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Running title: Palmer response to herbicides

# Response of Palmer Amaranth Accessions in South Carolina to Selected Herbicides

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**Abstract**

Palmer amaranth resistant to dicamba, glufosinate, and protoporphyrinogen oxidase inhibitors has been documented in several southern states. With extensive use of these and other herbicides in South Carolina, a survey was initiated in the fall of 2020 and repeated in the fall of 2021 and 2022 to determine the relative response of Palmer amaranth accessions to selected preemergence (PRE) and postemergence (POST) herbicides. A greenhouse screening experiment was conducted where accessions were treated with three PRE (atrazine, s-metolachlor, and isoxaflutole) and six POST (glyphosate, thifensulfuron-methyl, fomesafen, glufosinate, dicamba, 2,4-D) herbicides at the 1× and 2× use rates. Herbicides were applied shortly after planting (PRE) or at the 2 to 4 leaf growth stage (POST). Percent survival was evaluated 5-14 days after application depending on herbicide activity. Sensitivity to atrazine PRE was lower for 49 and 33 accessions out of 115 to atrazine PRE at the 1× and 2× rate, respectively. Most of the accessions (90%) were controlled by isoxaflutole PRE at the 1× rate. Response to *S*-metolachlor PRE indicated 34% of the Palmer amaranth accessions survived the 1× rate (>60% survival). There were 11 accessions with reduced sensitivity to fomesafen POST; however, these percentages were not different from the 0% survivor group. Glyphosate POST at the 1× rate did not control most accessions (79%). Palmer amaranth response to thifensulfuron-methyl POST varied across the accessions, with only 36 and 28% controlled at the 1× and 2×rate, respectively. All accessions were controlled by 2,4-D, dicamba, or glufosinate POST. Palmer amaranth accessions from this survey exhibited reduced susceptibility to several herbicides commonly used in agronomic crops in South Carolina. Therefore, growers should continue to utilize multiple management tactics to minimize the evolution of herbicide resistance in Palmer amaranth in South Carolina.

**Nomenclature:** Atrazine, isoxaflutole, *S*-metolachlor, glyphosate, thifensulfuron-methyl, fomesafen, glufosinate, dicamba, 2,4-D, Palmer amaranth, *Amaranthus palmeri* S. Wats.

**Key Words:** accession; survey; survivors; susceptibility

## Introduction

Palmer amaranth is a summer annual broadleaf weed that has been a consistent threat to a crop production in the US. With its high production of seeds from one female plant, Palmer amaranth can quickly alter the soil seedbank (Webster and Grey 2015). Studies have shown the potential for one female plant to produce over 600,000 seeds if left untreated for an entire growing season (Keeley et al. 1987). Its rapid and vigorous vegetative growth habit allows it to preferentially accumulate water and nutrients and intercept light necessary for optimum crop productivity (Berger et al. 2015b, Meyers et al. 2010). Yield reductions up to 91%, 68%, and 59% have been observed in corn, soybean, and cotton, respectively, from season long competition (Bensch et al. 2003; Massinga et al. 2001; Morgan et al. 2001). Research has also shown Palmer amaranth control can increase yield 14% for every 0.3-meter increase away from a Palmer amaranth plant (Berger et al. 2015b). Palmer amaranth can also interfere with harvest operations from control failure during the growing season. Morgan et al. (2001) reported mechanical harvest impediments in cotton with Palmer amaranth densities more than six plants per 9.1 m.

Herbicides are a chemical management tactic used by growers throughout the United States. The insertion of glyphosate tolerance into corn, cotton, and soybeans has provided growers with a broad-spectrum herbicide for the management of weeds, including Palmer amaranth. Glyphosate-resistant crops simplified weed management strategies and reduced labor costs allowing growers to make fewer sprayer passes through the field and reduce soil erosion from tillage (Triplett and Dick 2008). The adoption rate for varieties tolerant to glyphosate was rapid (USDA-ERS 2024). Soon after adoption, glyphosate was used as the sole weed management tool. This glyphosate-only weed management tactic resulted in heavy selection pressure, which resulted in glyphosate-resistant Palmer amaranth accessions (Beckie 2011; Diggle et al. 2003; Heap and Duke 2018; Shaner and Beckie 2014). The first documented Palmer amaranth accession resistant to glyphosate was confirmed in Georgia in 2006 (Culpepper et al. 2006). Many states would later confirm glyphosate resistance in Palmer amaranth in the following years, resulting in the need for diversification of herbicide modes of action and utilization of cultural practices including tillage and cover crops (Berger et al. 2015a; Butts and Davis 2015; Chahal et al. 2017; Culpepper et al. 2006; Kohrt et al. 2017; Nandula et al. 2012; Norsworthy et al. 2008; Steckel et al. 2008).

The loss of glyphosate as an effective herbicide for the management of Palmer amaranth resulted in the adoption of strategies including rotating herbicide modes of action, incorporating preemergence soil residual herbicides at planting, and tank-mixing multiple modes of action (Norsworthy et al. 2008). Protoporphyrinogen oxidase (PPO) and very long chain fatty acid synthesis (VLCFA) inhibiting herbicides became widely adopted as alternatives in soybean and cotton due to their foliar and/or soil residual activity on Palmer amaranth (Hay et al. 2018, Whitaker et al. 2010). Photosystem II (PS-II) and hydroxyphenyl pyruvate dioxygenase (HPPD) inhibitors were often used in corn because of its natural tolerance to these herbicides (Jachetta and Radosevich 1981). The introduction of glufosinate-and auxinic-resistant traits in cotton, soybean, and corn provided additional over-the-top control options for Palmer amaranth biotypes with multiple resistance (i.e., glyphosate and ALS-inhibitors). However, Palmer amaranth resistance to PPO-inhibitors, VLCFA-inhibitors, HPPD-inhibitors, PS-II inhibitors, glufosinate, and auxinic herbicides has been confirmed throughout the southern and mid-southern states (Brabham et al. 2019; Foster and Steckel 2022; Heap 2023; Jhala et al. 2017; Kumar et al. 2019; Nakka et al. 2017; Priess et al. 2022; Salas et al. 2016). Palmer amaranth resistance to the microtubule assembly inhibitors (Group 3), acetolactate synthase inhibitors (Group 2), and 5-enolpyruvylshikimate-3-phosphate synthase inhibitors (Group 9) has been documented in South Carolina (Gossett et al. 1992; Gossett et al. 1998; Heap 2023). South Carolina growers have concerns about the ability to control Palmer amaranth in cotton, corn, soybean, and peanut production. Therefore, the objectives of this study were to 1) collect escaped female Palmer amaranth accessions from key agronomic producing regions of South Carolina, and 2) determine susceptibility of these accessions to commonly used preemergence and postemergence herbicides in row crop production in South Carolina.

## Materials and Methods

### *Plant collection*

Palmer amaranth accessions were collected from September to November in 2020, 2021, and 2022 from 27 counties in the state of South Carolina (Figure 1). This study was conducted as a survey to determine the relative susceptibility of Palmer amaranth accessions in South Carolina to commonly used herbicides; therefore, herbicide program history at each field site was not collected. Approximately 30 to 40 female seedheads were collected from each field sampling site

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and combined into one representative sample. A total of 142 accessions were collected from 5 corn (*Zea mays* L.), 65 cotton (*Gossypium hirsutum* L.), and 72 soybean (*Glycine max* L.) fields (Supplemental Table S1). The accessions were processed at the greenhouse complex at the Clemson University Edisto Research and Education Center (EREC) located near Blackville, SC (33.36424°N 81.33155°W; 100 m above sea level). Seedheads were oven dried at 30 C for 5 days, hand-threshed, cleaned to remove the chaff from the mature, black seed, and stored in paper bags at 5 C.

*Preemergence susceptibility bioassay*

Soil was collected from a production field at EREC and placed in a Pro-Grow electric sterilizer (Pro Grow Supply LLC, Phoenix, AZ) at 93°C for 24 hours. The soil used in the preemergence study was a Fuquay sandy loam (Loamy, kaolinitic, thermic Arenic Plinthic Kandiudults) with a sand, silt, and clay content of 88%, 10%, and 2%, respectively. The soil pH was 5.8 and the organic matter content was 1.1%. The soil was then passed through a 4 mm sieve and placed in 48-cell trays (Greenhouse Megastore, Danville, IL). Greenhouse conditions during the study were maintained at 27/21 C day/night temperature with supplemental lighting (450 umol $m^{-2}$ $s^{-1}$) on a 16-hr day period. Twenty Palmer amaranth seed from each accession were planted in a 0.64 cm deep cell. The volume in each cell was 12.86 $cm^3$. Each 48-cell tray contained eight accessions with six cells per accession and trays were grouped according to herbicide and rate. To quantify germination ability of each accession, twenty seed per $cell^{-1}$ were also planted as nontreated control (Moore et al. 2021). The experiment was arranged in a randomized complete block design with six replications (cells) per accession and study was conducted twice.

The herbicides in this study were atrazine (Aatrex, Syngenta Crop Protection, Greensboro, NC) at 1,121 and 2,242 g $ha^{-1}$, *S*-metolachlor (Dual Magnum, Syngenta Crop Protection, Greensboro, NC) at 1,068 and 2,136 g $ha^{-1}$, and isoxaflutole (Alite 27, BASF, Raleigh, NC) at 105 and 210 g $ha^{-1}$, which were applied immediately after planting. The rates for each preemergence herbicide were 1× and 2× of the recommended use rate except for atrazine where 1× was 1,120 g $ha^{-1}$ (2,240 g $ha^{-1}$ is the 1× rate on the product label) which is the typical single application rate for growers in South Carolina. Herbicides were applied using a $CO_2$-pressurized backpack sprayer using a 11002 nozzle (TeeJet Technologies, Spraying Systems Co., Glendale Heights, IL) calibrated to deliver 140 L $ha^{-1}$ at 207 kPa. Herbicides were activated with 1.3 cm of water within 12 hours of herbicide application and watered as needed afterwards.

Plants that emerged with no visible herbicide injury symptomology (i.e., green meristems and the emergence of the $1^{st}/2^{nd}$ true leaves) were counted as survivors 14 days after application for each PRE herbicide. Survival percentage was then calculated by dividing the number of survivors in each cell by the number of untreated control plants in each cell (to account for potential germination differences between accessions). Each PRE herbicide bioassay was treated as a separate experiment. Percent survivor data were subjected to ANOVA using the MIXED procedure in SAS (SAS v 9.4, SAS Institute, Cary, NC) where accession and experimental run were considered fixed variables while replication was random. Differences between experimental runs were not significant ($P>0.05$); therefore, percent survivor data were pooled within each accession.

*Postemergence susceptibility bioassay*

For the POST greenhouse bioassay experiment, approximately twenty seed $cell^{-1}$ from each accession were planted in 48-cell trays (Greenhouse Megastore, Danville, IL) filled with commercial potting mix (Miracle-Gro, Scotts Company North America, Columbus, OH) at a 0.3 cm depth. Each cell volume was 12.86 $cm^3$. Each 48-cell tray contained eight accessions with six cells per accession and trays were grouped according to herbicide and rate. The plants were watered daily using an automated irrigation system. Greenhouse conditions during the study were maintained at 27/21 C day/night temperature with supplemental lighting (450 umol $m^{-2}$ $s^{-1}$) on a 16-hr day period. At emergence, plants in each cell were thinned to three plants $cell^{-1}$ with eight cells per replication. The experiment was arranged in a randomized complete block design with six replications per accession. The POST bioassay experiment was conducted twice.

At the 2- to 4-leaf growth stage (5 to 10 cm height), glyphosate (Roundup PowerMAX 3, Bayer CropScience, Chesterfield, MO) at 840 and 1,680 g ae $ha^{-1}$, glufosinate (Liberty 280 SL, BASF Ag Products, Raleigh, NC) at 656 and 1,312 g ai $ha^{-1}$, fomesafen (Reflex, Syngenta Crop Protection, Greensboro, NC) at 280 and 560 g ai $ha^{-1}$, thifensulfuron-methyl (Harmony SG, FMC Corporation, Philadelphia, PA) at 8.75 and 17.5 g ai $ha^{-1}$, dicamba (Xtendimax, Bayer CropScience, Chesterfield, MO) at 560 and 1,120 g ae $ha^{-1}$, and 2,4-D (Enlist One, Corteva AgriScience, Indianapolis, IN) at 1,065 and 2,130 g ae $ha^{-1}$ were applied in separate experiments. A 1% volume-to-volume crop oil concentrate (CropSmart, Carolina Eastern, Inc., Charleston, SC.) was included with fomesafen. A 0.25% v/v nonionic surfactant (TradeMark, Carolina Eastern, Inc., Charleston, SC.) and 2.5% v/v ammonium sulfate (AS-34 Plus, Carolina Eastern, Inc., Charleston, SC.) was included with thifensulfuron-methyl. Herbicides were applied using a $CO_2$-pressurized backpack sprayer with a 11002 VS nozzle (Spraying Systems Co., Glendale Heights, IL) calibrated to deliver 140 L $ha^{-1}$ at 207 kPA.

Survivor counts were collected 5 to 14 days after application, depending on the relative activity of each of the POST herbicides. The foliar symptoms after POST herbicide application included chlorosis/necrosis or death. Palmer amaranth survivors had green leaves and active growth at the apical meristems. Survivor counts for each herbicide rate was divided by the total number of plants in each cell to determine the survival percentage for each accession. Each POST herbicide bioassay was a separate experiment. Percent survivor data were subjected to ANOVA using the MIXED procedure in SAS (SAS v 9.4, SAS Institute, Cary, NC) where accession and experimental run were considered fixed variables while replication was random. Differences between experimental runs was not significant ($P>0.05$); therefore, percent survivor data were pooled.

*Percent survivor data analysis*

Survival percentages for each accession ranged from 0 to 100% for each herbicide rate where 0 indicates no survivors and 100 indicates all plants survived the treatment. Accession survival percentages were then assigned to an interval group (0, 1-10, 11-20, 21-30, 31-40; 41-50, 51-60, 61-70, 71-80, 81-90, and 91-100%) with 1-30, 31-60, 61-100% representing the low, moderate, and high survivor groups, respectively (Mahoney et al. 2020). Dunnett's procedure ($\alpha=0.05$) was then used to determine significant differences between survival percentages across accessions (Mahoney et al. 2020). In addition, accession survival percentages were compared to the 0% (no survivors) using 95% confidence intervals. Survivor percentage intervals not containing 0% were considered to have reduced herbicide sensitivity. Accessions with 0% survival were not included in the analysis (Moore et al. 2021).

## Results and Discussion

*Preemergence susceptibility bioassay*

A total of 115 Palmer amaranth accessions were evaluated for sensitivity to atrazine, isoxaflutole, and S-metolachlor PRE. Twenty-seven accessions from 2020 were not included in

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the PRE bioassay experiment because there was insufficient seed to conduct both PRE and POST bioassay experiments. The authors prioritized the seed for the POST bioassay because that information would provide the highest benefit for South Carolina growers.

No atrazine resistance in Palmer amaranth has been documented in South Carolina; however, resistant Palmer amaranth accessions have been reported in Texas, Kansas, Georgia, Nebraska, and North Carolina (Heap 2023). Differences were observed for Palmer amaranth survival percentages at the 1× ($P<0.0001$) and 2× ($P<0.0001$) rate of atrazine. In South Carolina, following an application of atrazine at the 1× and 2× rate, 38 and 45 out of 115 accessions had zero survivors at the 1× and 2× rates, respectively (Table 1). Based on 95% confidence intervals, the moderate (31 to 60%) and high survival (61 to 100%) were different than the no survivors (0%). Twenty-seven and twenty-two accessions had moderate (31-60%) to high (61-100%) survival at the 1× rate of atrazine, respectively. There were 28 accessions in the low survivor (1-30%) range at the 1× rate which was not different than the 0% according to 95% confidence intervals. Similar to the 1× rate, there were 24 accessions in the moderate (31-60%) survival range for the 2× rate of atrazine. However, there were fewer survivors (9) in the high (61-100%) range. There were 37 accessions in the low survivor category (1-30%) at the 2× rate of atrazine. No difference in the low versus the no survivor (0%) at the 2× rate of atrazine was observed. In this survey, 49 and 33 accessions out of 115 were less susceptible to atrazine at the 1× and 2× rate, respectively. These results indicate a reduction in Palmer amaranth susceptibility to atrazine; however, the atrazine 1× rate used in this study was half of the recommended rate on the product label (2,242 g $ha^{-1}$). The 1121 g ai $ha^{-1}$ rate is the typical atrazine rate used in South Carolina. The number of survivors in the high range (61-100%) was higher at the 1× rate than the 2× rate of atrazine. A survey in Texas found 16% of the Palmer amaranth accessions sampled were resistant to atrazine (Garetson et al. 2019). However, the 120 Palmer amaranth accessions from North Carolina were controlled at the recommended field use rate of atrazine (Moore et al. 2021).

Palmer amaranth biotypes resistant to HPPD-inhibitor herbicides mesotrione, tembotrione, and topramezone have been documented in Kansas, Nebraska, and North Carolina (Heap 2023; Jhala et al. 2017; Mahoney et al 2020; Nakka et al. 2017). However, there have been no reports of Palmer amaranth resistance to isoxaflutole. Determining the sensitivity or response of Palmer amaranth to isoxaflutole PRE was critical for this study because its use in South Carolina will significantly increase after the introduction of HPPD-tolerant soybean and cotton varieties (M. Marshall, personal observation). Differences were observed for Palmer amaranth survival percentages at the 1× isoxaflutole (P<0.0001) rate but not the 2× rate (P>0.05). At the 1× isoxaflutole rate, there were 103 Palmer amaranth accessions with no survivors (0%) [Table 1]. Survivors from five accessions ranged from 1-10%. Four accessions had survivors between 11-20% and one accession in each of the 21-30%, 31-40%, and 41-50% survivor ranges, respectively. While there were two accessions that exhibited reduced susceptibility (31-50%) to the 1× rate, most of the accessions (112 out of 115) were not different from the 0% (no survivors) according to 95% confidence intervals. In addition, there were no (0%) survivors observed at the 2× rate of isoxaflutole (Table 1). The relative low number of survivors observed from the isoxaflutole PRE study indicate that this will be an effective soil residual herbicide in HPPD-tolerant soybean and cotton in South Carolina; however, additional screening is needed to determine sensitivity to POST HPPD-inhibitor herbicides including mesotrione, tembotrione, and tompramezone.

In the United States, *S*-metolachlor is the fourth most used active ingredient in corn behind glyphosate, mesotrione, and atrazine (USDA-NASS 2022a). It is a widely used PRE and POST residual herbicide in cotton, soybean, and peanut in South Carolina (M. Marshall, personal observation). Arkansas and Mississippi have confirmed Palmer amaranth resistance to *S*-metolachlor (Brabham et al. 2019; Heap 2023; Kouame et al. 2022; Rangani et al. 2021). In the South Carolina survey, *S*-metolachlor was applied as a PRE at the 1× and 2× rate to 115 accessions (Table 1). Differences were observed for Palmer amaranth survival percentages at the 1× (P < 0.0001) and 2× (P < 0.0001) use rate of *S*-metolachlor. There were 24 and 35 accessions with no survivors (0%) at the 1× and 2× rate of *S*-metolachlor, respectively. No differences were observed between the low and no survivor percentages according to 95% confidence intervals, whereas, differences were observed between moderate and high survivor percentages. The low survival (1 to 30%) had 27 and 41 accessions for the 1× and 2× rate, respectively. The moderate survivor (31 to 60%) had 25 and 20 accessions for the1× and 2× rate, respectively (Table 1). At the high survivor (61 to 100%) range, 39 accessions at the 1× rate were observed. This survey showed that 34% of the accessions in the high survivor range were not controlled by *S*-metolachlor at the 1× rate. These results agree with a survey conducted in North Carolina where 18 populations survived s-metolachlor at the 1× rate (Moore et al. 2021). Overall, 39 out of 115

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accessions survived (>60% threshold) at the 1× rate of *S*-metolachlor indicating a reduction in susceptibility. In addition, there were 19 accessions that survived the 2× rate of s-metolachlor (>60% threshold). Additional research is needed to determine if these survivors in this study are resistant.

*Postemergence susceptibility bioassay*

A total of 142 Palmer amaranth accessions collected in South Carolina were screened at the 1× and 2× rates of fomesafen, glufosinate, 2,4-D, and dicamba to determine the survival frequency of these accessions. Fomesafen resistance has been confirmed in Arkansas and Tennessee (Salas et al. 2016; Umphres et al. 2018). No differences were observed for Palmer amaranth survival percentages at the 1× (P = 0.8422) and 2× (P = 0.9872) rate of fomesafen. There were 132 out of 142 and 140 out of 142 accessions with 0% survival for the 1× and 2× rates, respectively (Table 1). There were 9 surviving accessions in the low range (1-30%) at the 1× rate. However, the low survival percentages did not differ from the 0% survival according to 95% confidence intervals. Similarly, there were 2 accessions in the low survival range (1-30%) at the 2× rate of fomesafen (Table 1) which was also not different than the 0% according to 95% confidence intervals. A survey conducted in North Carolina found 4 accessions with a 1-10% survival percentage for fomesafen at the 1× rate (Mahoney et al. 2020). In this study, 10 out of 142 accessions from South Carolina had reduced sensitivity to fomesafen; therefore, these accessions should be monitored and resampled in the future.

Glyphosate-resistant Palmer amaranth accessions were first confirmed in 2006 in South Carolina (Heap 2023; Nichols et al. 2008). Differences were observed for Palmer amaranth survival percentages at the 1× (P<0.0001) and 2× (P<0.0001) rate of glyphosate. At the 1× rate, one accession did not have any survivors (0%). The low survival (1-30%) range had 11 and 11 accessions at the 1× and 2× rate, respectively (Table 1). No differences were observed between the low survival percentages and the no survivor according to the 95% confidence intervals. At the moderate survival (31-60%) range, there were 18 accessions that survived the 1× rate while there were 31 accessions that survived the 2× rate. However, 79% of the accessions from the survey (112 out of 142) survived the 1× rate of glyphosate (high survival range, 61-100%). At the 2× rate of glyphosate, there were 99 accessions out of 142 that survived the 2× rate of glyphosate (Table 1). Two studies from North Carolina observed high levels of Palmer amaranth

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resistance to glyphosate (Poirier et al. 2014; Mahoney et al. 2020). Based on these results, most accessions were low in susceptibility indicating that Palmer amaranth remains resistant to glyphosate in South Carolina.

Palmer amaranth resistance to ALS-inhibiting herbicides was first observed in 1993 in Kansas (Heap 2023; Horak and Peterson 1995). In 1997, Palmer amaranth resistance to imazapic, imazaquin, and imazethapyr was confirmed in South Carolina (Gossett et al. 1998; Heap 2023). In this survey, 142 Palmer amaranth accessions were tested for susceptibility to thifensulfuron-methyl. Differences were observed for Palmer amaranth survival percentages at the 1× (P = 0.0381) and 2× (P = 0.0079) rate of thifensulfuron-methyl. Three accessions were controlled (0% survival) following 1× and 2× rate of thifensulfuron-methyl (Table 1). No differences were observed between the low survival percentages (1-30%) and the no survivor according to the 95% confidence intervals. The low survival percentage (1-30%) had 44 accessions at the 1× rate. In the moderate survival category (31 to 60%), there were 43 accessions, and 52 accessions in the high survival (61 to 100%) category at the 1× rate. There were 56, 42, and 41

accessions in the low (1-30%), moderate (31-60%), and high (61-100%) survival categories at the 2× rate. Overall, there was lower survival observed in the high category (37 and 29% for the 1× and 2×rate, respectively) than for glyphosate. Although Palmer amaranth accessions resistant to ALS-inhibitors were confirmed in South Carolina (Gossett et al. 1998), the overall response among the accessions varied (31 and 39% for the 1× and 2× rate, respectively) for the low survival range, indicating genetic heterogeneity. Mahoney et al. (2020) reported that 41 out of 110 North Carolina accessions were sensitive to thifensulfuron-methyl (16% or less) despite the previously documented ALS-resistance in the state. However, the 1× rate of thifensufluron was 17.5 g ai ha$^{-1}$ which was equivalent to the 2× rate in this study. The relatively low to moderate survival observed in this survey may be due to the reduction in the use of ALS-inhibitor herbicides in South Carolina following the adoption of herbicide-tolerant crops in the late 1990’s.

There were no Palmer amaranth survivors (0%) following an application of glufosinate, 2,4-D, or dicamba POST at the 1× and 2× rate (data not shown). However, other states have confirmed Palmer amaranth resistance to glufosinate (Jones et al. 2022; Priess et al. 2022), 2,4-D (Kumar et al. 2019), and dicamba (Foster and Steckel 2022).

This survey demonstrated the relative response of selected Palmer amaranth accessions to three PRE and six POST herbicides commonly used in agronomic crops in South Carolina. Reduced sensitivity at the normal use rates of atrazine and *S*-metolachlor PRE was observed in about 40% of the accessions; however, only about 10% of the accessions demonstrated lower sensitivity to the 1× rate of isoxaflutole PRE. Additional research is needed to determine if there is potential evolved resistance to these PRE herbicides. For the POST-applied herbicides, moderate to high levels of survivors were observed for the glyphosate and thifensulfuron-methyl POST. In addition, there was one accession with reduced sensitivity to fomesafen POST at the 2× rate which warrants future research on this accession for potential resistance. It should be noted that the higher potency of PPO POST herbicides in the greenhouse may have increased the sensitivity among the sampled accessions compared to field conditions. Glufosinate, 2,4-D, and dicamba provided 100% control of all Palmer amaranth accessions collected in this survey. The intent of this survey was to evaluate Palmer amaranth accession susceptibility to commonly used PRE and POST herbicides in South Carolina. However, this survey did not sample these accessions at random and does not represent the actual distribution of Palmer amaranth in the state, and conclusions from this study should be drawn with caution. In summary, growers in South Carolina should consider using multiple control tactics when managing Palmer amaranth to minimize selection pressure. This would reduce the likelihood of the evolution of Palmer amaranth resistance to glufosinate, 2,4-D, and dicamba.

**Practical Implications**

Palmer amaranth is one of the most problematic weeds in corn, soybean, and cotton production. It is well documented that it can reduce crop yield by competing for water, light, and nutrients. In addition, Palmer amaranth has also evolved resistance to multiple herbicides across different modes-of-action. Therefore, growers see Palmer amaranth as the toughest challenge in their weed management programs. Without the development of new herbicide modes-of-action, there will be fewer effective products to mitigate Palmer amaranth effect on yield. Palmer amaranth resistance to different modes-of-action is prevalent throughout the southern region of the United States. The introduction of HPPD-tolerant cotton and soybean will provide additional PRE and POST timing options for isoxaflutole. In the South Carolina accessions, isoxaflutole PRE controlled 90% of the accessions in this survey indicating a high susceptibility in Palmer amaranth., There were 38 and 49% of the survivors in the high (61-100%) category for atrazine and *S*-metolachlor PRE indicating a reduction in susceptibility. However, additional research is needed to confirm whether these accessions with a low response have evolved resistance to atrazine and *S*-metolachlor PRE. Fomesafen POST controlled most of the accessions in this survey at both rates. However, susceptibility to glyphosate and thifensulfuron-methyl POST at the 1× and 2× rates was relatively low in the survey accessions. However, there were several accessions that were controlled by thifensulfuron-methyl POST. All accessions were effectively controlled with dicamba, 2,4-D, and glufosinate POST at both rates. These herbicides are available in transgenic corn, cotton, and soybean varieties. Overall, several of the PRE and POST herbicides evaluated in this study effectively controlled Palmer amaranth; however, reduced susceptibility was observed to *S*-metolachlor and atrazine herbicides, which were not known at the time of the survey. This research provides critical information to agronomic producers in developing an effective management plan for Palmer amaranth involving different control tactics, which reduces the potential selection pressure given the widespread use of these herbicides in South Carolina.

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Table 1. Response of Palmer amaranth accessions from South Carolina to selected preemergence (PRE) and postemergence (POST) herbicides.

| Herbicide | Rate[a] | % survivor[b] | | | |
|---|---|---|---|---|---|
| | | 0 | 1-30 | 31-60 | 61-100 |
| | g ai or ae ha$^{-1}$ | ------ Number of accessions ------ | | | |
| atrazine PRE | 1121 | 38 | 28 | 27 | 22 |
| atrazine PRE | 2242 | 45 | 37 | 24 | 9 |
| fomesafen POST | 280 | 133 | 9 | 0 | 0 |
| fomesafen POST | 560 | 140 | 2 | 0 | 0 |
| glyphosate POST | 840 | 1 | 11 | 18 | 112 |
| glyphosate POST | 1680 | 1 | 11 | 31 | 99 |
| isoxaflutole PRE | 105 | 10 | 2 | 0 | 0 |
| isoxaflutole PRE | 210 | 0 | 0 | 0 | 0 |
| *S*-metolachlor PRE | 1068 | 24 | 27 | 25 | 39 |
| *S*-metolachlor PRE | 2136 | 35 | 41 | 20 | 19 |
| thifensulfuron-methyl POST | 8.75 | 3 | 44 | 43 | 52 |
| thifensulfuron-methyl POST | 17.5 | 3 | 56 | 42 | 41 |

[a]The herbicide rates were 1× and 2× of the recommended use rate except for atrazine where 1× was 1,121 g ha$^{-1}$ (2,242 g ha$^{-1}$ is the recommended 1× rate on the product label) which is the typical single application rate for growers in South Carolina. A 1% volume-to-volume crop oil concentrate was included with fomesafen POST. A 0.25% v/v nonionic surfactant and 2.5% v/v ammonium sulfate was included with thifensulfuron-methyl POST.

[b]Palmer amaranth survivors were based on green leaves and active growth at the apical meristems.

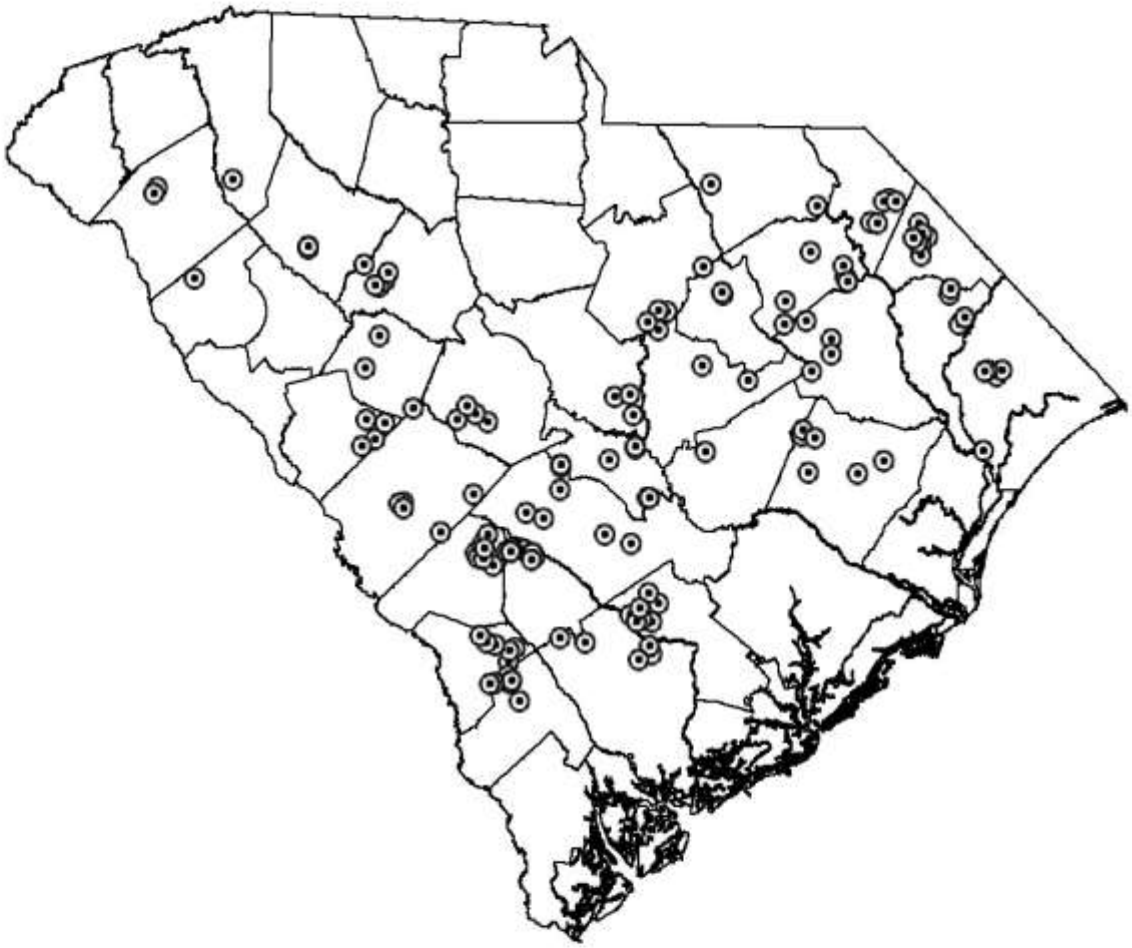

Figure 1. Sampling field locations for Palmer amaranth seed collection in South Carolina from 2020 to 2022.