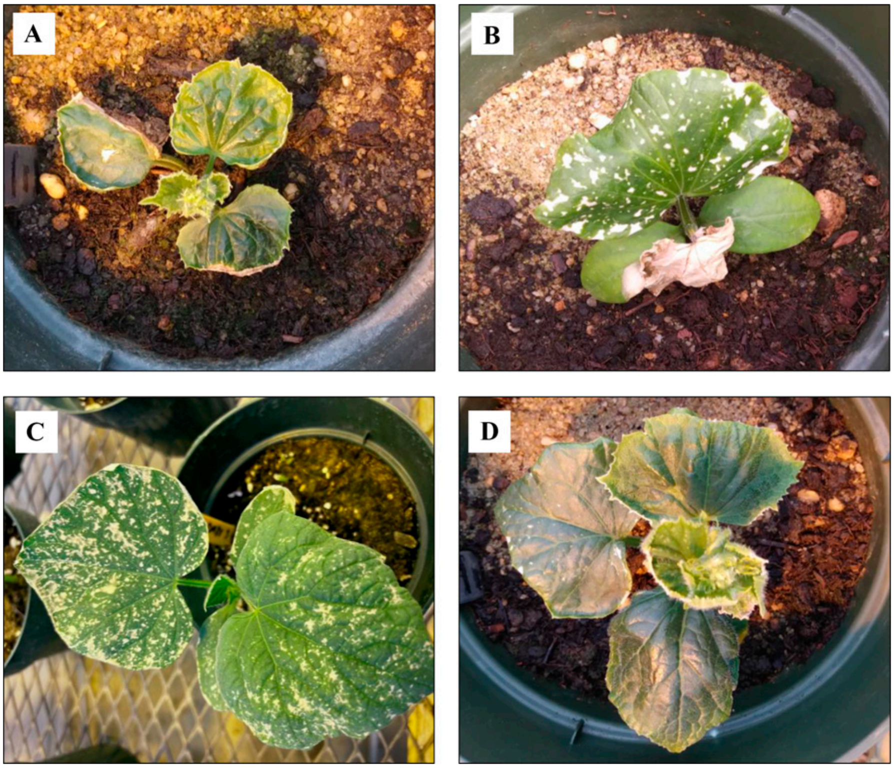

Fig. 1. Seedling stunting (A) and leaf necrosis (B), and chlorosis (C) observed on cucumber 4 weeks after postemergence application of *S*-metolachlor at 5.70 lb/acre as compared with untreated control (D).

loss of yield (Syngenta 2016; VanGessel 2024). Although crop mortality in response to POST applications of *S*-metolachlor, some cultivars may show increased injury and potential for reduced early-season growth as demonstrated in this study by 'Munchkin' and to a lesser extent 'Prankster'. However, is important to note that the observations were made under greenhouse conditions, which could alter injury potential relative to field-grown plants because of differences in the development of the leaf epidermis. In a multistate evaluation of pumpkin tolerance to *S*-metolachlor, Meyers et al. (2022) reported between 0% and 23% injury 3 WAT following POST applications at 1.25 or 2.5 lb/acre with no difference between rates in most of the field trials. Pooled across *S*-metolachlor rates, applications made 2 WAP resulted in greater fruit number (1200 fruits/acre) than the NTC (980 fruits/acre) and similar fruit number to applications made 4 WAP (1030 fruits/acre).

Cucumber. In the absence of a significant *S*-metolachlor rate by cucumber cultivar interaction ($P > 0.05$), leaf injury, plant stunting, relative dry weight, and leaf area data were pooled across the main effects (Table 4). Symptomology associated with *S*-metolachlor damage to cucumber leaves included cupping and crinkling, as well as marginal necrosis and chlorosis. All rates of *S*-metolachlor applied POST significantly ($P < 0.05$) injured young cucumber relative to the nontreated check. At 3 and 4 WAT, cucumber leaf injury varied between 3% and 8% when *S*-metolachlor was applied at rates ranging from 0.71 to 2.85 lb/acre. The 5.70-lb/acre rate caused damage to 20% of the total leaf surface on average across observation timings. Significant stunting was observed in response to *S*-metolachlor applications ($P < 0.05$). The response was dose-dependent, with greater reduction in plant size occurring at the highest *S*-metolachlor rates. Across both observation timings (i.e., 3 and 4 WAT), cucumber stunting, relative to the nontreated control, averaged 9%, 17%, 23%, and 63% at rates of 0.71, 1.42, 2.85, and 5.70 lb/acre, respectively. The stunting effect of *S*-metolachlor on cucumber seedlings was confirmed by the dry weight measurements, which showed a 19% and 55% reduction in dry matter accumulation following POST application

Table 1. Analysis of variance for visual estimation of leaf injury and plant stunting as well as measurements of seedling height, relative dry weight, and leaf area for pumpkin, cucumber, and squash. Data combined from trials conducted at Bridgeton, NJ, Georgetown, DE, and Geneva, NY, between 2018 and 2022. *S*-metolachlor was applied at the two-leaf stage to each cucurbitaceous crop.

	Injury			Stunting				
Factor	1 WAT[i]	3 WAT	4 WAT	3 WAT	4 WAT	DW	Ht	Leaf area
Pumpkin								
S-metolachlor rate	**0.0002**[ii]	—	—	—	—	**0.0303**	0.5809	—
Cultivar	**<0.0001**	—	—	—	—	**<0.0001**	**<0.0001**	—
S-metolachlor rate × cultivar	**0.0393**	—	—	—	—	0.9727	0.8883	—
Cucumber								
S-metolachlor rate	—	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0011**	—	**<0.0001**
Cultivar	—	**0.0020**	**0.0007**	**0.0073**	**0.0015**	0.4686	—	**0.0106**
S-metolachlor rate × cultivar	—	0.3164	0.2126	0.3673	0.3284	0.5329	—	0.0911
Squash								
S-metolachlor rate	—	**0.0001**	—	**0.0007**	—	**0.0131**	—	0.5146
Cultivar	—	**<0.0001**	—	0.2993	—	**<0.0001**	—	**0.0113**
S-metolachlor rate × cultivar	—	0.2460	—	0.4088	—	0.0852	—	0.4584

[i] DW = dry weight; WAT = weeks after treatment.
[ii] Bold type indicates *P* values significant at $P < 0.05$ and a "—" indicates that no data were collected for this parameter and specific crop.

Table 2. Interaction effect of *S*-metolachlor rate and pumpkin variety on leaf necrosis injury 1 week after treatment. Data are combined over runs for trials conducted at Georgetown, DE, in 2019.

	Cultivar necrosis											
S-metolachlor rate	Baby Bear		Champion		Gladiator		Munchkin		Prankster		Solid Gold	
(lb/acre)[i]	---	---	---	---	---	---	%	---	---	---	---	---
0	0 b[ii]	X	0 b	X	0 a	X	0 b	X	0 a	X	0 b	X
1.42	2 ab	XY	6 a	X	0 a	Y	0 b	Y	1 a	Y	2 ab	XY
2.85	3 a	XY	6 a	X	0 a	Y	2 a	XY	0 a	Y	3 a	XY

[i] 1 lb/acre = 1.1209 $kg \cdot ha^{-1}$.
[ii] Data were pooled across runs and means followed by the same letter in a column (a-b) or row within cultivars (X-Y) are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

at 2.85 and 5.70 lb/acre, respectively, relative to the NTC. No significant ($P > 0.05$) reduction in seedling dry weight was noted at the 0.71- and 1.42-lb/acre rates, which are close to current rates recommended by the Massachusetts and New York 24(c) Special Local Need labels (Syngenta 2016, 2018). Leaf area, expressed as a percent of the NTC, was also significantly ($P < 0.05$) affected by *S*-metolachlor rate; reductions of 36%, 47%, and 89% were observed for rates of 1.42, 2.85, and 5.70 lb/acre, respectively.

Significant differences in leaf injury, plant stunting, biomass accumulation, and leaf area responses were also observed among cucumber cultivars. Averaged over *S*-metolachlor rates and observation dates, leaf damage and stunting ratings were greater for 'Bristol' (8% and 27%, respectively) as compared with 'Python' and 'Diamondback' (3% and 13%, respectively). Lower necrotic and chlorotic injury (3%) was also noted for 'Deli King' compared with 'Bristol'. If no significant difference of relative dry weight was noted between cultivars ($P > 0.05$), Python and Diamondback averaged relative leaf area was greater (60%) than measured for Bristol and Supreme (40%), supporting the visual rating of injury and stunting for these cultivars.

Besançon et al. (2020) reported 15% and 26% injury on 'Python' cucumber within 1 week of POST application of *S*-metolachlor at 0.62 and 1.25 lb/acre (second- to third-leaf stage) in field studies conducted in New Jersey. The low tolerance of cucumber to *S*-metolachlor applied POST at 1.25 lb/acre was also demonstrated by the persistence of up to 17% stunting 4 WAT. By the end of the season, total yield was reduced 36% and 49% following *S*-metolachlor at 0.62 and 1.25 lb/acre, respectively. In the current study, Python was one of the least responsive cultivars, indicating that the sensitivity of cucumber cultivars to *S*-metolachlor applied postemergence may not be fully evident in a controlled environment, as opposed to field conditions in which plants face additional stressors.

These results demonstrate that cultivars frequently grown in the mid-Atlantic and Northeast regions of the United States may be severely affected by *S*-metolachlor applied POST, especially at rates greater than 0.71 lb/acre, which constitutes the lowest rate currently recommended by existing 24(c) Special Local Need labels.

Summer squash. In the absence of a significant *S*-metolachlor rate by summer squash cultivar interaction ($P > 0.05$), injury, stunting, relative dry weight, and leaf area data were pooled across main effects (Table 5). Summer squash leaf injury in response to POST applications of *S*-metolachlor was minor ($\leq$ 5% or less) and limited to small necrotic spots, mostly at the margin of the leaves. Increased injury was observed with increasing rates; *S*-metolachlor injury was significantly higher than for the NTC at rates of 1.42, 2.85, and 5.70 lb/acre. All *S*-metolachlor rates significantly ($P < 0.05$) stunted summer squash relative to the NTC, although the impact on plant size was minor (2% to 4%). Measurements of dry weight and relative leaf area 3 WAT confirmed the tolerance of summer squash to POST application of *S*-metolachlor with no significant difference between the various herbicide rates. Measurements of dry weight and relative leaf area 3 WAT confirmed the tolerance of summer squash to POST application of *S*-metolachlor with no significant difference detected across herbicide rates. To a lesser extent than observed for cucumber, summer squash cultivars varied in their response to *S*-metolachlor with Multipik showing marginally greater leaf injury (3%) than Golden Glory, Gold Prize, or Respect (1%). Nonetheless, although exhibiting a comparable injury response to *S*-metolachlor, the

Table 3. Pumpkin relative seedling height and dry weight 2 weeks after treatment as influenced by *S*-metolachlor rate and pumpkin cultivar at Georgetown, DE, in 2019.

Treatment	Ht	DW
S-metolachlor rate (lb/acre)[i]	% NTC[ii]	
0	100	100 a
1.42	98	97 ab
2.85	98	94 b
Pumpkin cultivar		
Baby Bear	107 a[iii]	105 a
Champion	99 ab	102 ab
Gladiator	101 a	97 ab
Munchkin	89 c	82 b
Prankster	94 bc	99 ab
Solid Gold	99 ab	89 ab

[i] 1 lb/acre = 1.1209 $kg \cdot ha^{-1}$. Average NTC vine height and DW were 22.1 cm/plant and 2.45 g/plant, respectively.
[ii] DW = dry weight; NTC = nontreated control.
[iii] Data were pooled across runs and means followed by the same letter in a column are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

Table 4. Main effect of *S*-metolachlor rate and cultivar on leaf injury and plant stunting as well as relative leaf area and dry weight 4 weeks after treatment for five cucumber cultivars. Data are combined over runs for trials conducted at Bridgeton, NJ, and at Geneva, NY, in 2020 and 2022.

	Injury		Stunting			
	3 WAT[i]	4 WAT	3 WAT	4 WAT	DW	Leaf area
S-metolachlor (lb/acre)[ii]	--------%--------				----% NTC----	
0	0 c[iii]	0 d	0 d	0 d	100 a	100 a
0.71	3 b	4 bc	10 c	8 c	91 ab	85 ab
1.42	3 b	3 c	17 bc	17 b	86 ab	64 bc
2.85	6 b	8 b	23 b	24 b	81 b	53 c
5.70	20 a	21 a	60 a	67 a	45 c	11 d
Cultivar						
Bristol	7 a	9 a	26 a	27 a	82	43 b
Deli King	3 b	4 bc	21 ab	21 ab	83	54 ab
Diamondback	3 b	3 c	13 b	13 b	71	58 a
Python	3 b	4 bc	15 b	13 b	77	63 a
Supreme	6 ab	7 ab	19 ab	21 ab	75	38 b

[i] DW = dry weight; NTC = nontreated control; WAT = weeks after treatment.
[ii] 1 lb/acre = 1.1209 kg·ha^{-1}. Average DW and leaf area of the NTC 4 WAT was 1.41 g/plant and 240 cm^2, respectively.
[iii] Data were pooled across runs and means followed by the same letter in a column are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

'Gold Prize' dry weight and relative leaf area were 26% and 31% lower, respectively, than observed for 'Respect'. This suggests that differences between cultivars may be primarily linked to the genetic background of the crop rather than the application of the herbicide. These results agree with previous studies indicating excellent squash tolerance to *S*-metolachlor applied POST. For example, Sosnoskie et al. (2008) reported that *S*-metolachlor applied POST at 0.45 lb/acre did not cause any yield reduction for summer squash. Besançon et al. (2020) did not observed more than 3% stunting within 7 weeks of POST application of *S*-metolachlor at 0.62 and 1.25 lb/acre on 'Gold Prize' summer squash at the second- to third-leaf stage. Consequently, the overall fruit harvest after applying *S*-metolachlor POST matched the yield of a manually weeded control and showed a 99% increase compared with a control plot overrun with weeds. In general, the injury and stunted growth caused by *S*-metolachlor were less noticeable in summer squash compared with cucumber, suggesting that summer squash may have a higher tolerance to POST applications of this herbicide.

Previous studies conducted on pumpkin (Ferebee et al. 2019; Meyers et al. 2022), summer squash (Besançon et al. 2020; Grey et al. 2000a; Sosnoskie et al. 2008; Trader et al. 2008; Webster et al. 2003), watermelon (*Citrullus lanatus*) (Grey et al. 2000b; Macrae et al. 2008), cantaloupe and honeydew (*Cucumis melo*) (Bean et al. 2023; Johnson and Mullinix 2005), and cucumber (Besançon et al. 2020; Peachey et al. 2012) have shown large variation in tolerance to soil-applied herbicides among species, as well as within cultivars of the same species. In conclusion, our findings complement the results of limited previous studies showing that *S*-metolachlor applied at 0.71 to 1.42 lb/acre over the top of summer squash at the second- to third-leaf stage will not cause serious injury and will not affect the development of emerged seedlings, regardless of cultivar. In the case of pumpkin, greater effect of the cultivar was noted with regard to the onset of injury induced by *S*-metolachlor but did not translate into reduced development or biomass accumulation at rates currently registered on the New York and Massachusetts 24(c) Special Local Need labels. As previously observed in field studies, cucumber showed the greatest level of sensitivity to *S*-metolachlor applied POST at rates greater than 0.71 lb/acre as demonstrated by significant crop injury, stunting, and reduced biomass accumulation. It is possible that in our study, *S*-metolachlor injury from POST application might be more evident due to the thinner leaf cuticle usually observed when plants are grown under protected conditions as encountered in greenhouses (Hull et al. 1975). This thinner cuticle, along with *S*-metolachlor's solvency characteristics, often results in greenhouse-to-field translation coefficients that differ significantly from other herbicide chemistries. Based on this premise, the satisfactory crop safety demonstrated for pumpkin and summer squash in controlled environments supports the future registration of *S*-metolachlor for POST use on these crops at the growth stages

Table 5. Main effect of *S*-metolachlor rate and cultivar on leaf injury, plant stunting, relative leaf area ad dry weight 3 weeks after treatment for five squash cultivars. Data are combined over runs for trials conducted at Bridgeton, NJ, and at Geneva, NY, in 2020 and 2022.

	Injury	Stunting	DW	Leaf area
S-metolachlor (lb/acre)[i]	--------%--------		-----% NTC[ii]------	
0	0 c[iii]	0 b	100 b	100
0.71	2 ab	2 a	122 ab	103
1.42	1 bc	2 a	117 ab	104
2.85	3 ab	3 a	120 ab	112
5.70	4 a	3 a	129 a	114
Cultivar				
Golden Glory	1 b	1	90 b	92 b
Gold Prize	1 b	2	123 a	112 ab
Respect	1 b	1	116 a	123 a
Multipik	3 a	3	135 a	103 ab
Sunburst	2 ab	2	129 a	104 ab

[i] 1 lb/acre = 1.1209 kg·ha^{-1}. Average DW and leaf area of the NTC was 2.21 g/plant and 276 cm^2, respectively.
[ii] DW = dry weight; NTC = nontreated control; WAT = weeks after treatment.
[iii] Data were pooled across runs and means followed by the same letter in a column are not significantly different based on based on Tukey's honestly significant difference (α = 0.05).

assessed in this study. Given the observed variability in varietal tolerance among cucumbers in this study, further research is necessary to determine if similar crop responses would be seen under field conditions.

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