Jack O'Lantern Pumpkin Response to Carfentrazone, Glufosinate, and Glyphosate Applied to the Distal Portion of the Vine

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KEYWORDS. crop injury, *Cucurbita pepo*, herbicide, postemergence application

ABSTRACT. Chemical weed control in pumpkin (*Cucurbita pepo*) often relies on herbicide applications made at planting, which results in weed escapes later in the growing season. The use of postemergence herbicides in row middles is useful, especially in no-till pumpkin production, but there are limited effective options. We conducted field research in 2023 at Wanatah and Lafayette, IN, USA, to evaluate 'Bayhorse Gold' pumpkin response to carfentrazone, glufosinate, and glyphosate applied to 10% of the vine tip 5 weeks after planting. A non-treated control was included for comparison. Pooled across both locations at 1, 2, and 4 weeks after treatment, glyphosate resulted in greater visible foliar injury (32%, 21%, and 9%, respectively) than carfentrazone (16%, 8%, and 5%, respectively) or glufosinate (13%, 8%, and 6%, respectively). Injury did not differ among the herbicide treatments at 6 weeks after treatment; crop injury was 9% for glyphosate, 7% for carfentrazone, and 6% for glufosinate. The nontreated control yielded 2420 orange pumpkins/acre weighing 48,016 lb/acre, which was statistically similar to plots treated with glyphosate (2766 pumpkins and 50,684 lb/acre), carfentrazone (2593 pumpkins and 50,303 lb/acre), and glufosinate (3111 pumpkins and 54,495 lb/acre). All treatments resulted in 346 green and 173 nonmarketable pumpkin fruit (<3.3 lb) per acre. Our results suggest that the herbicide glufosinate, which is not currently registered for use in pumpkins, offers crop safety similar to carfentrazone and greater crop safety than glyphosate, which are both currently registered for use between pumpkin rows. Despite differences in visible crop injury, no herbicide treatment resulted in decreased pumpkin yield.

The United States ranked ninth for pumpkin production globally in 2022 (Food and Agriculture Organization of the United Nations 2024). Three of the top four pumpkin-producing states in the United States are located in the Midwest, with Illinois producing 634 million pounds, Indiana producing 161 million pounds, and Michigan producing 90 million pounds in 2022 [US Department of Agriculture Economic Research Service (USDA-ERS) 2024]. The value of production that same year was $30 million in Indiana, $22 million in Illinois, and $16 million in Michigan, with the majority of Illinois production dedicated to processing and Indiana and Michigan production dedicated to the fresh market (USDA-ERS 2024). The wide within-row (1.5 to 5 ft) and between-row (4 to 8 ft) spacing requirements for pumpkin (Phillips et al. 2023) allow early season weeds to grow with limited competition from the crop, ultimately reducing yield and quality. Weed interference results in decreased pumpkin fruit weight and diameter, ultimately decreasing the economic return on investment (Walters and Young 2022).

Limited herbicides are registered for use in pumpkins (Phillips et al. 2023). Most provide residual control and must be applied to the soil either after direct-seeding and before crop emergence or before transplanting. To be effective, these soil-applied, residual herbicides require sufficient rainfall or overhead irrigation to be moved into the soil profile where weed seeds are germinating. Over-the-top postemergence herbicides are limited to halosulfuron-methyl [Weed Science Society of America (WSSA) Group 2] for broadleaf weeds and sedges, and the grass-selective herbicides clethodim and sethoxydim (both WSSA Group 1) (Phillips et al. 2023). The application of these herbicides and their corresponding adjuvants can result in crop injury (Kammler et al. 2008). Given the long growing season for most pumpkin cultivars (≥95 d), a weed management program consisting of herbicides applied only at planting will most likely result in late-season weed escapes. For example, Walters and Young (2022) reported that clomazone plus ethalfluralin, a commercial standard among pumpkin producers, provided only 72% broadleaf weed control and 51% to 87% grass weed control 28 d after treatment.

Between-row cultivation is an option for managing small, emerged weeds in conventional tillage pumpkin fields but has limited utility due to the decumbent growth of most pumpkin cultivars and their relatively shallow root system. Additionally, an increasing percentage of fresh market pumpkins are grown in a no-till system where pumpkins are planted into a terminated cover crop. Due to the high amount of cover crop residue, cultivation in this system is impractical. An alternative to between-row cultivation is the use of directed or shielded applications of nonselective, postemergence herbicides. In the United States, there are currently three conventional herbicides registered for control of emerged weeds between pumpkin rows: glyphosate (WSSA Group 9; hooded or shielded application only), carfentrazone (WSSA Group 14; hooded application only), and paraquat (WSSA Group 22; directed, shielded, or spot spray application based on state). Glyphosate is a nonselective, foliar-applied herbicide that inhibits the enolpyruvyl shikimate-3-phosphate synthase enzyme in sensitive plants (Shaner 2014). It is moderately absorbed across the plant cuticle and transported primarily in the symplast, resulting in accumulation in underground tissues, immature leaves, and meristems (Shaner 2014). Historically an effective herbicide, populations of numerous weed species common to pumpkin fields in the Midwest now have confirmed resistance to glyphosate,

Received for publication 23 Aug 2024. Accepted for publication 11 Oct 2024.

Published online 3 Dec 2024.

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We thank Chloe Henscheid, Stephen Boyer, Alex Leman, and Liz Maynard for assisting with this research. We also thank Rupp Seeds, Inc. for providing the pumpkin seeds for the project. This work is supported by the US Department of Agriculture–National Institute of Food and Agriculture Hatch project 7000862.

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https://doi.org/10.21273/HORTTECH05530-24

including marestail (*Erigeron canadensis*), common waterhemp (*Amaranthus tuberculatus*), Palmer amaranth (*Amaranthus palmeri*), and common ragweed (*Ambrosia artemisiifolia*) (Heap 2024). Because glyphosate is systemic, growers have expressed concerns that unintended exposure of pumpkin vines during a post-directed, between-row application may result in long-term injury or death of exposed pumpkin plants. Carfentrazone is a nonselective, foliar-applied, contact herbicide that inhibits the porphyrinogen oxidase enzyme (Shaner 2014). Unlike glyphosate, carfentrazone is rapidly absorbed by plant foliage, but symplastic movement is limited (Shaner 2014). Although it can be an effective herbicide on select small, emerged broadleaf weeds, carfentrazone provides insufficient control of some problematic pumpkin weeds. For example, Byker et al. (2013) reported ≤58% control of up to 11-cm-tall marestail 2 weeks after treatment with glyphosate (900 g/ha) plus carfentrazone (17.5 g/ha). Similarly, Boyd (2016) reported that carfentrazone applied to 2- to 4-cm-tall weeds between plasticulture beds did not differ from a nontreated control 2 to 10 weeks after treatment. Although paraquat is registered for use in pumpkin, it is only available by supplemental label in California, Delaware, Georgia, Hawaii, Maryland, Maine, New Jersey, Pennsylvania, Tennessee, and Virginia. Additionally, in 2020, the US Environmental Protection Agency (2024) announced new restrictions to the use of paraquat that included additional paraquat specific training requirements, closed cab tractors or respirators, increased reentry intervals, and closed system packaging. These requirements make applications of paraquat less likely in pumpkins and provide an additional incentive to register herbicide alternatives with fewer application restrictions.

Beginning with the 2023 cropping season, glufosinate (WSSA Group 10) was registered for use with hooded or precision directed application equipment to control emerged weeds between rows of plasticulture-grown watermelon (*Citrullus lanatus*), cantaloupe (*Cucumis melo*), cucumber (*Cucumis sativus*), and summer squash (*Cucurbita pepo*) (BASF Corp 2023). However, pumpkins were not included in the cucurbit supplemental label. Glufosinate is a nonselective, foliar-applied, Group 10 herbicide that inhibits the glutamine synthetase enzyme. As with carfentrazone, translocation within xylem or phloem is limited (Shaner 2014). Increasingly, glufosinate has been used more widely to manage glyphosate-resistant weeds, especially in glufosinate-resistant transgenic agronomic crops (Takano and Dayan 2020). Sharpe and Boyd (2019) reported that glufosinate is also a suitable alternative to paraquat between rows in Florida plasticulture production systems. Given the increased role of glufosinate as a glyphosate alternative and its recent registration for use in other cucurbits, our objective was to document pumpkin crop safety of a between-row application of glufosinate compared with currently registered products glyphosate and carfentrazone.

Materials and methods

Field trials were conducted in 2023 at the Pinney Purdue Agricultural Center (PPAC), Wanatah, IN, USA (41.4445°N, 86.9212°W) and the Meigs Horticulture Research Farm (MEIGS) Lafayette, IN, USA (40.2928°N, 86.8765°W). At PPAC, the soil was a Bourbon sandy loam (coarse-loamy, mixed, active, mesic Aquultic Hapludalfs) with 1.3% organic matter and pH 6.4. At MEIGS, the soil was a Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls) with 2.2% organic matter and pH 6.8. MEIGS was planted with cereal rye (*Secale cereale*; Byron Seeds, Rockville, IN, USA) at 100 lb/acre on 19 Oct 2022 with a no-till grain drill (Great Plains Ag, Salina, KS, USA) and roller-crimped on 1 Jun 2023. Due to historical crop losses from pumpkin seed predation in terminated cereal rye cover crop fields at PPAC, this location was not planted with cereal rye and was a bare ground trial. Plots at both locations consisted of three rows, 6 ft apart, and 16 ft long at PPAC and 12 ft long at MEIGS. 'Bayhorse Gold' pumpkin seeds (Rupp Seeds, Inc, Wauseon, OH, USA) were planted 4 ft apart within each row by hand at PPAC (7 Jun 2023) and with a jab planter (Easy-Plant, RT Adkins, Parsonburg, MD, USA) at MEIGS (23 Jun 2023) at a density of two seeds per planting hole. Both fields received a standard recommended preemergence herbicide program that consisted of 4 pt per acre Strategy® herbicide (0.8 lb a.i./acre ethalfluralin, 0.25 lb a.i./acre clomazone; Loveland Products, Inc., Greeley, CO, USA) and 1 pt/acre Reflex® herbicide (0.25 lb/acre a.i. fomesafen; Syngenta Crop Protection, LLC, Greensboro, NC, USA) applied within 1 d after planting. Escaped weeds were removed from all plots by hand as needed to maintain weed-free conditions. Between 3 and 4 weeks after planting, planting holes were thinned by hand to one pumpkin plant per hole.

At 5 weeks after planting, pumpkin shoots were turned to the east of each row and then treated with one of three herbicides: glyphosate (0.688 lb a.i./acre; 22 fl oz/acre Credit 41 Extra, Nufarm Inc., Alsip, IL, USA), carfentrazone (0.031 lb a.i./acre; 2 fl oz/acre Aim® EC, FMC Corp, Philadelphia, PA, USA), or glufosinate (0.530 lb a.i./acre; 29 fl oz/acre Liberty 280SL, BASF Corp, Research Triangle Park, NC, USA). A nontreated control was included for comparison. All herbicide applications included 0.25% (v/v) nonionic surfactant (×-99 NIS 90, Heartland Ag Inc., Farmer City, IL, USA). Applications were made in a 20-inch band using a CO_2-pressurized backpack sprayer calibrated to deliver 20 gallons/acre at 24 PSI and equipped with a single brass even flat spray nozzle tip (8002E; Spraying Systems Co., Wheaton, IL, USA). To simulate herbicide exposure that may occur during a post-directed, between-row application this application was made in a manner that resulted in herbicide spray contacting ~10% of the distal vine tips. The experiment design was a randomized complete block design with four replications.

Data collection included visible crop injury on a scale of 0 (no injury) to 100% (crop death), relative to the nontreated control at 1, 2, 4, and 6 weeks after treatment (WAT). All pumpkin fruits from each plot were harvested on 25 Sep 2023 at MEIGS and 8 Sep 2023 at PPAC, individually weighed, and graded. Marketable fruit were defined as ≥3.3 lb and divided into two subcategories based on a visual assessment of rind color: "orange" (≥50% of the rind surface area was orange) or "green" (<50% of the surface area was orange). Fruits with green and tender rinds were classified as "immature" and were not harvested.

Data were subjected to analysis of variance (ANOVA) by SAS PROC GLM (SAS 9.4, SAS Institute, Cary, NC, USA) with the fixed effects of treatment and random effects of replication and location. Percent crop injury data were square root arcsin transformed and green pumpkin fruit number and weight data were square root transformed to meet the assumptions of ANOVA. Mean data were back-transformed to facilitate the interpretation of results. Crop injury data for the nontreated control were excluded from the analysis due to lack of variance. Means were separated by Fisher's protected least significant difference ($P \leq 0.05$).

Results and discussion

Because of a lack of treatment-by-location interaction, pumpkin injury and yield data were combined across both locations. At 1, 2, and 4 WAT, glyphosate resulted in greater injury (32%, 21%, and 9%, respectively) than carfentrazone (16%, 8%, and 5%, respectively) or glufosinate (13%, 8%, or 6%, respectively) (Table 1). During this time, pumpkin injury from carfentrazone and glufosinate were similar. At 6 WAT, injury did not differ among plots treated with glyphosate (9%), carfentrazone (7%), and glufosinate (6%). Glyphosate injury presented as chlorosis and bleaching in the distal pumpkin leaf tissues, whereas injury from carfentrazone and glufosinate appeared as localized necrotic spots or patches across the contacted portion of the distal vine tip (Fig. 1). In some instances, the primary growing point of the pumpkin was killed by carfentrazone and glufosinate, but lateral branches emerged later.

The nontreated control yielded 2420 orange pumpkins per acre weighing 48,016 lb (Table 1). Compared with the nontreated control, orange pumpkin yield per plot was statistically similar for pumpkins treated with glyphosate (2766 pumpkins; 50,684 lb), carfentrazone (2593 pumpkins; 50,303 lb), and glufosinate (3111 pumpkins; 54,495 lb). All treatments resulted in 346 green pumpkin fruit per plot, weighing 3049 lb/acre in the nontreated check, 5716 lb/acre in the glyphosate and carfentrazone plots, and 5335 lb/acre for glufosinate. All treatments contained 173 non-marketable (<3.3 lb in weight) fruit/acre (data not shown).

Table 1. Visible 'Bayhorse Gold' pumpkin crop injury 1, 2, 4, and 6 weeks after treatment (WAT) and orange and green pumpkin yield pooled across the Pinney Purdue Agriculture Center (Wanatah, IN, USA) and Meigs Horticulture Research Farm (Lafayette, IN, USA) in 2023.

	Crop injury[i]				Pumpkin yield[ii]			
Treatment[iii]	1 WAT	2 WAT	4 WAT	6 WAT	Orange	Green	Orange	Green
	%-				lb/acre		no./acre	
Nontreated	—	—	—	—	48,016	3,049	2,420	346
Glyphosate	32 a[iv]	21 a	9 a	9	50,684	5,716	2,766	346
Carfentrazone	16 b	8 b	5 b	7	50,303	5,716	2,593	346
Glufosinate	13 b	8 b	6 b	6	54,495	5,335	3,111	346

[i] Injury was rated on a scale of 0% (no injury) to 100% (crop death) relative to a nontreated control plot in each replicate of each location.

[ii] Averaged across both location, plot area was 252 ft^2 and contained 10.5 pumpkin plants. Orange fruit had ≥50% of the rind surface area orange; green fruit had <50% of the surface area was orange.

[iii] Herbicides were applied at the following a.i. rates in a 20-inch band, directed to 10% of the distal vine tip of 5-week-old pumpkin plants: 0.688 lb a.i./acre glyphosate, 0.031 lb a.i./acre carfentrazone, and 0.530 lb a.i./acre glufosinate.

[iv] Different letters within each rating period represent significant differences among means based on Fisher's protected least significant difference ($P \leq 0.05$).

Although there is some research documenting cucurbit crop response to glufosinate applied before planting or transplanting, the authors are not aware of an applicable comparison with the present study using glufosinate applications in row middles or intentional foliar exposure. There is limited research on the response of Cucurbitaceae weeds to glufosinate. Esbenshade et al. (2001) made a broadcast application of glufosinate to burcucumber (*Sicyos angulatas*) growing in glufosinate-resistant corn (*Zea mays*) and reported 79% to 90% control. Glufosinate applied to 2-to-4 and 6-to-8 leaf citronmelon

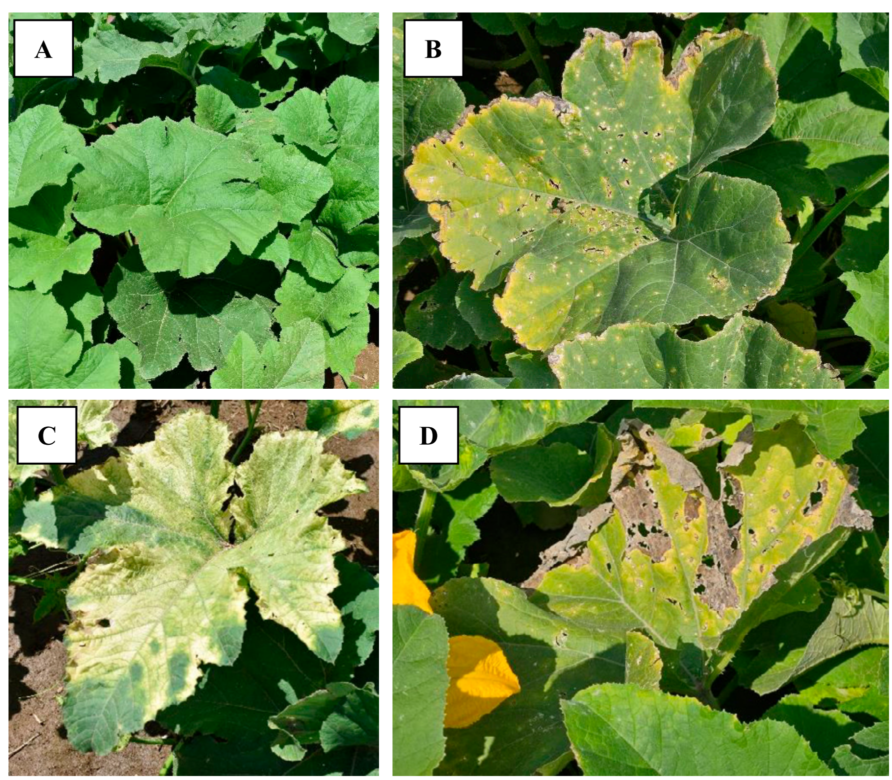

Fig. 1. A representative 'Bayhorse Gold' pumpkin leaf 4 weeks after treatment documenting injury symptomology from plots with no herbicide (A) or 0.031 lb a.i./acre carfentrazone (B), 0.688 lb a.i./acre glyphosate (C), or 0.530 lb a.i./acre glufosinate (D) at the Pinney Purdue Agricultural Center, Wanatah, IN, USA, in 2023. Herbicides were applied in a 20-inch band, directed to 10% of the distal vine tip of 5-week-old pumpkin plants.

(*Citrullus lanatus* var. *citroides*) provided 100% control by 7 d after treatment (Ramirez et al. 2012). These findings along with our observation of necrosis on pumpkin stems and leaves contacted by our glufosinate application suggest that exposed cucurbit tissues are susceptible to glufosinate. However, despite differences in observed crop injury from the post-directed herbicide treatments, all pumpkins yielded similarly to the nontreated control. Injury from carfentrazone and glufosinate was minimal and transient. These data suggest that relative to registered products glyphosate and carfentrazone, glufosinate can be applied in a post-directed manner in Jack O'Lantern pumpkins with minimal risk of crop injury and yield loss. However, it is important to note the limitations of this research, which was conducted with a single glufosinate rate applied at a single timing to a single cultivar of pumpkin, and within one state in 1 year. Glufosinate is currently registered for between-row use in plasticulture-grown watermelon, cantaloupe, cucumber, and summer squash (BASF Corp 2023). Its registration in pumpkins would benefit the industry by providing an effective, broad-spectrum, postemergence between-row weed management option for no-till/reduced-till pumpkin producers with greater weed control efficacy potential than the currently available options of glyphosate and carfentrazone.

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