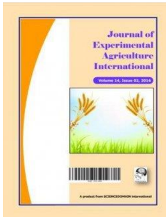

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Evaluation of Weed Control Efficacy and Peanut Tolerance to Pyroxasulfone Herbicide in the South Texas Peanut Production Area

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Authors' contributions

This work was carried out in collaboration between all authors. Author WJG designed the studies, performed the statistical analysis and wrote the first draft of the manuscript while authors PAD and TAB reviewed the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Determine weed efficacy and peanut tolerance to pyroxasulfone in the south Texas peanut growing area.
Study Design: Randomized complete block design with 3 replications.
Place and Duration of Study: Texas A&M AgriLife Research Site near Yoakum (29.276°N, 97.123°W) in south-central Texas during the 2013 and 2014 growing seasons.
Methodology: Two studies were conducted: 1) determine weed efficacy with pyroxasulfone and 2) determine variety tolerance to pyroxasulfone. Each plot at Yoakum consisted of two rows spaced

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97 cm apart and 7.9 m long. Herbicides were applied with a CO_2 compressed air backpack sprayer equipped with Teejet 11002 DG flat fan spray tips which delivered a spray volume of 190 L/ha at 180 kPa. In the weed efficacy study, all field plots were naturally infested with dense populations of *Urochloa texana* Buckl.(6 to 8 plants/m^2) and *Cucumis melo* L. (6 to 8 plants/m^2), and moderate *Amaranthus palmeri* S. Wats. (4 to 6 plants/m^2) populations. In the variety tolerance study, pyroxasulfone alone at 0.12 and 0.25 kg ha^{-1} was compared with flumioxazin alone at 0.11 and 0.22 kg ha^{-1}, flumioxazin plus pyroxasulfone at 0.07 + 0.09 and 0.14 + 0.18 kg ha^{-1}, and *S*-metolachlor alone at 1.46 and 2.82 kg ha^{-1}. All herbicides were applied preemergence and the test area was kept weed-free. Weed control and peanut injury was visually estimated on a scale of 0 to 100 (0 indicating no control or plant death and 100 indicating complete control or plant death), relative to the untreated control.

Results: Pyroxasulfone alone at 0.09 kg ha^{-1} provided erratic control of *Urochloa texana* and *Cucumis melo* but excellent control of *Amaranthus palmeri*. Peanut varieties exhibited excellent tolerance to pyroxasulfone at 0.12 and 0.25 kg ha^{-1}.

Conclusion: These results indicate that pyroxasulfone can be an effective herbicide for weed control in south Texas peanut growing region. Also all peanut varieties showed excellent tolerance to pyroxasulfone.

Keywords: Preplant incorporated; preemergence; postemergence; texas millet; palmer amaranth; smellmelon.

1. INTRODUCTION

Weed problems in peanut (*Arachis hypogaea* L.) may reduce the income of the producer in several different ways. Herbicide costs range from \$37 to \$124 ha^{-1} with a net cost to U. S. peanut producers in excess of \$70 million annually [1]. Weeds also increase the need for additional tillage operations with a net loss to producers of \$7 to \$20 ha^{-1} [1]. Weed escapes then cost producers another \$49 to \$124 $ha^{-}1$ due to reduced yield and \$7 to \$62 ha^{-1} due to quality reductions [2,3]. Reductions in harvesting efficiency associated with pod loss are estimated to range from \$7 ha^{-1} in Alabama to \$17 ha^{-1} in Oklahoma and South Carolina [2]. Estimated total income losses from poor weed control, yield and quality reductions, increased cultural inputs, and reduced harvesting efficiency range from \$132 ha^{-1} in Texas to \$391 ha^{-1} in Florida [2].

The three most common weeds found in the south Texas peanut production area include *Amaranthus palmeri* S. Wats., *Urochloa texana* (Buckl.), and *Cucumis melo* (L.). *Amaranthus* spp. are listed as one of the 10 most common weeds in most peanut-growing states in the United States, with *A. palmeri* ranked as the most troublesome weed in Alabama, Arkansas, Florida, Georgia, and North Carolina [4]. *A. palmeri* is a common weed in many crops produced around the world and is currently found in most states of the U. S. [5]. In Texas, *A. palmeri* can be found in all areas of the state [6], and is a severe problem in many peanut fields, when not properly controlled (P. Dotray personal observation).

The annual grass, *U. texana*, is a large seeded, vigorous, fast growing grass commonly found in peanut fields in parts of Florida, South Carolina, Oklahoma, and Texas [7] and is listed as one of the most troublesome weeds in all peanut growing states except Alabama and Arkansas [4]. During the digging operation, the peanut plant is lifted out of the ground and inverted and a heavy stand of *U. texana* can reduce the effectiveness of the process. The tight fibrous root system becomes intertwined with the peanut plant, causing peanut pods to be stripped from the vine during digging. Peanuts that become detached from the plant remain unharvested in or on the soil [8].

C. melo (L.) is becoming more of a problem in south Texas peanut production fields and has become a problem in several crops along the Texas Gulf coast (author's personal observation). The range of *C. melo* stretches from Georgia to the southern part of California and as for north as Arkansas [5]. It can be a problem at peanut harvest as the melon can become broken apart when run through the combine and increase drying time because of the high moisture content of the melon itself (author's personal observation). In *Zea mays* (L.), Thompson et al. [9] reported imazapic at 0.07 and 0.14 kg ai ha^{-1} applied preemergence (PRE), early postemergence (EPOST), or late postemergence (LPOST) controlled *C. melo* greater than 90%. Tingle and

Chandler [10] reported that *C. melo* control was at least 93% with low-, medium-, and high-input herbicide systems in a *Zea mays*-*Gossypium hirsutum* (L.)-*Zea mays* rotation. Glyphosate and glufosinate systems have provided effective *C. melo* control [11,12] in *G. hirsutum*. Tingle et al. [13] reported when *C. melo* was allowed to compete with *G. hirsutum* for at least 6 wks, yield was reduced 7% compared to the weed free check, but when *C. melo* was allowed to compete for 10 to 12 wks *G. hirsutum* yield was reduced 22 and 27%, respectively.

Pyroxasulfone is a newly registered herbicide in the US. It is cleared for use either preplant, preplant incorporated, preemergence (PRE), or EPOST use in corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), peanut, soybean (*Glycine max* L.), and wheat (*Triticum aestivum* L.) [14-16]. Application timing is crop specific and it controls *Amaranthus* spp., *Lolium* spp, *Urochloa* spp., *Eleusine indica* L., *Dactyloctenium aegyptium* L., and *Digitaria* spp. [17-20]. Although pyroxasulfone has a similar weed control spectrum as *S*-metolachlor and dimethenamid-P, it has a higher specific activity allowing for use rates approximately eight times lower than dimethenamid-P [21]. Pyroxasulfone inhibits very long chain fatty acid synthesis similar to chloroacetamide, oxyacetamide, and tetrazolinone herbicides [17].

Previous research in the southeastern U. S. has determined that pyroxasulfone has good peanut crop tolerance and provides control of problem weeds; however, pyroxasulfone applied PRE to peanut has been documented to cause early-season stunting but no yield loss [22]. The three above mentioned weeds cause major problems in south Texas peanut production and therefore research was undertaken to determine peanut tolerance and weed efficacy with pyroxasulfone herbicide systems.

2. MATERIALS AND METHODS

Two separate studies were conducted during the 2013 and 2014 growing seasons in the south Texas peanut growing region: 1) weed efficacy study where various herbicide systems which included pyroxasulfone were evaluated for *U. texana*, *C. melo*, and *A. palmeri* control, and 2) peanut tolerance studies where pyroxasulfone was compared with flumioxazin and *S*-metolachlor for peanut growth and yield. For both studies, the conditions discussed below are virtually the same unless otherwise noted.

2.1 Field Studies

Field studies were conducted at the Texas A&M AgriLife Research site near Yoakum, (29.276°N, 97.123°W) in south-central Texas. These studies were in the same general area but different parts of the field in each year. Soils were a Tremona loamy fine sand (thermic Aquic arenic Paleustalfs) with less than 1% organic matter and pH 7.0 to 7.2. The experimental design for the weed efficacy and peanut tolerance studies were a randomized complete block with three replications. An untreated check was included each year in all studies.

2.2 Plot Size and Weed Populations

Each plot was two rows wide, rows spaced 97 cm apart and plot was 7.9 m long. Peanut varieties, planting dates, and herbicide application timings for the weed efficacy and peanut tolerance studies are shown in Table 1. For the weed efficacy studies, all field plots were naturally infested with dense populations of *U. texana* (6 to 8 plants m^2) and *C. melo* (6 to 8 plants m^2), and moderate *A. palmeri* (4 to 6 plants m^2) populations. *A. palmeri* failed to develop in 2013. For the peanut tolerance studies, the test area was maintained weed-free throughout the growing season. All plots received a dinitroaniline herbicide (pendimethalin at 1.12 kg ha^{-1}) applied preplant incorporated (PPI) and were cultivated and hand-weeded throughout the growing season to maintain weed-free conditions. Clethodim at a dose of 0.18 kg ha^{-1} was applied postemergence (POST) to control annual grass escapes.

2.3 Herbicide Application

Herbicides were applied with a CO_2 compressed air backpack sprayer equipped with Teejet 11002DG nozzles that delivered 190 L/ha at 180kPa. Preemergence applications were made within 24 hours of peanut planting. In the weed efficacy studies, the EPOST herbicide applications (also referred to as peanut cracking) were made when the peanut plants had begun to emerge or were no bigger than saucer size. All weeds at this stage were less than 5 cm tall. The LPOST applications were made when *A. palmeri* was 20 to 40 cm tall, *C. melo* was 25 to 60 cm in length, or *U. texana* was 20 to 50 cm tall. All POST treatments included a crop oil concentrate (Agridex®) at 1.25% v/v or a non-ionic surfactant (Induce®) at 0.25% v/v.

Table 1. Peanut variety, planting date, and herbicide application dates for the various studies using pyroxasulfone at Yoakum[a]

	2013	2014
Weed efficacy studies		
Peanut variety	Georgia 09B	McCloud
Planting date	June 10	June 16
Application		
PRE	June 10	June 16
EPOST	June 17	June 27
LPOST	July 13	July 23
Peanut tolerance studies		
Peanut varieties	Tamrun OL11	McCloud
	Georgia 09B	Georgia 09B
Planting date	June 6	June 9
PRE application	June 9	June 10

[a]*Abbreviations: PRE, preemergence; EPOST, early postemergence; LPOST, late postemergence*

2.4 Irrigation, Weed Control, and Peanut Harvest

Sprinkler irrigation was applied on a 2- to 3-wk schedule throughout the growing season as needed. Weed control (based on density and growth) and peanut injury (based on peanut stunting, chlorosis, and necrosis) was visually estimated on a rating scale of 0 to 100 (0 indicating no control or plant death and 100 indicating complete control or plant death), relative to the untreated control (24). In the weed efficacy studies, weed control evaluations were recorded 37 to 120 days after PRE application (DAT); however, only the late-season ratings are presented since many of the herbicide systems evaluated contained multiple herbicide timing applications. In the peanut tolerance studies, injury evaluations were recorded 16 to 90 days after DAT. Peanut yields were obtained by digging each plot separately, air-drying in the field for 4 to 7 d, and harvesting peanut pods from each plot with a combine. Weights were recorded after soil and trash were removed from plot samples. Peanuts were not dug for yield in the weed efficacy studies due to the difficulty of digging heavy weed infested plots [8].

2.5 Data Analysis

Weed control data were arcsine transformed prior to analysis of variance. However, because the transformation did not alter treatment means and for practical interpretation of the data original data are presented. Means were compared with Fisher's Protected LSD test at the 5% probability level. The untreated control was not included in weed control or peanut injury analysis but was included in the yield analysis.

3. RESULTS AND DISCUSSION

3.1 Weed Efficacy Studies

There was a treatment by year interaction for *C. melo* and *U. texana* control; therefore, the efficacy data for each of those years are presented separately.

3.1.1 *A. palmeri* control

In 2014 all herbicide systems provided excellent control of this weed (> 92%) with the exception of the local standard of pendimethalin applied PRE followed by imazapic applied LPOST which provided 86% control (Table 2). Steele et al. [23] reported that pyroxasulfone alone at 0.125 to 0.5 kg ha^{-1} provided similar levels of *A. palmeri* control as *S*-metolachlor at 1.1 to 4.3 kg ha^{-1}. Knezevic et al. [24] reported that 90% control of *Amaranthus tuberculatus* (Moq.) was achieved with pyroxasulfone at 0.16 kg ha^{-1} 28 DAT. They also stated that a higher dose was required to obtain the same control at 45 (0.2 kg ha^{-1}) and 65 DAT (0.27 kg ha^{-1}). Jha et al. [25] found the addition of pendimethalin to pyroxasulfone improved control of *Kochia scoparia* (L.) Schard, *Chenopodium album* (L.), and *Polygonum convolvulus* (L.) over pyroxasulfone alone. Mahoney et al. [26] reported, in *Glycine max* (L.), that flumioxazin/pyroxasulfone combinations under conventional tillage systems provided 100% control of *Amaranthus retroflexus* (L.) and *Amaranthus hybridus* (L.) and 53 to 100% control under no-till systems. They noted that the differences in the weed efficacy with flumioxazin/pyroxasulfone combinations under conventional and no-till systems could not be ascribed to environment alone but may be related to differences in weed populations between the two systems.

Dotray et al. [27] reported on a peanut study in the Texas High Plains region, when evaluated late-season, that in one year dimethenamid-*P* alone applied PRE provided only 75% *A. palmeri* control while all treatments containing pyroxasulfone, applied either PRE or EPOST, provided at least 95% control. This was better than the local standard of *S*-metolachlor applied PRE or EPOST which controlled Palmer amaranth less than 85%. In another year, pyroxasulfone in combination with either pendimethalin or flumioxazin applied PRE and followed by an EPOST application of aciflurofen plus bentazon plus paraquat controlled Palmer amaranth at least 98% when evaluated late-season.

3.1.2 *U. texana* control

Only pyroxasulfone alone and flumioxazin plus pyroxasulfone applied PRE failed to control U. texana at least 90% in 2013 (Table 2). In 2014 all herbicide treatments, with the exception of flumioxazin plus pyroxasulfone, controlled this weed at least 90% (Table 2). Baughman et al [28] reported that in Oklahoma, when evaluated late-season (104 DAT), only herbicide systems that included a preplant incorporated (PPI) application of either pendimethalin or pyroxasulfone followed by a EPOST and LPOST herbicide application provided at least 80% *U. texana* control. In a two-year study, Mueller and Steckel [29] reported that *Urochloa platyphylla* [(Nash) R. D. Webster] control with pyroxasulfone at 0.125 to 0.33 kg ha^{-1} was 95% when evaluated 14 DAT; however, by 45 DAT, pyroxasulfone doseage differences were evident each year. In 2007, pyroxasulfone applied at 0.125 and 0.17 kg ha^{-1} controlled less than 55% while pyroxasulfone doses of 0.21 to 0.33 kg ha^{-1} provided 76 to 81% control. In 2008, the two lower doses controlled 70 to 76% broadleaf signalgrass while the higher doses of pyroxasulfone provided 76 to 89% control which was better than either acetolachlor, *S*-metolachlor, or dimethenamid-P [29].

Their explanation for the differences was that under the dry soil conditions of 2007, herbicide dissipation was slower thus allowing for more residual activity while during the wet year of 2008, the less persistent chloroacetamide herbicides dissipated more rapidly and thus provided less broadleaf signalgrass control later in the season.

3.1.3 Cucumis melo control

In 2013, pyroxasulfone alone applied PRE failed to adequately control (41%) this weed (Table 2). All herbicide systems which included a PRE herbicide followed by a LPOST application controlled smellmelon at least 88%. In 2014, all herbicide systems, with the exception of pyroxasulfone applied PRE in combination with either pendimethalin or flumioxazin, controlled smellmelon at least 92%.

The inconsistent control of smellmelon with pyroxasulfone may be attributed to lack of rainfall/irrigation after PRE application. In 2013, 1.3 mm of rain was received one day after PRE application and the next water event was 22 d later when 25.4 mm of irrigation was applied. In contrast, in 2014, 47.8 mm of rain was received within 8 d of PRE application. Several factors can influence the efficacy of soil-applied herbicides, such as the timing and amount of precipitation following herbicide application and timing of crop and weed emergence [30].

3.2 Peanut Tolerance Studies

Since 'Tamrun OL 11' was not available in 2014, 'McCloud' was used instead. Because the same varieties were not used in both years, no attempted was made to combine data over years.

3.2.1 Peanut injury

No peanut injury was noted with any herbicide treatments at any time during the growing season (data not shown). In Oklahoma, peanut stunting was observed with all PPI and PRE treatments in a 2 yr study [28]. Stunting with pyroxasulfone PPI or PRE combinations ranged from 1 to 13%. In the Texas High Plains, the high dose of pyroxasulfone alone or flumioxazin plus pyroxasulfone resulted in significant peanut stunting when compared with the untreated check for all market types [27]. Additionally, the low dose of flumioxazin plus pyroxasulfone caused stunting to the Spanish and runner market types when evaluated 20 weeks after treatment (WAT). Significant stunting was also observed 20 WAT with the low dose of pyroxasulfone alone or flumioxazin plus pyroxasulfone [27].

Table 2. Late season weed control with pyroxasulfone combinations at Yoakum in 2013 and 2014

Treatment and application[a,b]		Dose		Weed control				
				URODE[d]		CUMUS		AMAPA
				'13	'14	'13	'14	'14
PRE[c]	LPOST	PRE	LPOST					
		Kg ha^{-1}		%				
Pyroxasulfone (P)	-	0.09		69	92	41	96	93
Pendimethalin + P	-	0.84+0.06		90	90	88	76	92
Flumioxazin + P	-	0.11 + 0.09		71	73	80	86	100
Pendimethalin + P	Imazapic	0.84 + 0.06	0.07	97	99	100	97	98
P	Imazapic	0.09	0.07	90	100	100	97	98
Pendimethalin + P	Imazapic + P	0.84 + 0.06	0.07+0.06	100	99	100	92	99
P	Imazapic + P	0.09	0.07+0.06	92	100	99	95	100
S-Metolachlor	Imazapic	1.08	0.07	91	99	100	97	100
Dimethenamid-P		0.84		95	100	88	95	100
+ P	P	+ 0.09	0.06					
Pendimethalin	Imazapic	0.84	0.07	97	100	97	99	86
Untreated	-	-	-	0	0	0	0	0
LSD (0.05)				22	24	12	11	5

[a]*All treatments with the exception of pendimethalin applied PRE followed by imazapic applied late postemergence (LPOST) included paraquat at 0.21 kg ai ha^{-1} + acifluorofen at 0.28 kg ai ha^{-1} + bentazon at 0.62 kg ai ha^{-1} + Induce at 0.25% v/v applied EPOST.*

[b]*Induce included in all LPOST treatments at 0.25% v/v.*

[c]*Abbreviations: PRE, preemergence; LPOST, late postemergence.*

[d]*Bayer code for weeds: URODE (Texas millet), Urochloa texana; CUMUS (smellmelon), Cucumis melo; AMAPA (Palmer amaranth), Amaranthus palmeri.*

Table 3. Peanut yields as influenced by different herbicides and doses applied preemergence in 2013 and 2014

		2013		2014	
		Tamrun	Georgia	Georgia	
Herbicide	Dose	OL 11	09B	McCloud	09B
	Kg ai ha^{-1}	Kg ha^{-1}			
Pyroxasulfone	0.12	3300	4080	4581	4478
Pyroxasulfone	0.25	3446	4114	4609	4099
Flumioxazin + pyroxasulfone	0.07 + 0.09	3411	4003	3765	4822
Flumioxazin + pyroxasulfone	0.14 + 0.18	3257	3471	4667	4874
S-Metolachlor	1.46	3471	3822	5003	3927
S-metolachlor	2.82	3232	3796	4426	4667
Flumioxazin	0.11	3591	3702	4417	4719
Flumioxazin	0.22	3291	3900	4392	4874
Untreated	-	3279	3763	4745	4590
LSD (0.05)		499		618	

In a 2-yr study, Eure et al. [31] reported that peanut stunting ranged from 38 to 55% and 3 to 11% during 2012 and 2013 respectively, depending on peanut cultivar. Several factors played a role in the differences observed between the two years as more rainfall occurred through the EPOST application in 2012 compared to 2013 (50.8 mm vs. 25.4 mm). Enhanced peanut stunting has been observed following the application of other PRE herbicides under cool, wet conditions [32]. In previous research, Prostko et al. [22] documented transient peanut stunting at one of two locations following pyroxasulfone applied PRE.

Research in other crops has shown greater crop injury from pyroxasulfone applied PRE on course-textured soils than on fine-textured or organic soils [33-37]. *Zea mays* var. saccharata injury has been documented to be greater than 10% following pyroxasulfone at 0.25 kg ha^{-1} on soil with 82% sand [35] while no injury with *Gossypium hirsutum* has been observed on soils high in organic matter [33]. With *G. hirsutum*, Koger et al. [36] reported only transient injury on a silt loam soil following pyroxasulfone applied PRE. Also, Hardwick [38] reported in an application timing study that *Glycine max* injury was observed when pyroxasulfone was applied PRE and POST and injury was more severe following the POST application. Injury following pyroxasulfone at 0.06 kg ha $^{-1}$ applied POST was 15% 10 days after application and by 14 days after application injury had dropped to 5%. They stated that plant height and yield were not affected by pyroxasulfone applied PRE or POST at rates as high as 0.3 kg ha^{-1}.

3.2.2 Peanut yield

In 2013, no differences in peanut yield were noted between any herbicide treatments and the untreated check with Tamrun OL 11 (Table 3). With Georgia 09B, no differences in yield were noted between the untreated check and any herbicide treatment; however, pyroxasulfone alone at 0.12 and 0.25 kg ha^{-1} and the combination of flumioxazin at 0.07 kg ha^{-1} plus pyroxasulfone at 0.09 kg ha^{-1} produced yields greater than flumioxazin at 0.14 kg ha^{-1} plus pyroxasulfone at 0.18 kg ha^{-1}.

In 2014, with McCloud, the PRE treatment of flumioxazin at 0.07 kg ha^{-1} plus pyroxasulfone at 0.09 kg ha^{-1} produced lower yields than the untreated check while with Georgia 09B lower yields than the untreated check were produced with *S*-metolachlor at 1.49 kg ha^{-1} (Table 3).

In the Texas High Plains, pyroxasulfone alone or flumioxazin plus pyroxasulfone at any dose had no effect on Spanish or the Virginia market type yield when compared with the untreated check [27]. With the runner market type, the high dose of flumioxazin plus pyroxasulfone reduced yield compared with the untreated check. Eure et al. [31] reported that treatments that included pyroxasulfone at 0.12 kg ha^{-1} yielded similar to treatments without pyroxasulfone; however, pyroxasulfone applied at 0.24 kg ha^{-1} reduced peanut yield 6%. Prostko et al. [22] did not observe a yield loss following pyroxasulfone applied PRE.

The use of pyroxasulfone has resulted in reductions in yield in other crops as well [39-44].

Solanum tuberosum (L.) showed tolerance to pyroxasulfone at doses up to 0.15 kg ha^{-1} with minor yield reduction and quality losses [43]. Pyroxasulfone at 0.125 kg ha^{-1} caused unacceptable yield losses in *Hordeum vulgare* (L.) as well as *Avena sativa* (L.) [44]. *Helianthus annus* (L.) has also shown acceptable tolerance to pyroxasulfone up to 0.33 kg ha^{-1} although injury (but not yield loss) did occur at locations with heavy precipitation events shortly after application [45].

In *Glycine max*, pyroxasulfone at 0.18 kg ha^{-1} applied preplant incorporated resulted in a 6% reduction in yield when compared with the untreated check [26]. Mahoney et al. [26] also found that pyroxasulfone plus flumioxazin should be applied prior to crop emergence as yield reductions up to 9% can occur if the herbicide is applied at the cotyledon stage. No effect on *Zea mays* yield has been noted with doses of pyroxasulfone ranging from 0.25 to 0.5 kg ha^{-1} [23].

4. CONCLUSION

These results indicate that pyroxasulfone is an effective herbicide for weed control in the south Texas peanut growing region and can control weeds that are commonly found in this area when included in a herbicide systems approach. No peanut injury or yield reduction was noted with the use of pyroxasulfone and it appears to be safe to use with multiple peanut varieties.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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