

Characterization and Management of Glyphosate- and HPPD-Inhibitor- Resistant Palmer Amaranth in Kansas Corn Production

V. Kumar, R. Liu, and T. Lambert

Summary

Multiple herbicide-resistant (MHR) Palmer amaranth is an increasing management concern for Kansas grain producers. The main purpose of this research was to 1) characterize the resistance levels to glyphosate (Roundup PowerMax) and mesotrione (Callisto) in an MHR Palmer amaranth population collected from Stafford County, KS, compared to a known herbicide-susceptible (SUS) population; and 2) to evaluate the effectiveness of preemergence (PRE), PRE followed by (*fb*) early post emergence (EPOST), and PRE *fb* late POST (LPOST) herbicide programs for controlling this MHR population in Roundup Ready and LibertyLink corn. To achieve these objectives, a whole plant dose-response study was conducted in a greenhouse at the Kansas State University Agricultural Research Center near Hays, KS; and a field study was conducted in Stafford County, KS (from where the MHR population was originally collected). Dose-response study indicated that the MHR population had 7.2- and 3.5-fold resistance to glyphosate and mesotrione, respectively, on the basis of visual control (LD_{50} values). Results from field study indicated that PRE application of Clarity + Acuron in combination with Aatrex, Callisto, Dual II Magnum, or Sencor *fb* a sequential EPOST application of Acuron alone or in combination with Aatrex, Callisto, or Dual II Magnum provided 80 to 95% control of MHR Palmer amaranth population in corn throughout the season. Furthermore, control with PRE applied Clarity + Acuron *fb* a LPOST application of Acuron + Status or Acuron + Liberty averaged 85% at the final rating. Based on these results, the tested Palmer amaranth population from Stafford County has evolved multiple resistance to glyphosate and mesotrione. Two-pass herbicide programs, including PRE *fb* EPOST or LPOST investigated in this research can provide adequate control of this population throughout the season in Roundup Ready and LibertyLink corn.

Introduction

Palmer amaranth (*Amaranthus palmeri* L.) is a problematic, summer annual broad-leaf weed species in agronomic crops across central and western parts of Kansas. It is a dioecious (male and female flowers on separate plants) plant species that belongs to the pigweed family (Amaranthaceae). Palmer amaranth initiates its emergence around late spring (mid to late May) and manifests an extended period of emergence throughout

the season and produces numerous seeds (up to 0.6 million seeds per female plant) (Keeley et al., 1987; Klingaman and Oliver, 1994). Glyphosate was an effective POST herbicide for Palmer amaranth control until the evolution of glyphosate-resistant (GR) populations, which were first discovered in Kansas in 2011 (Heap, 2019). The recent survey suggests that glyphosate resistance has become fairly common among Palmer amaranth populations in Kansas. Furthermore, multiple herbicide-resistant (MHR) Palmer amaranth is also an increasing concern for Kansas growers. Palmer amaranth populations that have resistance to one or more of the following herbicide site(s) of action, including sulfonylureas (ALS inhibitors), atrazine (PS II inhibitor), mesotrione (HPPD inhibitor), glyphosate (EPSPS inhibitor), and more recently to 2,4-D (synthetic auxins) have been reported in Kansas (Heap, 2019; Kumar et al., 2019).

An MHR Palmer amaranth population showing an inadequate control with glyphosate (Roundup PowerMax) and mesotrione (Callisto) herbicides was identified in Stafford County, KS, in 2017. The main objectives of this research were to 1) characterize the response of suspected MHR Palmer amaranth population to Roundup PowerMax and Callisto herbicides in the whole plant dose-response assays, and 2) to evaluate and develop effective herbicide programs in corn for controlling this MHR Palmer amaranth population.

Procedures

Greenhouse Study

Fully-matured seeds of MHR Palmer amaranth population were collected from Stafford County, KS. Seeds of a susceptible (SUS) Palmer amaranth population were collected from the Kansas State University Agricultural Research Center (KSU-ARC) near Hays, KS. Whole plant dose-response experiments were conducted in greenhouse conditions at KSU-ARC near Hays, KS. Seedlings of MHR and SUS Palmer amaranth population were grown in 4 × 4 in.² plastic pots containing commercial potting mixture. Experiments were conducted in a randomized complete block design (blocked by population) with 12 replications. Young Palmer amaranth seedlings (3–4 inches tall) from each population were separately sprayed with Roundup PowerMax at doses of 0, 16, 32, 64, 128, and 256 fluid oz/a. Ammonium sulfate (AMS) at 2% (wt/v) was included with all Roundup PowerMax doses. Doses for Callisto herbicide included 0, 0.75, 1.5, 3, 6, and 12 oz/a along with 1% v/v of crop oil concentrate (COC) and 2.5% v/v of urea ammonium nitrate (UAN, 28%). All herbicide treatments were applied using a cabinet spray chamber equipped with a flat-fan nozzle tip (TeeJet 8001EXR) calibrated to deliver 14 gallons per acre of spray solution at 40 psi. The treated plants were returned to the greenhouse and watered and fertilized as needed. For both herbicides, data on percent visual control (0 = no control, 100 = dead plant) were visually assessed at 7, 14, and 21 days after treatment. Data were analyzed using a 3-parameter log-logistic model in *R* software using the following equation (Ritz et al., 2015):

$$Y = \{D / 1 + \exp [B (\log X - \log E)]\} [1]$$

Where Y represents % visual control, D is the upper limit, B is the slope of each curve, E is the herbicide dose required to achieve 50% control (referred to as LD₅₀), and X is the herbicide dose. Nonlinear regression parameter estimates and standard errors for each population were determined using the *drc* package in *R* software. Resistance level

(referred as R/S ratio) to Roundup PowerMax and Callisto herbicides was estimated by dividing the LD₅₀ value of MHR population by the LD₅₀ value of the SUS population.

Field Study

A field study was conducted in 2018 on a grower field in Stafford County, KS (from where MHR Palmer amaranth population was collected). A Roundup Ready and LibertyLink corn hybrid was planted at 30,000 seeds/a on April 24, 2018. The experiment was established in a randomized complete block design, with 4 replications and a plot size of 10 by 30 ft. Ten different herbicide programs, including PRE alone, PRE followed by (*fb*) early POST (EPOST), and PRE *fb* late POST (LPOST) were tested (Table 1). A nontreated control was also included. All PRE and POST treatments were applied in combination with Roundup PowerMax at 27 fl oz/a. PRE herbicide programs were applied immediately after corn planting (April 24, 2018); while EPOST and LPOST treatments were applied on May 17 and June 1, 2018, respectively. All herbicide treatments were applied with a CO₂-pressurized backpack sprayer equipped with TeeJet AIXR 110015 flat spray nozzle tips (Spraying Systems Co., Wheaton, IL), calibrated to deliver 15 gallons per acre spray solution. Data on visual Palmer amaranth control on a scale of 0 to 100% (0 being no control and 100 being complete control) were collected at 3 weeks after PRE (WAPRE), 2 weeks after early POST (WAEPOST), and 2 and 7 weeks after late POST (WALPOST). Data on Palmer amaranth control (%) were subjected to ANOVA using PROC MIXED in SAS v. 9.3 software (SAS Inst. Inc., Cary, NC). Means were separated using Fisher's protected least significant difference test at $P < 0.05$.

Results

Multiple Resistance to Glyphosate and Mesotrione

The glyphosate dose-response study revealed that the LD₅₀ (effective dose of Roundup PowerMax required to obtain 50% control) value of MHR Palmer amaranth population was 131 fl oz/a, and was significantly higher than the 18 fl oz/a value obtained for the SUS population (Figure 1). On the basis of visual control data (LD₅₀ values), the MHR population showed 7.2-fold level resistance to glyphosate relative to the SUS population (Figure 1). In a separate mesotrione (Callisto) dose-response study, the MHR population also exhibited 3.5-fold resistance to mesotrione herbicide on the basis of visual control data (LD₅₀ values) (Figure 2). In comparison, a Palmer amaranth population from Barton County, KS, has recently been reported with multiple resistance to 2,4-D, glyphosate (Roundup PowerMax), chlorsulfuron (Glean), atrazine (Aatrex), and mesotrione (Callisto) (Kumar et al., 2019).

Herbicide Programs for MHR Palmer Amaranth Control

A single PRE application of Clarity + Corvus + Aatrex and Clarity + Acuron provided more than 90% control of MHR Palmer amaranth at 3 WAPRE; however, control declined in late-season and did not exceed 75% at final rating (7 WALPOST) (Figures 3 and 4). In contrast, control with all PRE applied Clarity + Acuron in combination with Aatrex, Callisto, Dual II Magnum, or Sencor followed by a sequential EPOST application of Acuron alone or in combination with Aatrex, Callisto, or Dual II Magnum ranged from 80 to 95% throughout the season (Figure 3). Similarly, control

with PRE applied Clarity + Acuron followed by a LPOST application of Acuron + Status or Acuron + Liberty averaged 85% at the final rating (Figure 3).

Conclusions and Implications

The greenhouse study confirmed that MHR population from Stafford County had evolved multiple resistance to glyphosate and mesotrione herbicides. Results from the field study indicated that two-pass herbicide programs, including PRE tank-mixtures of Clarity + Acuron in combination with Aatrex, Callisto, Dual II Magnum, or Sencor followed by a sequential EPOST tank-mixtures of Acuron alone or in combination with Aatrex, Callisto, or Dual II Magnum can provide adequate control of MHR population in corn throughout the season.

References

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Table 1. List of herbicide programs tested for controlling MHR Palmer amaranth in Roundup Ready and LibertyLink corn in Stafford County, KS, in 2018.

Herbicide programs ^{a,b,c}	Rate (oz/a)	Timing
Clarity + Corvus + Aatrex	8 + 5.6 + 24	PRE
Clarity + Acuron	8 + 96	PRE
Clarity + Acuron + Aatrex <i>fb</i> Acuron + Aatrex	8 + 48 + 8 <i>fb</i> 48 + 8	PRE <i>fb</i> EPOST
Clarity + Acuron + Aatrex + Dual II Magnum + Callisto <i>fb</i> Acuron + Aatrex + Dual II Magnum + Callisto	8 + 48 + 8 + 8 + 1 <i>fb</i> 48 + 8 + 8 + 1	PRE <i>fb</i> EPOST
Clarity + Acuron + Callisto <i>fb</i> Acuron + Callisto	8 + 64 + 1 <i>fb</i> 32 + 1	PRE <i>fb</i> EPOST
Clarity + Acuron + Dual II Magnum <i>fb</i> Acuron + Dual II Magnum	8 + 64 + 8 <i>fb</i> 32 + 8	PRE <i>fb</i> EPOST
Clarity + Acuron + Aatrex <i>fb</i> Acuron + Aatrex	8 + 64 + 8 <i>fb</i> 32 + 8	PRE <i>fb</i> EPOST
Clarity + Acuron + Sencor <i>fb</i> Acuron	8 + 48 + 3 <i>fb</i> 48	PRE <i>fb</i> EPOST
Clarity + Acuron <i>fb</i> Acuron + Status	8 + 48 <i>fb</i> 48 + 2.5	PRE <i>fb</i> LPOST
Clarity + Acuron <i>fb</i> Acuron + Liberty	8 + 48 <i>fb</i> 48 + 22	PRE <i>fb</i> LPOST
Nontreated	-	-

^aPRE, preemergence. EPOST = early postemergence. LPOST = late postemergence. *fb* = followed by.

^bAll PRE and POST herbicide treatments were applied with Roundup PowerMax at 27 fl oz/a.

^cTreatments were applied with appropriate adjuvants as dictated by each herbicide label.

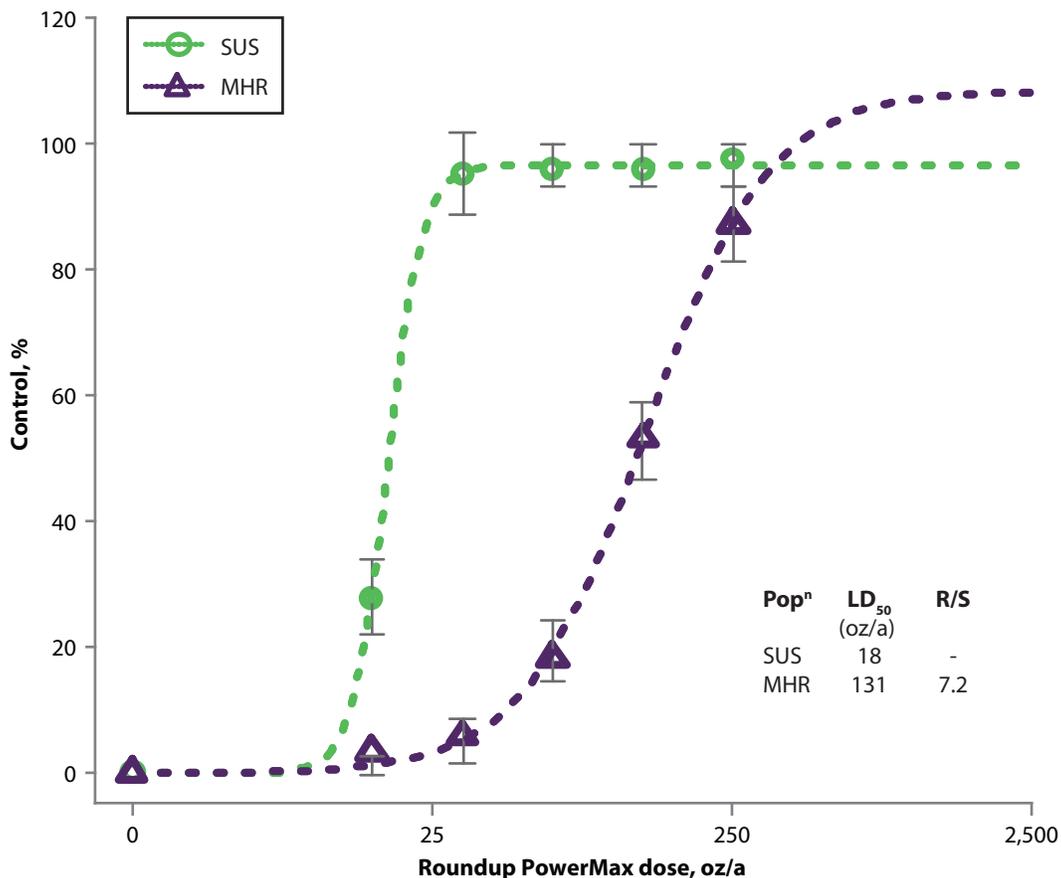


Figure 1. Percent visual control of a susceptible (SUS) and multiple herbicide-resistant (MHR) Palmer amaranth populations treated with various Roundup PowerMax doses at 21 days after treatment. R/S = resistance level ratio. Pop = population. LD₅₀ is the estimated amount of Roundup PowerMax (oz/a) required to achieve 50% control of SUS and MHR population.

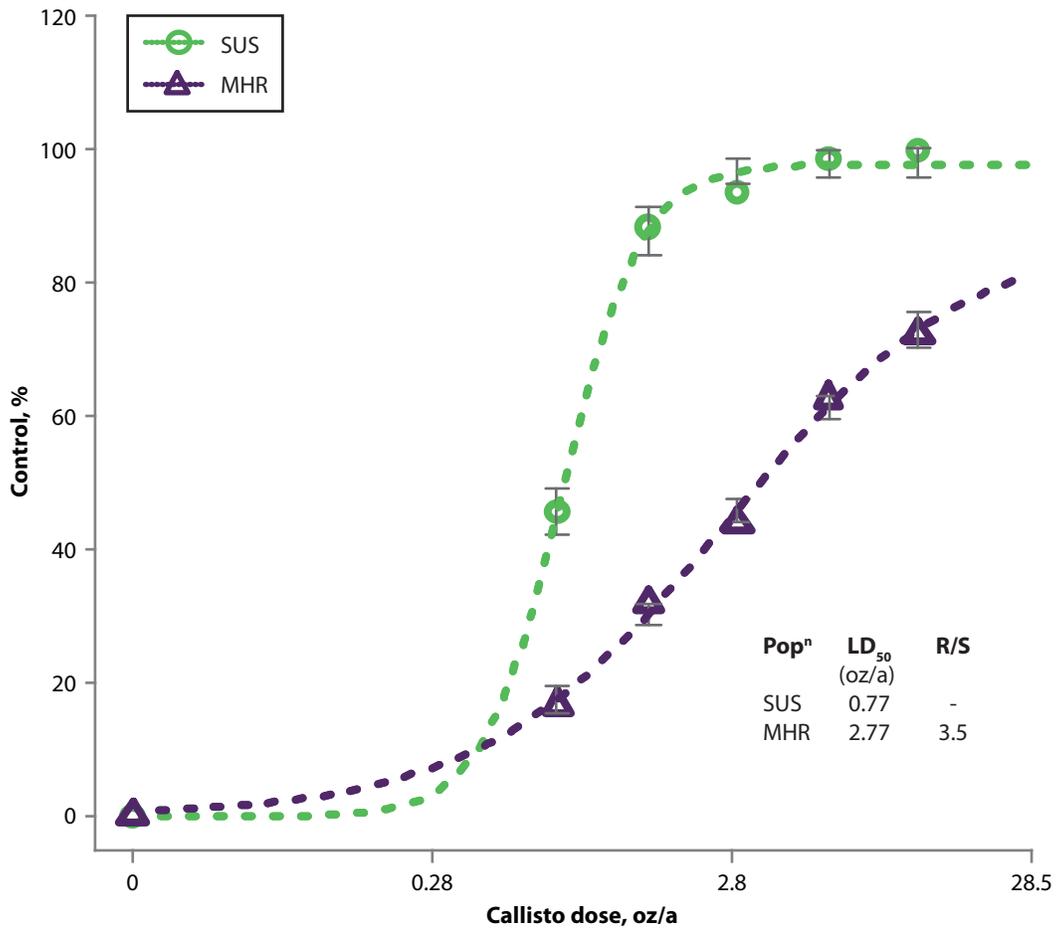


Figure 2. Percent visual control of a susceptible (SUS) and multiple herbicide-resistant (MHR) Palmer amaranth populations treated with various doses of Callisto herbicide at 21 days after treatment. R/S = resistance level ratio. Pop = population. LD₅₀ is the estimated amount of Callisto herbicide (oz/a) required to achieve 50% control of SUS and MHR population.

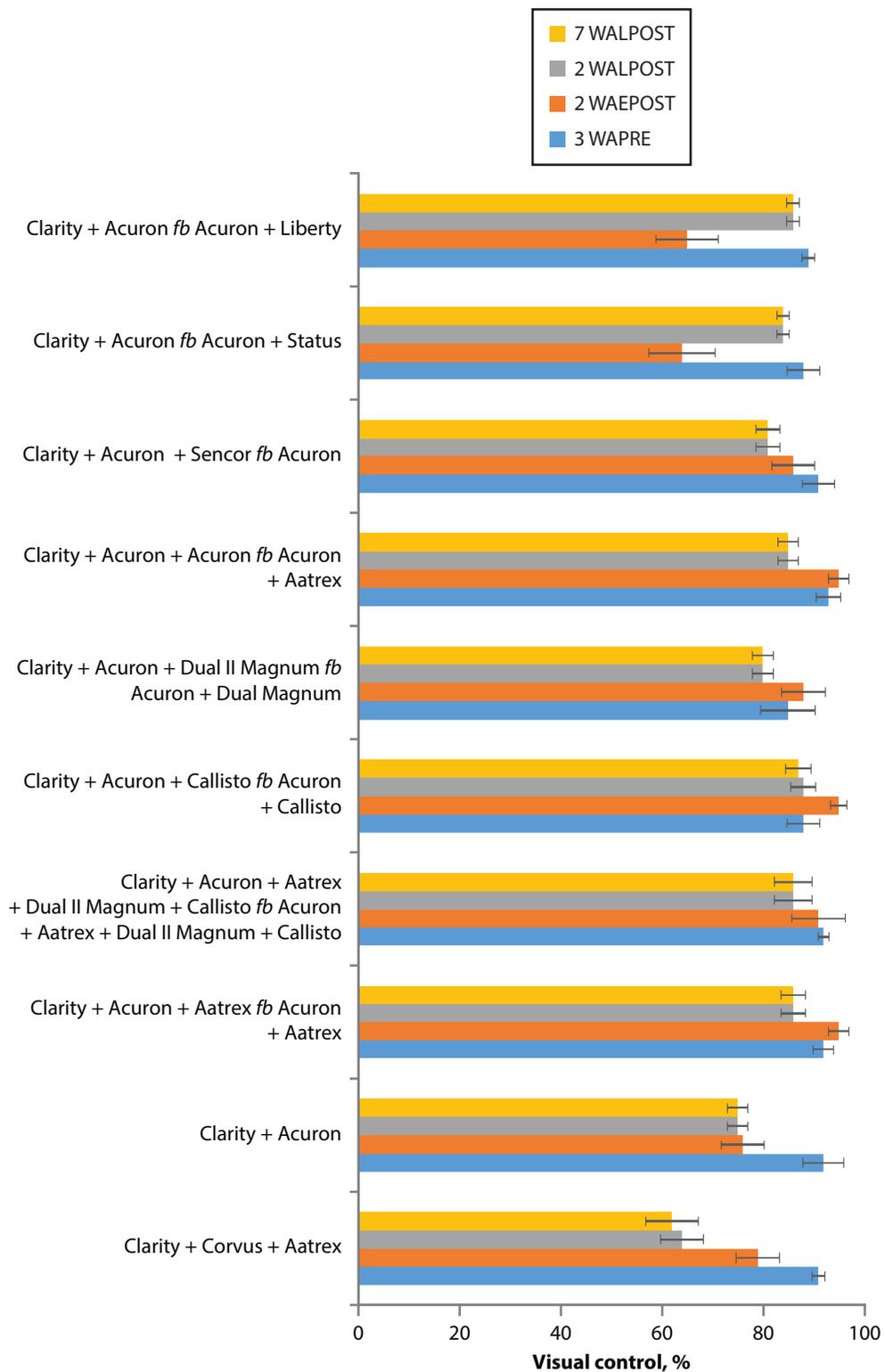


Figure 3. Percent visual control of multiple herbicide-resistant (MHR) Palmer amaranth with various preemergence (PRE), PRE followed by (*fb*) early post emergence (EPOST), and PRE *fb* late POST (LPOST) herbicide programs throughout the growing season in corn. WALPOST = weeks after late POST. WAEPOST = weeks after early POST. WAPRE = weeks after early PRE.



Figure 4. Visual response of multiple herbicide-resistant (MHR) Palmer amaranth in Roundup Ready and LibertyLink corn with various herbicide programs at 2 weeks after early post emergence (POST): Nontreated (A), preemergence (PRE) applied Clarity + Corvus + Atrazine (B), PRE applied Clarity + Acuron (C), PRE applied Clarity + Acuron + Dual II Magnum followed by early POST applied Acuron + Dual II Magnum (D).