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Plasticulture banana pepper response to clomazone applied pretransplanting

Jeanine Arana[1], Stephen L. Meyers[2], Emmanuel Cooper[3], Luis F. Medina Castro[4], Josué Cerritos[5] and Carlos A. López[6]

[1]Graduate Research Assistant, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA; [2]Assistant Professor, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA; [3]Graduate Research Assistant, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA; [4]Research Scholar, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA; [5]Research Scholar, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA and [6]Research Scholar, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, IN, USA

Note

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Corresponding author:
Stephen L. Meyers;
Email: slmeyers@purdue.edu

Abstract

Few published studies exist documenting banana pepper tolerance to clomazone. Therefore, field trials were conducted in 2022 at two Indiana locations [Meigs Horticulture Research Farm and the Pinney Purdue Agricultural Center (PPAC)] to evaluate crop safety in plasticulture-grown banana pepper. The experimental design was a split-plot in which the main plot factor was the clomazone rate (0, 840, and 1,680 g ai ha^{-1}) and the subplot factor was cultivar ('Pageant' and 'Sweet Sunset'). Clomazone was applied over the top of black polyethylene mulch-covered raised beds and their respective bare-ground row middles 1 d prior to transplanting 12 pepper plants per subplot. Data collected included crop injury on a scale from 0% (no injury) to 100% (crop death) at 2, 4, and 6 wk after treatment (WAT), and plant stand. Two harvests were performed in which mature fruits were counted and weighed. Injury presented as interveinal bleaching only at PPAC 2 and 4 WAT. At this location 1,680 g ha^{-1} clomazone resulted in greater injury to 'Sweet Sunset' at 2 and 4 WAT (53% and 15%, respectively) than to 'Pageant' (19% and 3%, respectively); however, plant stand and yield were not affected by either clomazone rate. These results suggest that the clomazone rate range currently used for bell pepper (280 to 1,120 g ai ha^{-1}) can be applied prior to transplanting plasticulture-grown banana pepper with minimal crop injury and without reducing yield.

Introduction

Peppers in the United States can be categorized by their shape and flavor profiles. The US Department of Agriculture–Agriculture Marketing Service (2016) defines bell peppers as blunt or bell-shaped, thick-walled, and meaty, and usually multi-pointed at the blossom end. In contrast, non–bell peppers are typically elongated, thin-walled, and contain a single point at the blossom end (USDA-AMS 2016). Although non–bell pepper production in the United States is concentrated in California and New Mexico, commercial production of the crop occurs throughout the country, including the state of Indiana. In 2021, US non–bell pepper production totaled ~85 million kg on 4,290 harvested hectares valued at $74.5 million (USDA NASS 2022).

Peppers are established using plug plants (seedlings) and transplanted into polyethylene mulch-covered raised rows (beds) for fresh-market production (P. Langenhoven, personal communication). The polyethylene mulch provides some, but not complete, control of weeds within the row. Weeds can grow in holes in the mulch, including those used for transplanting. Additionally, weeds between rows require management. Uncontrolled, weeds in plasticulture production systems reduced marketable yield of 'Carmen' pepper by 33% (Braun 2017) and 'Aristotle' pepper by 10% (Dayton et al. 2017). The most common and troublesome weeds in fruiting vegetable crops, including banana pepper, are pigweeds (*Amaranthus* spp. L.), common lambsquarters (*Chenopodium album* L.), nightshades (*Solanum* spp. L.), nutsedges (*Cyperus* spp. L.), foxtails (*Setaria* spp. P.Beauv.), and ragweeds (*Ambrosia* spp. L.) (Van Wychen 2022).

At the initiation of this research, nine preemergence herbicides were registered for use in banana peppers in the state of Indiana (bensulide, fomesafen, halosulfuron, imazosulfuron, napropamide, pendimethalin, *S*-metolachlor, sulfentrazone, and trifluralin) (Phillips 2022) representing Weed Science Society of America (WSSA) site of action (SOA) Groups 0, 2, 3, 14, and 15. An additional herbicide, clomazone, was registered for use in other bell and non–bell peppers in Indiana, but could not be used on banana peppers (Anonymous 2021). However, clomazone could be used in banana peppers in Michigan with a special-local-needs label authorized under §24(c) of the Federal Insecticide, Fungicide, and Rodenticide Act (EPA 2022).

Clomazone is a WSSA Group 13 herbicide from the isoxazolidinone family. An active 5-keto clomazone metabolite inhibits 1-deoxy-D-xylulose 5-phosphate synthase, a necessary enzyme in plastid isoprenoid synthesis (Shaner 2014). Clomazone applied preemergence can provide control of broadleaf weeds including velvetleaf (*Abutilon theophrasti* Medik.), cocklebur (*Xanthium strumarium* L.), common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters, and common purslane (*Portulaca oleracea* L.), and grasses including barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], crabgrass (*Digitaria* spp.), foxtails (*Setaria* spp.), and goosegrass [*Eleusine indica* (L.) Gaertn.] (Cavero et al. 1996; Frost et al. 2004; Mohseni-Moghadam and Doohan 2015; Shaner 2014). Adding another preemergence herbicide SOA would allow farmers to rotate their herbicides to slow the progression of herbicide resistance (Hulme 2021), and when combined with currently registered preemergence herbicides, it can improve the spectrum of weed species controlled.

There are limited reports of crop response to clomazone for non–bell peppers. Cavero et al. (1996) applied clomazone at 1 and 2 kg ai ha^{-1} and reported reduced plant stand when it was applied to direct-seeded paprika and pimiento peppers under clear plastic mulch, but no reduction in stand, plant biomass, or yield when applied to six- to eight-leaf pepper plants. When applied 2 d prior to transplanting 'Ethem' banana pepper into bare ground (no polyethylene mulch), Mohseni-Moghadam and Doohan (2015) reported ≤5% injury from clomazone plus *S*-metolachlor and no injury from clomazone alone. Galloway et al. (2000) applied clomazone immediately after transplanting 'Banana Supreme' banana pepper into bare ground and reported ≤3% injury. The authors are aware of no published, peer-reviewed research either documenting the use of clomazone in plasticulture-grown banana pepper or comparing multiple banana pepper cultivars for crop response to clomazone.

The clomazone recommended use rates for all crops are based on soil type and crop tolerance (Harrison and Farnham 2013). In Indiana, clomazone is currently registered for use in bell pepper as a pre-transplanting application at rates from 280 to 1,120 g ai ha^{-1} (Anonymous 2021). To support the registration of clomazone for use in banana pepper through a §24(c) label in Indiana, it is advisable to have in-state crop tolerance data. Our objective was to evaluate the effect of clomazone on plasticulture-grown banana peppers in Indiana growing conditions.

Materials and Methods

Locations and Field Preparation

Field trials were conducted in 2022 at the Meigs Horticulture Research Farm (Meigs), Lafayette, IN (40.28° N, 86.884° W), and at the Pinney Purdue Agricultural Center (PPAC), Wanatah, IN (41.44° N, 86.93° W). At Meigs, the soil was a mixture of Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls, 10% sand, 33% clay) and Starks-Fincastle silt loam (fine-silty, mixed, superactive, mesic Aeric Endoaqualfs-Epiaqualfs, 18% sand, 14% clay) with 1.6% organic matter (OM) and pH 6.4. At PPAC, the soil type was a mixture of Tracy sandy loam (coarse-loamy, mixed, active, mesic Ultic Hapludalfs, 59% sand, 9% clay) and Bourbon sandy loam (coarse-loamy, mixed, active, mesic Aquultic Hapludalfs, 56% sand, 13% clay) with 1.6% OM and pH 6.8.

Fields were prepared with two passes of a field cultivator, one north and south pass and one east and west. Raised beds ~2 m apart with a single subsurface drip tape (Meigs: Aqua-Traxx, Toro Ag, El Cajon, CA; 8 mil, 20-cm emitter spacing, 0.8 L min^{-1}; PPAC: T-Tape by Rivulis, Fresno, CA, 6 mil, 30-cm emitter spacing, 1.7 L min^{-1}) placed 5 cm deep and just off-center and covered with embossed, black polyethylene mulch (Meigs and PPAC: FilmTech Corp./Sigma Plastics Group, Allentown, PA; 1 mil; 1.2 m wide) were prepared on May 20 at Meigs and May 31 at PPAC. Raised beds measured 10 cm tall and 0.76 m wide. To help manage weeds, 1.1 kg ai ha^{-1} of *S*-metolachlor (Dual Magnum®; Syngenta Crop Protection, LLC, Greensboro, NC) was broadcast-applied across all plots 1 d after laying the black polyethylene mulch. Crop fertilization, irrigation, and disease and insect management followed regional recommendations (Phillips 2022).

Plant Material

'Pageant' and 'Sweet Sunset' (Rupp Seeds, Inc., Wauseon, OH) banana pepper seeds were planted into 72-cell trays containing Berger BM2 Seed Germination Mix (Hummert International, Earth City, MO) at the Purdue University Horticulture Greenhouses on May 27 for PPAC and June 3 for Meigs. Transplants were grown under ambient daylight and daylength conditions with no supplemental lighting. Mean greenhouse temperature was 25.1 C and 25.7 C for plants grown for the PPAC and Meigs locations, respectively. Mean relative humidity was 75.2%. Plants were fertilized three times per week with a water-soluble fertilizer (20-1.3-15.8; ICL Specialty Fertilizers, Dublin, OH) to provide 150 mg L^{-1} N, with nitrate and ammoniacal sources of N provided as 61% and 39% total N, respectively. Irrigation water was supplemented with 93% sulfuric acid (Water Solutions Unlimited, Camby, IN) at 0.08 ml L^{-1} to reduce alkalinity to 100 mg L^{-1} and pH to a range of 5.8 to 6.2. Plants with four to six true leaves were relocated in a shade house at the Meigs horticulture farm to harden off for 24 h prior to transplanting.

Treatments and Experiment Design

The experimental design was a randomized complete block with a split-plot treatment arrangement and four replications. The main plot consisted of one of three clomazone rates (0, 840, or 1,680 g ha^{-1}), and the subplot consisted of one of two banana pepper cultivars ('Pageant' or 'Sweet Sunset') randomly placed within each main plot. Clomazone (Command 3ME®; FMC Corp., Philadelphia, PA) was broadcast-applied over the top of the black polyethylene mulch and respective row middles on June 27 at PPAC and July 5 at Meigs using a CO_2-pressurized backpack sprayer equipped with four TeeJet XR 11004 VS nozzles (Spraying Systems Co., Wheaton, IL) and an output of 187 L ha^{-1} at 206 kPa. This represents the preferred application method of Indiana vegetable farmers who would rather not make banded or hooded applications to the row middles only. Furthermore, compared to a row-middle-only application, the authors believed the broadcast application would create the best opportunity to observe any possible adverse crop response. One day after spraying clomazone, a water wheel transplanter punched holes in the center of the plastic mulch, and pepper seedlings were hand-transplanted 46 cm apart in a single row 5.9 m long, totaling 12 plants per subplot. Weeds were removed by hand from planting holes and with hoes from row middles, as needed, to maintain plots weed-free and avoid yield loss due to weed interference.

Data Collection and Analysis

Data collection included visual crop injury using a scale of 0% (no injury) to 100% (crop death) relative to the nontreated control

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at 2, 4, and 6 WAT. Two harvests were performed. At PPAC, the first harvest was performed on August 23 and the second on September 22. At Meigs, the first harvest was performed on August 29 and the second on October 6. All fruits >10 cm in length that were yellow to red were harvested, counted, and weighed. Average fruit weight was calculated by dividing the total yield weight by the total fruit number. Plant stand, defined as the number of living pepper plants per subplot, was also counted at both harvests.

All data were subjected to statistical analysis using R software (RStudio®; PBC, Boston, MA). Data were first analyzed for each location with a linear model [*lm()* function], subjected to the *summary()* function to determine the overall models' statistics, subjected to ANOVA to determine the significance of each explanatory variable ($P \leq 0.05$) for each location, and plotted to check for normality. The normality of the data was assessed by reviewing the Normal Q-Q plots generated with the *autoplot*() function. These plots compare the quantiles of observed data to the quantiles of a theoretical normal distribution (Marden 2004). In an ideal scenario, data points on the Q-Q plot should closely follow a straight diagonal line. Departures from this line can indicate deviations from normality, and help identify potential outliers or the need for appropriate data transformations when performing statistical analyses. If overall models were significant, data were combined across locations to check the normality of the data and determine if statistically significant interactions ($P \leq 0.05$) existed between the explanatory variables (clomazone rate, cultivar, and location) for each response variable (crop injury, plant stand, and total fruit number, average fruit weight, and total yield for both harvests). If the data lacked normality, we considered transformations.

Only the total fruit number and average fruit weight data models for both locations were combined for analysis, because all the other data models were not significant, except for injury at PPAC at 2 and 4 WAT. There was no visible crop injury at Meigs. PPAC visible crop injury data were arcsine-square root–transformed for analysis and are presented as back-transformed data to facilitate interpretation of the results. The PPAC injury data analysis excluded data from the nontreated control due to zero variance. Significant mean data were then subjected to a Tukey's honestly significant difference test performed at a $P \leq 0.05$ significance level.

Table 1. 'Pageant' and 'Sweet Sunset' banana pepper injury at 2 and 4 wk after treatment (WAT) with clomazone at the Pinney Purdue Agricultural Center (PPAC), Wanatah, IN, in 2022.[a,b]

	Injury			
	2 WAT		4 WAT	
Rate	'Pageant'	'Sweet Sunset'	'Pageant'	'Sweet Sunset'
(g ai ha^{-1})	%			
840	1 b	16 b	0	5 b
1,680	19 a B	53 a A	3 B	15 a A

[a]Injury was arcsine transformed for analysis then back-transformed. Scale: 0% = no injury, 100% = crop death.
[b]Means separation using Tukey's HSD test $P \leq 0.05$. Means followed by different lowercase letters within a column are significantly different. Means followed by different uppercase letters within the same row and rating timing are significantly different.

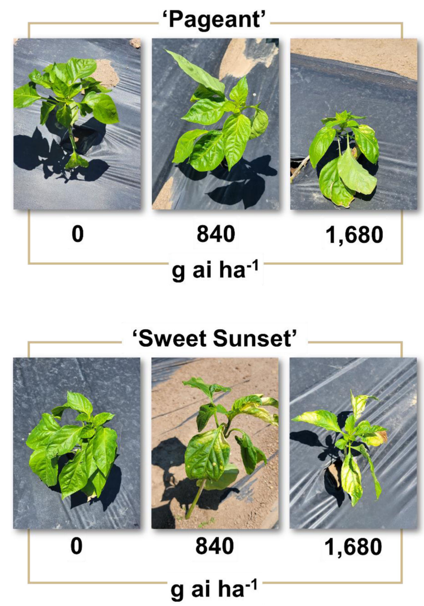

Figure 1. 'Pageant' and 'Sweet Sunset' banana pepper injury symptoms from clomazone at 4 wk after treatment at the Pinney Purdue Agricultural Center (PPAC), Wanatah, IN, in 2022.

Results and Discussion

Banana Pepper Injury

No injury was observed at Meigs during the study, regardless of clomazone rate or banana pepper cultivar. At PPAC, the main effects of clomazone rate (2 WAT: $F_{1,12} = 20.94$, $P < 0.01$; 4 WAT: $F_{1,12} = 5.81$, $P = 0.03$) and cultivar (2 WAT: $F_{1,12} = 10.02$, $P < 0.01$; 4 WAT: $F_{1,12} = 13.34$, $P < 0.01$) were significant, but there was no significant interaction between clomazone rate and cultivar (2 WAT: $F_{1,12} = 0.40$, $P = 0.54$; 4 WAT: $F_{1,12} = 5.81$, $P = 0.27$). At PPAC, injury presented as interveinal bleaching at 2 and 4 WAT (Figure 1). Injury at 2 and 4 WAT did not differ statistically between 'Pageant' (1% and 0%, respectively) and 'Sweet Sunset' (16% and 5%, respectively) when clomazone was applied at 840 g ha^{-1} (Table 1). However, when clomazone was applied at 1,680 g ha^{-1}, injury 2 and 4 WAT was more severe in 'Sweet Sunset' (53% and 15%, respectively) than in 'Pageant' (19% and 3%, respectively). Injury in both cultivars decreased between 2 and 4 WAT, and at 6 WAT, no crop injury was observed.

We presume that the soil characteristics were the main factor influencing the injury response between the two locations. It has been reported that clomazone's sorption to the soil depends more on the OM content than the soil particles (clay or sand) (Gunasekara et al. 2009). However, it has also been reported that a higher clay fraction increases clomazone's soil sorption (Đurović-Pejčev et al. 2020; Li et al. 2004; Loux et al. 1989). For instance, Đurović-Pejčev et al. (2020) reported that clomazone sorption in two soils with similar organic carbon (Regosol: 1.15% and Chernozem: 1.93%), was greater in the soil that had a higher clay content (Regosol: 23.4% and Chernozem: 28.9%); the Chernozem. At both of our locations the OM content was 1.6%, but the clay content was higher at Meigs than at PPAC. Accumulated rainfall within the 2 wk after planting was similar at both sites (Meigs: 34 mm; PPAC: 31 mm). Because of this, we believe that the lower clomazone soil sorption at PPAC, compared to Meigs, could be a contributing factor for crop injury.

Plant Stand, Total Fruit Number, Average Fruit Weight, and Total Yield

The overall models of plant stand and yield for each location were not significant, because neither clomazone rate nor cultivar affected plant stand or yield; thus, data for plant stand and yield were pooled across both locations, clomazone rates and cultivars. The overall model for total fruit number, pooled across locations, was significant ($F_{6,41} = 4.15$, $P < 0.01$), in which only the cultivar main effect was significant (cultivar: $F_{1,41} = 17.79$, $P < 0.01$; clomazone rate: $F_{2,41} = 2.23$, $P = 0.12$; clomazone rate by cultivar: $F_{2,41} = 1.28$, $P = 0.29$). The overall model for average fruit weight, pooled across locations, was significant ($F_{6,41} = 4.92$, $P < 0.01$), in which only the cultivar main effect was significant (cultivar: $F_{1,41} = 24.50$, $P < 0.01$; clomazone rate: $F_{2,41} = 0.34$, $P = 0.71$; clomazone rate by cultivar: $F_{2,41} = 1.89$, $P = 0.16$).

The average plant stand was 11.5 plants per plot (data not shown). 'Pageant' produced significantly fewer fruits (169 fruits per plot) than 'Sweet Sunset' (216 fruits per plot) (data not shown). However, on average, 'Sweet Sunset' had smaller fruits (69 g fruit^{-1}) than 'Pageant' (80 g fruit^{-1}), and for this reason, total yield was not different between the two cultivars and averaged 14.4 kg plot^{-1} (data not shown).

Similar to the present study, Mohseni-Moghadam and Doohan (2015) reported no yield loss in banana pepper treated with clomazone at 560 and 1,120 g ha^{-1} when compared to a nontreated, weed-free control. Galloway et al. (2000) also reported that clomazone applied preemergence at 0.6 and 1.1 kg ha^{-1} had no effect on plant stand nor yield compared to a nontreated control. Mohseni-Moghadam and Doohan (2015) documented little to no crop injury from clomazone applications. Galloway et al. (2000) reported that injury differed by clomazone formulation and rate, whereby pre-plant incorporated applications of 1.1 kg ha^{-1} clomazone formulated as an emulsifiable concentrate resulted in greater injury (21%) than the same rate applied pre-plant incorporated or preemergence using a microencapsulated formation (7% and 3%, respectively). In this study, injury was minimal with the exception of one location and cultivar at the highest rate of clomazone used. Similarly, Nurse et al. (2006) reported that clomazone applied prior to transplanting 'Heinz 9478' tomato (*Solanum lycopersicum* L.) resulted in minimal injury (≤6%) at one location but up to 26% injury at a second location and that injury was rate-dependent, transient, and had no negative effect on yield. Nurse et al. (2006) observed greater injury at a field location with soils containing less clay content and less organic matter. This result is similar to our findings in that injury was greater at the the PPAC location, which consisted of a sandy loam soil; whereas the Meigs location consisted of a combination of silty clay loam and silt loam soils. The current 24(c) special-local-need label for Command® herbicide (Anonymous 2019) in the state of Michigan is structured such that use rates vary from 280 to 560 g ha^{-1}, 560 to 840 g ha^{-1}, and 840 to 1,120 g ha^{-1} on coarse-, medium-, and fine-textured soils, respectively.

Overall, crop safety was uniformly acceptable when clomazone was applied at 840 g ha^{-1} broadcasted over the top of the polyethylene mulch and respective row middles 1 d before banana pepper was transplanted. However, crop injury did differ by location and by cultivars within one location when clomazone was applied at 1,680 g ha^{-1}. Plants that demonstrated bleaching injury recovered by 6 WAT, and the early-season injury did not affect yield. Even though we applied clomazone in a way that growers prefer to use it (over the top of the polyethylene mulch and respective row middles before transplanting), we acknowledge that clomazone applied only to the row middles is preferable to mitigate the risk of crop injury while reducing the amount of herbicide applied on a broadcast-equivalent basis. The authors also recommend, as a best management practice, that growers who apply herbicides on top of plasticulture beds allow for rainfall events or overhead irrigation to remove residual herbicide from the plastic prior to punching holes and transplanting.

Practical Implications

In Indiana, banana peppers are often grown in the same field as bell peppers. The registration of a 24(c) special-local-need use for banana peppers in the state of Indiana will allow for a single weed management protocol across a mixed pepper planting and contribute to greater weed control of diverse weed species, including velvetleaf and annual grasses. The registered use of clomazone in banana pepper will also contribute an additional site of action (SOA, WSSA herbicide Group 13) and allow for the increased rotation of SOAs, thereby decreasing herbicide resistance selection pressure. Moreover, this research provides photographs of confirmed clomazone injury symptomology on banana pepper plants and documents variable banana pepper cultivar tolerance. Banana pepper farmers who use clomazone should confirm cultivar tolerance prior to widespread on-farm use.

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