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PRE- AND POST-EMERGENCE HERBICIDE SELECTIVITY IN PEANUTS AT AN EARLY STAGE

Augusto Guerreiro Fontoura COSTA[1], Valdinei SOFIATTI[1], Taís de Moraes Falleiro SUASSUNA[1]

[1]Brazilian Agricultural Research Corporation, Embrapa Cotton, Campina Grande-PB, Brazil.

Corresponding author:
Augusto Guerreiro Fontoura Costa
augusto.costa@embrapa.br

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Abstract
Studies on herbicide selectivity to peanuts detected differences according to the evaluated active ingredient and genotypes. This study analyzed the herbicide selectivity of two genotypes at an early stage. Pre-emergence (trifluralin, pendimethalin, diclosulam, s-metolachlor, imazethapyr + flumioxazin, clomazone, sulfentrazone, and imazapic) and post-emergence (imazapic, bentazon, bentazon + imazamox, clethodim, quizalofop-p-ethyl, cloransulam-methyl, s-metolachlor, lactofen, 2,4-D, and carfentrazone) applications were assessed in 1253 OL and 2133 OL breeding lines. The effects of pre- (PRE) and post-emergence (POST) herbicides were the same for both genotypes, with PRE not affecting seedling emergence and shoot and root dry mass. Diclosulam was among the most selective PRE herbicides, while the clomazone treatment caused only mild damage. All tested POST herbicides caused damage for up to 14 days after application (DAA). At 28 DAA, most herbicides exhibited the same damage as the untreated control. Lactofen caused mild damage (11.8%) without reducing plant height and shoot and root dry mass. Diclosulam, clomazone, and lactofen are unregistered for peanut crops in Brazil, and further studies should test their selectivity for peanut cultivars. Screening studies on selectivity to imazapic, 2,4-D, and carfentrazone are also relevant to identifying sources of tolerance in peanut germplasm.

Keywords: *Arachis hypogaea L.* Chemical control. Tolerance. Weed.

1. Introduction

Weeds may cause yield losses higher than 70% in peanut crops (Hare et al. 2019; Seale et al. 2020; Arthur et al. 2022). Furthermore, late-season weeds may interfere with harvest processes (digging, threshing, and drying), increasing production costs and the risk of contamination by mycotoxins (Suassuna et al. 2009; Johnson 2019; Alam et al. 2020). In order to avoid these problems, chemical control is used to manage several monocot and eudicot weeds due to its efficiency and low cost (Jat et al. 2011). Various herbicides are commonly sprayed at pre-plant-incorporated (PPI), pre-emergence (PRE), and post-emergence (POST) for season-long weed management in peanut crops (Seale et al., 2020).

Selectivity studies are crucial for herbicide recommendations, identifying active ingredients that cause maximum damage to weeds with the minimum effect on crops, reducing yield losses and the seed bank of weeds.

Among herbicides registered for peanut crops in Brazil, five have a predominant action on monocot weeds: trifluralin, pendimethalin, and pyroxasulfone for PRE applications and quizalofop-p-ethyl and clethodim for POST. Other herbicides control monocot and eudicot weeds: glyphosate for POST before peanut sowing (burndown); alachlor, s-metolachlor, sulfentrazone, and the mixture of flumioxazin + imazethapyr for PRE; imazapic for PRE and POST; and imazethapyr, bentazon, and bentazon + imazamox for POST (Brasil 2023).

However, the few herbicides registered to handle broadleaf weed species in peanut crops in Brazil inefficiently control the most common weeds: *Ricinus communis* (Silva et al. 2020a), *Mucuna aterrima*, and *Ipomoea* spp (Silva et al. 2020b). The climbing species *M. aterrima* and *Ipomoea* spp are especially critical in the late season for mechanical harvesting. The monocot *Urochloa decumbens* is the primary forage cultivated in Brazilian pastures (Ferreira et al. 2021), and its poor control may cause problems from the middle to the end of the peanut crop cycle when grown in rotation with forage crop areas.

Other herbicides may extend weed management options for peanut crops in Brazil: diclosulam, clomazone, lactofen, 2,4-D, and carfentrazone (Daita et al. 2012; Ferrel et al. 2015; Sperry et al. 2017; Zanardo et al. 2018; Price et al. 2021). However, the literature on herbicide selectivity to peanuts presents only a few studies on different genotypes reporting a genotype effect for PRE and POST treatments in Brazil (Zanardo et al. 2018 and 2019).

Therefore, this study evaluated the effect of PRE and POST herbicide applications on the initial development of two peanut genotypes, including active ingredients unregistered for peanut crops in Brazil.

2. Material and Methods

Two experiments evaluating the effect of PRE and POST herbicides in peanut plants were conducted in Jaguariúna, SP, Brazil (22° 43’ 38’’ S and 47° 01’ 01’’ W, 570 m altitude), from January to February 2021 and October to November 2022.

The substrate in both assays was an arable layer (0 to 20 cm) of soil extract from a fallow agricultural field in Jaguariúna, classified as Red-Yellow Latosol (Embrapa 2018), containing sand 80.5%, silt 1.5%, and clay 18.0%. The chemical characteristics were water pH = 5.3; Ca^{+2} = 0.9 cmolc dm^{-3}; Mg^{+2} = 0.4 cmolc dm^{-3}; H+Al = 1.6 cmolc dm^{-3}; CEC = 3.3 cmolc dm^{-3}; V = 50.8%; Al^{+3} = 0.0 cmolc dm^{-3}; P = 10.0 mg dm^{-3}; K+ = 0.35 cmolc dm^{-3}; and OM = 24.0 g kg^{-1}. The soil was sieved in a 2 mm mash, dried under shade, corrected, and fertilized with dolomitic limestone and monoammonium phosphate at 1 and 3 kg m^{-3}. This substrate was used to fill 4L plastic pots, constituting the experimental plots for both experiments.

The evaluated genotypes were 1253 OL and 2133 OL runner-type cultivars with high oleic acid content, developed by the Embrapa Peanut Breeding Program. The seeds had been treated with imidacloprid + thiodicarb insecticide and carboxin + thiram fungicide. Five seeds per pot were sowed in the first and second experiments at 3 cm deep. The thinning plants were removed seven days after seedling emergence, maintaining two plants per container. The pots remained in a greenhouse and received daily irrigation through preprogrammed micro-sprinklers.

The pots were arranged in a completely randomized design with four replicates. The PRE experiment organized the treatments in a 9x2 factorial scheme. Factor A comprised trifluralin (2,100 g ha^{-1}), pendimethalin (1,100 g ha^{-1}), diclosulam (35 g ha^{-1}), s-metolachlor (1,200 g ha^{-1}), imazethapyr + flumioxazin (127.5 + 60 g ha^{-1}), clomazone (1,250 g ha^{-1}), sulfentrazone (400 g ha^{-1}), and imazapic (98 g ha^{-1}) herbicides, and untreated control. Factor B corresponded to the 1253 OL and 2133 OL peanut breeding lines. The POST experiment arranged the treatments in an 11x2 factorial scheme. Factor A comprised imazapic (98 g ha^{-1}), bentazon (720 g ha^{-1}), bentazon + imazamox (720 + 33.6 g ha^{-1}), clethodim (108 g ha^{-1}), quizalofop-p-ethyl (100 g ha^{-1}), cloransulam-methyl (30 g ha^{-1}), s-metolachlor (1,056 g ha^{-1}), lactofen (144 g ha^{-1}), 2,4-D (456 g ha^{-1}), and carfentrazone (24 g ha^{-1}) herbicides, and untreated control. Factor B corresponded to the same peanut breeding lines in the first assay.

The herbicides were sprayed one day after sowing (DAS) for PRE and 19 DAS for POST (when plants presented four trefoils). The spraying equipment was a backpack sprayer with constant pressure (CO_2) equipped with four XR11002 flat fan nozzles in a boom, spaced 0.5 m apart, and positioned 0.5 m high from the target (equivalent to 200 L ha^{-1}). The spray solutions received adjuvants for post-emergence applications based on herbicide recommendations in Brazil (Brasil 2023). Clethodim and carfentrazone received 0.5% (v v^{-1}) mineral oil (756 g L^{-1}). The mixture of methyl esters, aromatic hydrocarbons, and phosphate polyol (933 g L^{-1}) at a concentration of 0.2% (v v^{-1}) was added to cloransulam-methyl and at

0.5% (v v^{-1}) to imazapic, bentazon, and bentazon + imazamox. A digital thermo-hygrometer recorded wind speed, temperature, and relative humidity data at the beginning and end of applications. The means of the data from the first and second experiments were recorded as 0 m s^{-1} and 1.2 m s^{-1} for wind speed, 31.0°C and 27.6°C for temperature, and 52.8% and 50.0% for relative humidity.

Peanut plant emergence was evaluated in PRE ten days after herbicide applications (DAA). Crop damage was measured at 11, 18, 25, and 32 DAA and 7, 14, 21, and 28 DAA in the first and second experiments, using visual rating scales (Velini et al. 1995) where 0% meant no damage and 100% represented plant death. Plant height and shoot and root dry biomass were evaluated at 32 and 28 DAA for PRE and POST herbicide experiments. Shoot and root dry biomass were determined after drying the collected plant material in a forced air ventilation oven at 65°C for 72 hours until constant mass and weighed in a semi-analytical balance.

The data were subjected to an analysis of variance (ANOVA) with the F-test. The Scott-Knott test then grouped the means at a 0.05 significance level using the Sisvar Software (Ferreira 2014).

3. Results

There were no significant effects for breeding lines and their interactions with PRE or POST herbicides for any evaluated trait (data not shown).

PRE herbicides did not interfere with peanut emergence (Table 1). Trifluralin, pendimethalin, diclosulam, s-metolachlor, and imazethapyr + flumioxazin applications caused the same damage as the control (untreated). Imazapic caused mild damage only at 11 DAA and clomazone at 25 DAA.

Table 1. Effect of pre-emergence herbicides on seedling emergence and damage to peanut breeding lines.

	Emergence (%)	Damage (%)			
Treatment	11 DAA	11 DAA	18 DAA	25 DAA	32 DAA
1253 OL breeding line	90.0	3.7	3.6	4.2	3.9
2133 OL breeding line	90.4	5.4	5.2	5.8	4.8
Untreated control	90.0	0.0^{c}	0.0^{b}	0.0^{c}	0.0^{c}
Trifluralin	100.0	1.9^{c}	1.0^{b}	0.3^{c}	0.4^{c}
Pendimethalin	90.0	0.4^{c}	1.6^{b}	0.0^{c}	0.0^{c}
Diclosulam	95.0	3.0^{c}	2.5^{b}	0.9^{c}	0.1^{c}
S-metolachlor	95.0	0.9^{c}	1.8^{b}	2.9^{c}	3.3^{c}
Imazethapyr + flumioxazin	95.0	3.4^{c}	4.1^{b}	3.4^{c}	3.1^{c}
Clomazone	100.0	6.1^{b}	5.9^{b}	9.9^{b}	7.4^{b}
Sulfentrazone	95.0	19.8^{a}	21.5^{a}	26.0^{a}	21.9^{a}
Imazapic	90.0	5.6^{b}	1.0^{b}	1.6^{c}	0.9^{c}
F_{calc} Breeding line	2.8^{ns}	2.4^{ns}	1.0^{ns}	1.0^{ns}	1.7^{ns}
F_{calc} Herbicide	1.5^{ns}	14.5^{*}	12.8^{*}	16.4^{*}	14.0^{*}
F_{calc} Breeding*Herbicide	1.3^{ns}	1.7^{ns}	0.9^{ns}	0.5^{ns}	0.5^{ns}
CV (%)	12.2	40.5	45.5	49.6	52.0

Means followed by the same letter in the column did not differ significantly by the Scott Knott test ($p \leq 0.05$). * Significant at a 5% probability; ^{ns} not significant.

The highest damage value occurred in the sulfentrazone treatment, recorded as 19.8% at 11 DAA and 26.0% at 25 DAA. Sulfentrazone, imazapic, and s-metolachlor PRE applications reduced plant height by 18.3, 10.1, and 7.3% compared to the untreated control treatment. However, PRE herbicides did not affect peanut plants' shoot or root dry biomass (Table 2).

In the POST treatments (Table 3), carfentrazone application promoted the highest damage value to peanut plants, ranging from 62.8% at seven DAA to 48.9% at 28 DAA. The damage from 2,4-D applications varied from 24.0 to 38.4%, and imazapic showed 14.6 to 18.7%. Overall, the other herbicides showed values lower than 10%, significant compared to the untreated control only up to 21 DAA. However, lactofen presented damage close to 12% at 21 and 28 DAA.

Carfentrazone (29.2%) and imazapic (18.3%) treatments reduced plant height compared to the untreated control. The shoot dry mass decrease was similar for carfentrazone (57.9%) and 2,4-D (52.6%), followed by imazapic (28.9%). These same herbicide compounds reduced root dry mass by 58.9, 42.5, and 34.2%, respectively (Table 4).

Table 2. Effect of pre-emergence herbicides on plant height, shoot and root dry mass of peanut breeding lines.

Treatment	Plant height (cm)	Shoot dry mass (g)	Root dry mass (g)
1253 OL breeding line	20.1	4.0	1.5
2133 OL breeding line	21.2	3.7	1.4
Untreated control	21.8[a]	3.4	1.7
Trifluralin	22.1[a]	3.8	1.3
Pendimethalin	23.3[a]	3.8	1.4
Diclosulam	22.5[a]	4.1	1.6
S-metolachlor	20.2[b]	3.9	1.4
Imazethapyr + flumioxazin	21.2[a]	3.8	1.4
Clomazone	21.4[a]	4.0	1.7
Sulfentrazone	17.8[b]	3.3	1.2
Imazapic	19.6[b]	4.4	1.5
F_{calc} Breeding line	0.1[ns]	1.3[ns]	0.2[ns]
F_{calc} Herbicide	3.3[*]	0.7[ns]	1.0[ns]
F_{calc} Breeding*Herbicide	0.4[ns]	0.7[ns]	1.4[ns]
CV (%)	12.4	31.2	32.0

Means followed by the same letter in the column did not differ significantly by the Scott Knott test (p ≤ 0.05). * Significant at a 5% probability; [ns] not significant.

Table 3. Effect of post-emergence herbicides on damage to peanut breeding lines.

	Damage (%)			
Treatment	7 DAA[1]	14 DAA	21 DAA	28 DAA
1253 OL breeding line	13.7	13.4	14.1	13.0
2133 OL breeding line	14.1	13.3	12.2	10.2
Untreated control	0.0[g]	0.0[f]	0.0[f]	0.0[e]
Imazapic	15.5[c]	18.4[c]	18.7[c]	14.6[c]
Bentazon + imazamox	7.0[e]	4.5[d]	3.9[e]	2.8[e]
Bentazon	4.2[f]	3.2[d]	2.5[f]	2.0[e]
Clethodim	8.0[d]	4.1[d]	4.0[e]	4.0[e]
Quizalofop-p-ethyl	6.3[e]	4.1[d]	3.0[f]	3.1[e]
Cloransulam-methyl	10.2[d]	5.0[d]	4.3[e]	3.4[e]
S-metolachlor	5.0[f]	2.4[e]	1.4[f]	1.3[e]
Lactofen	9.9[d]	7.7[d]	12.2[d]	11.8[d]
2,4-D	24.0[b]	36.1[b]	38.4[b]	35.8[b]
Carfentrazone	62.8[a]	61.3[a]	56.3[a]	48.9[a]
F_{calc} Breeding line	2.3[ns]	0.5[ns]	0.6[ns]	1.9[ns]
F_{calc} Herbicide	128.6[*]	86.8[*]	49.8[*]	40.2[*]
F_{calc} Breeding*Herbicide	1.4[ns]	1.2[ns]	1.2[ns]	1.0[ns]
CV (%)	14.8	22.5	30.9	34.1

Means followed by the same letter in the column did not differ significantly by the Scott Knott test (p ≤ 0.05). * Significant at a 5% probability; [ns] not significant.

4. Discussion

Five of the eight herbicides tested at pre-emergence (PRE) promoted the same damage as the untreated control, considering that diclosulam is an active ingredient unregistered in Brazil for peanut crops. Among these five herbicides, only s-metolachlor reduced plant height compared to the untreated control. Trifluralin, pendimethalin, diclosulam, imazethapyr + flumioxazin, and s-metolachlor did not affect shoot and root dry mass, and these PRE herbicides showed the highest selectivity to peanuts for both genotypes at early stage. Imazapic and clomazone applications caused mild damage, showing plant height reduction only for imazapic. Clomazone is unregistered in Brazil for peanut crops.

The sulfentrazone application resulted in high damage values up to 28 DAA, with the highest at 25 DAA. Regarding damage and plant height reduction, sulfentrazone was the least selective herbicide in PRE applications for these genotypes at an early stage, and it is registered for peanut crops in Brazil.

Table 4. Effect of post-emergence herbicides on plant height, shoot and root dry mass of peanut breeding lines.

Treatment	Plant height (cm)	Shoot dry mass (g)	Root dry mass (g)
1253 breeding line	20.2	3.1	0.67
2133 breeding line	20.8	3.4	0.64
Untreated control	21.9[a]	3.8[a]	0.73[a]
Imazapic	17.9[b]	2.7[b]	0.48[b]
Bentazon + imazamox	21.2[a]	3.8[a]	0.86[a]
Bentazon	21.9[a]	3.8[a]	0.75[a]
Clethodim	21.3[a]	3.3[a]	0.64[a]
Quizalofop-p-ethyl	22.1[a]	3.6[a]	0.69[a]
Chloransulam-methyl	20.1[a]	3.5[a]	0.74[a]
S-metolachlor	22.5[a]	4.3[a]	0.93[a]
Lactofen	20.4[a]	3.2[a]	0.68[a]
2,4-D	20.1[a]	1.8[c]	0.42[b]
Carfentrazone	15.5[c]	1.6[c]	0.30[b]
F_{calc} Breeding line	2.1[ns]	2.6[ns]	0.3[ns]
F_{calc} Herbicide	10.0*	7.4*	3.9*
F_{calc} Breeding*Herbicide	1.7[ns]	0.5[ns]	1.1[ns]
CV (%)	10.2	30.3	9.0

Means followed by the same letter in the column did not differ significantly by the Scott Knott test (p ≤ 0.05). * Significant at a 5% probability; [ns] not significant.

However, other studies reported severe effects of PRE or pre-plant-incorporated (PPI) treatments in peanuts. Peixoto et al. (2010) reported that PPI applications of trifluralin reduced plant height and shoot and root and dry mass of peanuts at 45 DAA. Zanardo et al. (2019) observed severe damage for PRE applications of sulfentrazone (600 g ha^{-1}) and clomazone (720 g ha^{-1}), impairing the emergence and development of all five tested genotypes. Imazapic (122 g ha^{-1}) and s-metolachlor (1,680 g ha^{-1}) herbicides caused mild damage and impaired the emergence and development of each tested genotype. However, the authors used higher herbicide doses than the present study because they aimed to simulate the carryover effect from sugarcane herbicide applications, as maximum doses are usually higher than recommended for peanut crops (Brasil 2023). Grichar et al. (2013) performed a field observation of a peanut cultivar-dependent stunt effect at 60 days with different pre-emergence doses of flumioxazin (53 to 214 g ha^{-1}). The authors mentioned that wet conditions might have favored the reductions in peanut canopy development caused by this herbicide. Leon and Tillmann (2015) evaluated 35 breeding lines and two cultivars, finding lower damage (less than 20%) and shoot dry mass reduction (less than 40%) for diclosulam (59 g ha^{-1}), s-metolachlor (1,940 g ha^{-1}), and bentazon (1,120 g ha^{-1}) treatments. However, flumioxazin (71.5 g ha^{-1}) showed values higher than 70% and 60% (Leon and Tillman 2015). The damage found in the present study for these same herbicides was lower than 10%, and shoot dry mass decreased, possibly from the PRE application and lower doses of these herbicides.

The damage observed for post-emergence (POST) was higher in all tested herbicides up to 14 DAA. The effects of bentazon + imazamox, bentazon, clethodim, quizalofop-p-ethyl, and s-metolachlor decreased at an equivalent level to the untreated control at 21 and 28 DAA, indicating plant recovery after initial damage. At 28 DAA, most herbicides exhibited the same damage as the untreated control. Imazapic and lactofen applications caused mild damage (14.6 and 11.8%), but only imazapic reduced plant height and shoot and root dry mass. Lactofen is unregistered for peanut crops in Brazil, but it might be a compelling option for future selectivity studies on mild damage and the neutral effect on plant growth.

Carfentrazone showed the highest damage (62.8%) at seven DAA, which lowered to 48.9% at 28 DAA. The application of 2,4-D also caused high damage values, peaking at 21 DAA (38.4%) and reducing slightly at 28 DAA (35.8%). Carfentrazone and 2,4-D demonstrated pronounced dry shoot mass and mild dry root mass, but only carfentrazone reduced plant height. Both herbicides were the least selective to the genotypes evaluated at an early stage and are unregistered for weed control in peanut crops in Brazil.

Grichar et al. (2013) observed a peanut cultivar-dependent stunt effect in the field at 60 DAA with different POST doses of imazapic (35 to 141 g ha^{-1}). The authors reported that this deleterious effect might be due to soils low in organic matter and with near-neutral pH, reducing imidazolinone herbicide absorption by soil particles and increasing its uptake by peanut cultivars.

Zanardo et al. (2018) found that POST applications of s-metolachlor (1,680 g ha^{-1}), imazapic (122 g ha^{-1}), clomazone (720 g ha^{-1}), sulfentrazone (600 g ha^{-1}), and 2,4-D (1,209 g ha^{-1}) at 30 DAS reduced root and dry mass in six peanut genotypes (IAC Tatu-ST, Line 870, IAC 505, IAC 503, and Granoleico) at 21 DAA. They concluded that clomazone and sulfentrazone at these doses must not be indicated for post-emergence sprayings. In Brazil, diclosulam, clomazone, and sulfentrazone are recommended mainly for PRE applications (Brasil 2023), such as those tested in this study. Also, the mean root and shoot dry mass reduction caused by 2,4-D was 47.5% in the two breeding lines in the present study and 43.3% in three cultivars evaluated by Zanardo et al. (2018). Thus, the herbicide effect may be similar between both investigations despite the different herbicide doses and genotypes.

The high oleic 1253 OL and 2133 OL runner-type lines were selected due to their high yields in more than 20 trials in the Brazilian south, southeast, and central regions. Such trials had a weed management program that included most registered herbicides for peanut crops in Brazil. The low damage observed in both lines with PRE and some POST treatments is unsurprising, as they were exposed to many of these herbicides during the tests.

5. Conclusions

The 1253 OL and 2133 OL breeding lines did not influence herbicide effects. The pre-emergence treatments did not affect seedling emergence and shoot and root dry mass. Trifluralin, pendimethalin, diclosulam, imazethapyr + flumioxazin, and s-metolachlor were the most selective pre-emergence herbicides to peanuts for both genotypes at an early stage.

Diclosulam, clomazone, and lactofen are unregistered for peanut crops in Brazil, and further studies should test their selectivity for peanut cultivars. Screening studies on selectivity to imazapic, 2,4-D, and carfentrazone are also relevant to identifying sources of tolerance in peanut germplasm.

Authors' Contributions: COSTA, A.G.F: conception and design, acquisition of data, analysis and interpretation of data, drafting the article; SOFIATTI, V.: interpretation of data, drafting the article, and critical review of important intellectual content; SUASSUNA, T.M.F: interpretation of data, drafting the article, and critical review of important intellectual content; All authors have read and approved the final version of the manuscript.

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