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Efficacy and phytotoxicity of post emergence herbicides in garlic

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Abstract: The incidence of weeds in the garlic crop interferes with the quality and quantity of the harvest. This study aimed to evaluate the efficiency of herbicides in different combinations of sequential applications during the cultivation of garlic. The experiment was carried out in a randomized block design, with ten treatments and four replications. The treatments consisted of sequential applications of the herbicides pendimethalin, pyroxasulfone/flumioxazin, ioxynil, and pendimethalin. The doses of Herbadox® (pendimethalin) were 4.0 l·ha^{-1}, Totril® (ioxynil) 1.5 l·ha^{-1}, and Kyojin® (pyroxasulfone/flumioxazin) 0.15 l·ha^{-1}. Treatments consisted of sequential applications of herbicide combinations. Applications were performed 7, 58, 97, and 128 days after planting. Phytotoxicity on the crop, efficacy in weed control, bulb classification, and productivity were evaluated. The results were submitted to ANOVA, and the means were compared by the Scott-Knott test. The sequential application of pyroxasulfone/flumioxazin at 7 days after planting (DAP), ioxynil at 58 DAP, pendimethalin at 97 DAP, and pyroxasulfone/flumioxazin at 128 DAP (T7) stood out (96–100 % control of weeds, average productivity of 11.42 t·ha^{-1}), which presented the best results relative to phytotoxicity, weed control, bulb classification, and crop productivity.

Key words: phytotoxicity, efficacy, weed control, post-emergence.

Učinkovitost in fitotoksičnost herbicidov uporabljenih po vzniku česna

Izvleček: Pojavnost plevelov v nasadih česna vpliva na količino in kakovost pridelka. V raziskavi je bila ovrednotena učinkovitost herbicidov v različnih kombinacijah v zaporednih nanosih med gojenjem česna. Poskus je bil zasnovan v naključni bločni obliki, z desetimi obravnavanji in štirimi ponovitvami. Obravnavanja so obsegala zaporedno uporabo herbicidov kot so pendimetalin, piroksasulfon/flumioksazin, ioksinilin pendimetalin. Odmerki Herbadox-a® (pendimetalin) so bili 4,0 l·ha^{-1}, Totril-a® (ioksinil) 1,5 l·ha^{-1}in Kyojin-a® (piroksasulfon/flumioksazin) 0,15 l·ha^{-1}. Obravnavanja so bila izvedena v zaporednih kombinacijah herbicidov. in sicer 7, 58, 97 in 128 dni po sadnji. Ovrednotene so bile fitotoksičnost za posevek, učinkovitost zatiranja plevelov, klasifiklacija čebulic in produktivnost. Rezultati so bili obdelani z ANOVA, poprečja so bila primerjana s Scott-Knottovim testom. Zaporedna uporaba piroksasulfona/flumioksazina 7 dni po sadnji (DAP), ioksinila 58 DAP, pendimetalina 97 DAP in piroksasulfona/flumioksazina 128 DAP (T7) je izstopala (96–100 % nadzor plevelov, poprečna produktivnost 11,42 t·ha^{-1}), kar je predstavljalo najboljše rezultate glede na fitotoksičnost, nadzor plevelov, klasifikacijo čebulic in produktivnost česna.

Ključne besede: fitotoksičnost, učinkovitost nadzora plevelov po vzniku

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1 INTRODUCTION

Garlic cultivation in Brazil is a profitable source for both small-family farmers and large producers. This crop is very important in generating jobs (Meneguzzo et al., 2022). In 2021, 167,102 t of this crop were harvested, with an average yield of 12.8 t·ha^{-1}, mostly in small farms (about 1–2 ha), totaling an acreage of 13,544 ha (IBGE, 2023). The garlic crop presents a reduction in development when there is the simultaneous presence of weeds due to its slow initial growth, with low height and narrow and erect leaves that do not cover the soil surface. The critical period of garlic competition with weeds occurs between the first 20 days after emergence and during bulb maturation. Despite not interfering so much with maturation, weeds make manual harvesting difficult and mechanical harvesting unfeasible (Patil et al., 2016; Siddhu et al., 2018).

The primary weeds in colder periods in southern Brazil are the lesser swinecress (*Coronopus didymus* (L.) Sm.), wild radish (*Raphanus* spp.), chickweed (*Stellaria media* (L.) Vill.), broad-leaved dock (*Rumex obtusifolius* L.), and Italian ryegrass (*Lolium multiflorum* Lam.) (Uzo & Currah, 1990). In warmer periods, crabgrass (*Digitaria* spp.), alexandergrass (*Urochloa plantaginea* (Link) R.D.Webster), barnyardgrass (*Echinochloa* spp.), beggartick (*Bidens pilosa* L.), wild poinsettia (*Euphorbia heterophylla* L.), arrowleaf sida (*Sida* spp.), starbur (*Acanthospermum* spp.), potato weed (*Galinsoga parviflora* Cav.), and pigweed redroot (*Amaranthus* spp.) occur (Abouziena & Haggag, 2016). Weeds that grow in summer and spring seasons do not tolerate frost (Guerra et al., 2020).

Pre-emergence herbicides are widely used in preplanting and, in some cases, incorporated into the soil. Post-emergence herbicides control weeds that are in full physiological development. At post-emergence, the management of weeds becomes problematic as they grow (Das & Mondal, 2014; Wilkinson et al., 2015).

Pre-emergence herbicides, such as pendimethalin (Herbadox®), which inhibits cell division, and linuron (Afalon®), a photosystem II inhibitor, are widely used by garlic producers in Brazil. These active principles have a good residual in the soil, keeping the area clean of weeds. Also, there is a large offer of these products on the market (Guerra et al., 2020).

Kyojin® is a selective, contact, and systemic herbicide composed of pyroxasulfone, a cell division inhibitor, and flumioxazin, a Protox inhibitor. It is broad-spectrum effective against many weeds of the garlic cultivation (Agrofit, 2022). Flumioxazin successfully controlled weeds in garlic crops (Guerra et al., 2020).

This work aimed to evaluate the efficiency of different herbicide combinations in the garlic crop, applied sequentially, with varying application intervals.

2 MATERIALS AND METHODS

The experiment was conducted on a farm in the municipality of São Marcos, Rio Grande do Sul State (geographical coordinates: 28°54' S, 51°07' W, and an altitude of 679 m above sea level). The local climate is classified as Cfa (subtropical humid climate with mild summer), characterized by an average yearly rainfall of 1,688 mm, an average minimum temperature of 13 °C, and an average maximum temperature of 23 °C (Alvares et al., 2013). During the experiment, the average temperature was 17.3 °C, varying between 0.6 °C and 33.4 °C, and the accumulated rainfall in the period was 571.8 mm (INMET, 2023).

The experimental design used was randomized blocks with four replications. The plots consisted of six rows spaced 0.2 m apart, 5 m long, and 1.2 m wide, totaling an area of 6 m^2. The two central lines of each plot were considered useful for evaluation and harvesting, the remainder being considered borders.

The garlic cultivar 'San Valentin' was planted in the experiment. The bulbs underwent viral cleaning and were in their third generation, coming from the 2020/2021 harvest. The bulbs were selected and classified, subsequently submitted to vernalization, where they remained for 48 days in a cold chamber at a temperature of 2 °C.

The area was prepared with a duck foot plow, harrowing and filling. A marker roller coupled to a rotary hoe was used for planting the bulbil, helping with the planting work. The fertilization was carried out before planting with 60 kg·ha^{-1} of N, 375 kg·ha^{-1} of P, and 180 kg·ha^{-1} of K (750 kg of NPK fertilizer Topmix® 4-25-12, with 4 wt.% of nitrogen compounds, 25 wt.% of phosphorus compounds and 12 wt.% of potassium compounds) before planting and two topdressing applications with a total of 36 kg·ha^{-1} of N and 96 kg·ha^{-1} of K (100 kg per hectare with NPK 9-00-24, containing 9 wt.% of nitrogen compounds and 24 wt.% of potassium compounds) during crop development.

The bulbils underwent phytosanitary treatments, in which the fungicides captan and abamectin were used at doses of 2.0 ml·l^{-1} and 2.5 ml·l^{-1}, respectively, before vernalization. Planting was carried out on July 20, 2022, and microsprinklers provided irrigation at the beginning of the crop cycle. The tested treatments, active ingredients, and doses are compiled in Table 1.

Herbicide application started seven days after planting (DAP) of the crop, in pre-emergence of weeds; the second application occurred at 58 DAP; the third ap-

Table 1: Compilation of treatments applied and their composition, days after planting, active ingredient, and doses of commercial product. São Marcos, UCS, 2022.

Treatment	DAP*	Active ingredient	Dose ($g{\cdot}ha^{-1}$)	Dose ($l{\cdot}ha^{-1}$)
Treatment 1 (Infested control)	-	-	-	-
Treatment 2 (Weeded control)	-	-	-	-
Treatment 3	7	Pendimethalin[1]	1,600	4.0
	58	Pyroxasulfone/flumioxazin [2]	45/30	0.15
	97	Ioxynil[3]	375	1.5
	128	Pendimethalin	1,600	4.0
Treatment 4	7	Pyroxasulfone/flumioxazin	45/30	0.15
	58	Pendimethalin	1,600	4.0
	97	Ioxynil	375	1.5
	128	Pyroxasulfone/flumioxazin	45/30	0.15
Treatment 5	7	Ioxynil	375	1.5
	58	pendimethalin	1,600	4.0
	97	Pyroxasulfone/flumioxazin	45/30	0.150
	128	Ioxynil	375	1.5
Treatment 6	7	pendimethalin	1,600	4.0
	58	Ioxynil	375	1.5
	97	Pyroxasulfone/flumioxazin	45/30	0.15
	128	pendimethalin	1,600	4.0
Treatment 7	7	Pyroxasulfone/flumioxazin	45/30	0.15
	58	Ioxynil	375	1.5
	97	pendimethalin	1,600	4.0
	128	Pyroxasulfone/flumioxazin	45/30	0.15
Treatment 8	7	Ioxynil	375	1.5
	58	Pyroxasulfone/flumioxazin	45/30	0.15
	97	pendimethalin	1,600	4.0
	128	Ioxynil	375	1.5
Treatment 9	7	Pyroxasulfone/flumioxazin	45/30	0.15
	58	Pyroxasulfone/flumioxazin	45/30	0.15
	97	Ioxynil	375	1.5
	128	Pyroxasulfone/flumioxazin	45/30	0.15
Treatment 10	7	Ioxynil	375	1.5
	58	Pyroxasulfone/flumioxazin	45/30	0.15
	97	Pyroxasulfone/flumioxazin	45/30	0.15
	128	Ioxynil	375	1.5

* – Days after planting. [1] – Herbadox®; [2] – Kyojin®; [3] – Totril®. Source: Authors (2025)

plication occurred at 97 DAP, and the last application was performed at 128 DAP. The herbicides were always applied in the morning. The equipment used to apply the treatment was a knapsack sprayer pressurized with CO_2, calibrated with a constant pressure of approx. 2.5 kPa, which provided a spray volume of 500 $l{\cdot}ha^{-1}$. Other aspects of cultural management, such as phytosanitary treatments and sprinkler irrigation, were carried out during the crop cycle when necessary, according to farmer's expertise.

The evaluation of weed control was carried out at the end of the cycle, in the pre-harvest period. The assessment of the classification of the bulbs occurred at the end of the crop cycle, quantifying, and classifying the bulbs of the two central lines. The bulbs were measured using an analog caliper and classified according to Mercosul GMC resolution 05/21 (Mercosul, 2021), considering the largest cross-sectional diameter of the bulb, expressed in millimeters (mm). Thus, bulbs > 56 mm were classified as number 7, > 47–56 mm as number 6, > 42–47 mm as number 5, > 37–42 mm as number 4, and > 32–37 mm as number 3 (Brazil, 1992). Bulbs smaller than 32 mm do not fit the regulation. Therefore, they were classified as industrial garlic.

The productivity evaluations were performed with a digital electronic scale (ALC500, Marte, Brazil), where ten random bulbs were weighed, harvested in each block, and divided by the number of bulbs present in the weighing. Per repetition (block), 1.1 kg were planted. With this, the average productivity was estimated considering 1,000 kg·ha^{-1} of planted bulbils.

Phytotoxicity symptoms were evaluated seven days after each application (DAA). Phytotoxicity scores were based on visual criteria, based on control, considering a scale from zero to 100 %, where zero represents the absence of injuries caused by the herbicides and 100 % (one hundred) corresponded to the death of the plants. For the visual evaluations of the infested plants, percentages of control provided by the herbicides were applied relative to the control (T1 – infested control) (SBCPD, 1995).

The results were evaluated for homoscedasticity (Levene's test) and normality (Shapiro-Wilk's test), being submitted to the Analysis of Variance (ANOVA). The means of the treatments were compared by the post hoc test of multiple comparison of means of Scott- Knott at a 5 % error probability (α = 0.05). The statistical analyses were performed using the AgroEstat® software (Brazil).

3 RESULTS AND DISCUSSION

For the evaluated variables, there was a statistical difference between the herbicide treatments tested (Tables 2 to 6). The results of phytotoxicity to garlic crops caused by each herbicide treatment are presented in Table 2.

The phytotoxicity caused by the different herbicides in the garlic crop was presented as follows: the combinations started seven days after planting (DAP) with pyroxasulfone and flumioxazin at a dose of 0.15 l·ha^{-1} and ioxynil at 1.5 l·ha^{-1} caused a reduction in development relative to the weeded control (T2). In contrast, pendimethalin at a 4.0 l·ha^{-1} dose did not cause crop phytotoxicity.

At 58 DAP, garlic was very susceptible to injuries caused by the herbicides tested after the second application. Yellowing symptoms were quite noticeable, where all herbicides showed percentages of phytotoxicity higher than 7 DAP. The active ingredient ioxynil (Totril®) caused less phytotoxicity than the other ingredients at a 1.5 l·ha^{-1} dose.

The combination in which the association pyroxasulfone/flumioxazin was applied at 97 DAP caused phytotoxicity symptoms of up to 33 % of the leaf area with signs of yellowing and whitish lesions caused by pyroxasulfone and flumioxazin. It is worth mentioning that there was a higher incidence of bacterial diseases in the plots

Table 2: Results of visual assessment of phytotoxicity symptoms in the garlic crop, seven days after the application (DAA) of herbicide combinations, at different development crop stages. São Marcos, UCS, 2022.

Treatment	Phytotoxicity (%) in 7 DAA			
	7 DAP	58 DAP	97 DAP	128 DAP
T1 – Infested Control	0 c	0 f	0 c	0 c
T2 – Weeded Control	0 c	0 f	0 c	0 c
T3 – Pen[1], Pyr/Flu[2], Iox[3], Pen	0 c	20 c	0 c	10 b
T4 – Pyr/Flu, Pen, Iox, Pyr/Flu	7 a	17 d	0 c	16 a
T5 – Iox, Pen, Pyr/Flu, Iox	4 b	17 d	33 a	5 c
T6 – Pen, Iox, Pyr/Flu, Pen	0 c	10 e	20 b	0 c
T7 – Pyr/Flu, Iox, Pen, Pyr/Flu	5 b	17 d	0 c	11 b
T8 – Iox, Pyr/Flu, Pen, Iox	4 b	36 a	0 c	0 c
T9 – Pyr/Flu, Pyr/Flu, Iox, Pyr/Flu	5 b	28 b	0 c	17 a
T10 – Iox, Pyr/Flu, Pyr/Flu, Iox	4 b	30 b	20 b	16 a
Coefficient of variation (%)	26.7	11.1	49.3	39.9

[1] – pendimethalin; [2] – pyroxasulfone/flumioxazin; [3] – ioxynil. The adopted doses were 4.0 l·ha^{-1} for pendimethalin®, 0.15 l·ha^{-1} for pyroxasulfone/flumioxazin, and 1.5 l·ha^{-1} for ioxynil. DAA – days after application of treatments; DAP – days after crop planting. Means in column followed by the same letter do not differ statistically by the Scott-Knott test at a 5 % error probability. Source: Authors (2025).

where pyroxasulfone/flumioxazin was applied at 0.15 l·ha^{-1} compared to the weeded control (T2), consequently, due to the lesions caused by the herbicide.

Pyroxasulfone and flumioxazin, when applied at 128 DAP, caused greater phytotoxicity than the other herbicides tested. However, the damage caused was lower than that seen at 97 DAP, not leading to the death of the culture of interest at the dose used. On the other hand, the ioxynil and pendimethalin principles caused a lower degree of injuries caused by phytotoxicity in the crop when applied at 128 DAP.

The damage capacity of the pyroxasulfone/flumioxazin association at a dose of 0.15 l·ha^{-1} was noticed on garlic plants at different stages of crop development, where significant damage to the leaves stood out. Among the best combinations, which caused the lowest percentages of phytotoxicity, those that started with applying pendimethalin at a dose of 4.0 l·ha^{-1} stood out.

The main weeds occurring in the experimental area were the wild carrot (*Daucus carota* L.), speedwell (*Veronica* spp.), potato weed (*Galinsoga parviflora*) and lesser swinecress (*Coronopus didymus*). The results of the

Table 3: Control (%) of potato weed (*Galinsoga parviflora*), lesser swinecress (*Coronopus didymus*), wild carrot (*Daucus carota*), and speedwell (*Veronica* spp.) in garlic crop due to different herbicides applied in the pre-harvest period. São Marcos, UCS, 2022.

Treatment	Control (%)			
	Potato weed	Lesser swinecress	Wild carrot	Crab-grass
T1 – Infested Control	0 b	0 b	0 d	0 c
T2 – Weeded Control	100 a	100 a	100 a	100 a
T3 – Pen[1], Pyr/Flu[2], Iox[3], Pen	100 a	97 a	58 b	96 b
T4 – Pyr/Flu, Pen, Iox, Pyr/Flu	98 a	97 a	68 b	98 a
T5 – Iox, Pen, Pyr/Flu, Iox	85 a	87 a	31 c	93 b
T6 – Pen, Iox, Pyr/Flu, Pen	100 a	100 a	68 b	100 a
T7 – Pyr/Flu, Iox, Pen, Pyr/Flu	96 a	97 a	100 a	100 a
T8 – Iox, Pyr/Flu, Pen, Iox	98 a	97 a	58 b	100 a
T9 – Pyr/Flu, Pyr/Flu, Iox, Pyr/Flu	96 a	100 a	79 b	100 a
T10 – Iox, Pyr/Flu, Pyr/Flu, Iox	96 a	100 a	68 b	100 a
Coefficient of variation (%)	9.8	9.6	20.5	2.6

[1] – pendimethalin; [2] – pyroxasulfone/flumioxazin; [3] – ioxynil. The adopted doses were 4.0 l·ha^{-1} for pendimethalin®, 0.15 l·ha^{-1} for pyroxasulfone/flumioxazin, and 1.5 l·ha^{-1} for ioxynil. DAA – days after application Means in column followed by the same letter do not differ statistically by the Scott-Knott test at a 5 % error probability. Source: Authors (2025).

Table 4: Classification of garlic bulbs, following the MAPA regulation 242, treated with different combinations of herbicides during the crop cycle. São Marcos, UCS, 2022.

Treatment	Classification - Class (%)					
	C7	C6	C5	C4	C3	Industry
T1 – Infested Control	0 b	0 d	0 b	5 b	57 a	37 a
T2 – Weeded Control	0 b	81 a	18 b	0 b	0 c	0 b
T3 – Pen[1], Pyr/Flu[2], Iox[3], Pen	2 b	25 b	52 a	20 a	0 c	0 b
T4 – Pyr/Flu, Pen, Iox, Pyr/Flu	0 b	30 b	50 a	17 a	2 c	0 b
T5 – Iox, Pen, Pyr/Flu, Iox	0 b	2 c	47 a	32 a	17 b	0 b
T6 – Pen, Iox, Pyr/Flu, Pen	0 b	32 c	47 a	20 a	0 c	0 b
T7 – Pyr/Flu, Iox, Pen, Pyr/Flu	7 a	50 b	32 a	5 b	2 c	0 b
T8 – Iox, Pyr/Flu, Pen, Iox	0 b	37 c	45 a	15 a	2 c	0 b
T9 – Pyr/Flu, Pyr/Flu, Iox, Pyr/Flu	0 b	52 b	40 a	5 b	0 c	0 b
T10 – Iox, Pyr/Flu, Pyr/Flu, Iox	0 b	10 d	32 a	37 a	12 b	2 b
Coefficient of variation (%)	33.8	52.6	43.1	16.4	78.9	84.7

[1] – pendimethalin; [2] – pyroxasulfone/flumioxazin; [3] – ioxynil. The adopted doses were 4.0 l·ha^{-1} for pendimethalin®, 0.15 l·ha^{-1} for pyroxasulfone/flumioxazin, and 1.5 l·ha^{-1} for ioxynil. DAA – days after application Means in column followed by the same letter do not differ statistically by the Scott-Knott test at a 5 % error probability. Source: Authors (2025).

control percentage of each weed species relative to the treatments tested are compiled in Table 3.

For the control of potato weed and lesser swinecress (Table 3), all combinations showed excellent control (> 85 %), with emphasis on the combination that started with pendimethalin at doses of 4.0 l·ha^{-1} at 7 DAP, ioxynil 1.5 l·ha^{-1} at 58 DAP, pyroxasulfone/flumioxazin 0.15 l·ha^{-1} at 97 DAP and pendimethalin again at 128 DAP, showing total control (100 %) of both evaluated weeds.

The association pyroxasulfone/flumioxazin, ioxynil, pendimethalin, and pyroxasulfone/flumioxazin (T7) stood out, which promoted total control (100 %) of these invasive species.

The combination of ioxynil, pendimethalin, pyroxasulfone/flumioxazin, and ioxynil (T5) proved to be the least effective concerning the other treatments, showing 93 % control of crabgrass, but only 31 % of control for wild carrot (Table 3). These differences are due to the specific sensitivity of each species to herbicides, resulting in greater control of crabgrass when compared to wild carrot.

Table 5: Bulb mass and yield estimate considering the planting of 1,000 kg·ha^{-1} of 'San Valentin' garlic bulbs treated with different combinations of herbicides during crop development. São Marcos, UCS, 2022.

Treatment	Mass of bulbs (g)	Productivity (t·ha^{-1})
T1 – Infested Control	19 d	4.50 d
T2 – Weeded Control	50 a	11.47 a
T3 – Pen[1], Pyr/Flu[2], Iox[3], Pen	42 b	9.74 b
T4 – Pyr/Flu, Pen, Iox, Pyr/Flu	40 b	9.16 b
T5 – Iox, Pen, Pyr/Flu, Iox	32 c	7.37 c
T6 – Pen, Iox, Pyr/Flu, Pen	41 b	9.42 b
T7 – Pyr/Flu, Iox, Pen, Pyr/Flu	49 a	11.42 a
T8 – Iox, Pyr/Flu, Pen, Iox	42 b	9.79 b
T9 – Pyr/Flu, Pyr/Flu, Iox, Pyr/Flu	40 b	9.20 b
T10 – Iox, Pyr/Flu, Pyr/Flu, Iox	36 b	8.44 b
Coefficient of variation (%)	10.8	11.1

[1] – pendimethalin; [2] – pyroxasulfone/flumioxazin; [3] – ioxynil. The adopted doses were 4.0 l·ha^{-1} for pendimethalin®, 0.15 l·ha^{-1} for pyroxasulfone/flumioxazin, and 1.5 l·ha^{-1} for ioxynil. DAA – days after application 4 - Considering the planting of 1,000 kg·ha-1 of bulbils. Means in column followed by the same letter do not differ statistically by the Scott-Knott test at a 5 % error probability. Source: Authors (2025).

Data on bulbs' classification according to the herbicide treatments used are compiled in Table 4.

Differences in bulb caliber were significant in class 7 (C7), highlighting the use of pyroxasulfone/flumioxazin 0.15 l·ha^{-1} in the first application, followed by ioxynil 1.5 l·ha^{-1}, pendimethalin 4.0 l·ha^{-1} and pyroxasulfone/flumioxazin in combination. In this treatment, 7 % of the total bulbs were classified as class 7, 50 % as class 6, and 32 % as class 5. Notably, weed control was important for greater uniformity and size of bulbs in the garlic crop.

The infested control (T1) showed statistical variation about the other treatments for bulbs smaller than 32 mm, with 37 % of the production as industry garlic, which indicates the negative effect of not controlling the weed species present during the development of the crop.

Data referring to the mass of bulbs and estimated productivity of the crop with the different herbicide application regimes are presented in Table 5.

According to Tables 4 and 5, the combination that stood out negatively from the others was ioxynil, pendimethalin, pyroxasulfone/flumioxazin, and ioxynil (T5), which had the smallest caliber of bulbs, being inferior to the other treatments due to the low control of weeds.

Among the evaluated treatments (Table 5), the combination of pyroxasulfone/flumioxazin herbicides at 7 DAP, ioxynil at 58 DAP, pendimethalin at 97 DAP, and pyroxasulfone/flumioxazin in its last application (T7), which had an average mass of 49 g per bulb stood out. The estimated productivity of 11.42 t·ha^{-1} was very close to the weeded control (T2 – 11.47 t·ha^{-1}).

The residual effect of the product pyroxasulfone/flumioxazin at 0.15 l·ha^{-1} was notorious when applied at 7 DAP, presenting an excellent residual effect and controlling the emergence of weeds, which kept the crop free of competition. The combination that had the slightest effect on yield was the one started with ioxynil, pendimethalin, pyroxasulfone/flumioxazin, and ioxynil (T5), with an estimated yield of 7.37 t·ha^{-1}, considering 1,000 kg·ha^{-1} of bulbils planted.

Wilkinson et al. (2015) pointed out that the symptoms of poisoning by photosystem II inhibitors (FSII), such as ioxynil, appear quickly and are characterized by interveinal chlorosis and leaf edge chlorosis in seagrass. These symptoms develop rapidly after herbicide application, as seen within seven days after application. Therefore, the combination of herbicides that stood out, showing less phytotoxicity at 58 DAP, was pendimethalin, ioxynil, pyroxasulfone and flumioxazin, and pendimethalin (T6).

As highlighted by Siddhu et al. (2018), in addition to favorable climatic conditions, the emergence of diseases is associated with injuries or stress caused by applying chemical pesticides, mainly post-emergence herbicides.

Furthermore, Mudge and Haller (2009) stated that herbicides can cause crop toxicity, affecting development, growth, and productivity, as verified by 7 DAA of pyroxasulfone and flumioxazin when applied in corn, cotton, soybean, and wheat, begonia, impatiens, and snapdragon. Therefore, the application of pyroxasulfone and flumioxazin principles in this period is not indicated. It is believed that this phenomenon occurred due to the size of the crop being more prominent and having a larger leaf area in this period. In this way, the contact of the formulations with the soil and weeds is reduced.

The herbicide pendimethalin inhibits microtubule arrangement in mitosis, efficiently controlling annual grasses and specific broad leaves in pre-emergence. However, this principle does not control established plants before application (Chen et al., 2021).

It was also possible to observe the control efficiency of pyroxasulfone/flumioxazin at 7 DAA, followed by ioxynil at 58 DAA, on wild carrot and speedwell regarding the other combinations tested. After application, the areas remained free of these weeds. According to the *Sociedade Brasileira da Ciência das Plantas Daninhas* (1995), a product must have a minimum control threshold of 80 % to be recommended for weed control of invasive species in that respective culture.

Uzo and Currah (1990) pointed out that weeds can cause great productivity losses as they compete with the crop for space, nutrients, water, and light. In addition, invasive species can host diseases and release toxins/allelopathics that can inhibit or reduce crop development, thus decreasing final productivity.

The increased competition pressure between the weeds and the culture may have caused a reduced bulb caliber. Luz et al. (2022) commented that when efficient weed control is not carried out, this can result in important yield losses for garlic crops.

Most of the tested combinations showed satisfactory results for weed control, with emphasis on the pyroxasulfone/flumioxazin treatment at a dose of 0.15 $l \cdot ha^{-1}$ at 7 DAP (T7), which showed excellent control of weeds when applied to the garlic crop, not causing significant injuries due to phytotoxicity when compared to applications at other stages of the crop.

It was also noticed that, at 97 DAP where pyroxasulfone/flumioxazin was used, highlighting the combination ioxynil, pyroxasulfone/flumioxazin, pyroxasulfone/flumioxazin, and ioxynil (T10), the culture showed reduced growth due to phytotoxicity concerning the controls (T1 and T2). Therefore, this product is not indicated in this period but in earlier periods, in which the leaf area of the crop is smaller.

When using the pendimethalin herbicide in post-emergence of the crop, less phytotoxicity was observed in garlic in different application periods when compared to the pyroxasulfone/flumioxazin product, in addition to achieving excellent control of potato weed, lesser swinecress, and speedwell. On the other hand, this product did not effectively manage wild carrot. The use of ioxynil at 7 DAP did not have reasonable control and productivity results, making the ioxynil, pendimethalin, pyroxasulfone/flumioxazin, and ioxynil combination less effective than the other combinations assessed. Thus, the importance of applying pre-emergence herbicides at earlier crop stages is suggested to reduce the toxic effects on the garlic plants.

4 CONCLUSIONS

The sequential application of pyroxasulfone/flumioxazin at 7 DAP, ioxynil at 58 DAP, pendimethalin at 97 DAP, and pyroxasulfone/flumioxazin at 128 DAP (T7) yielded the best results regarding the relationship between phytotoxicity to the crop, weed control, and bulb classifications, presenting itself as an alternative to garlic producers, considering the current options for chemical control of weeds in the crop.

5 REFERENCES

Abouziena, H. F., & Haggag, W. M. (2016). Weed control in clean agriculture: a review. *Planta Daninha*, *34*, 377-392. https://doi.org/10.1590/S0100-83582016340200019

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*, 711-728. https://doi.org/10.1127/0941-2948/2013/0507

Chen, J., Yu, Q., Patterson, E., Sayer, C., & Powles, S. (2021). Dinitroaniline herbicide resistance and mechanisms in weeds. *Frontiers in Plant Science*, *12*, 634018. https://doi.org/10.3389/fpls.2021.634018

Das, S. K., & Mondal, T. (2014). Mode of action of herbicides and recent trends in development: A reappraisal. *International Journal of Agricultural and Soil Science*, *2*, 27-32.

Guerra, N., Haramoto, R., Schmitt, J., Costa, G. D., Schiessel, J. J., & Oliveira Neto, A. M. (2020). Weed control and selectivity herbicides pre emerging in garlic cultivars. *Planta Daninha*, *38*, e020228966. https://doi.org/10.1590/S0100-83582020380100074

Instituto Brasileiro de Geografia e Estatística (IBGE). (2022). *Produção de Alho*. Retrieved from: https://

www.ibge.gov.br/explica/producao-agropecuaria/alho/br
Instituto Nacional de Meteorologia (INMET). (2023). *Sistema Tempo*. Retrieved from: https://tempo.inmet.gov.br/
Luz, L. M. Q., Azevedo, B. N. R., Silva, S. M., Oliveira, C. I. G., Oliveira, T. G., Oliveira, R. C., & Castoldi, R. (2022). Productivity and quality of garlic produced using below-zero temperatures when treating seed cloves. *Horticulturae*, *8*, 96. https://doi.org/10.3390/horticulturae8020096
Meneguzzo, R., Silvestre, W. P., & Pauletti, G. F. (2022). Effect of irrigation, planting position, and application of calcium silicate on garlic development in 'Serra Gaúcha' region, South Brazil. *Pesquisa Agropecuária Gaúcha*, *28*, 139-155. https://doi.org/10.36812/pag.2022281139-155
Mercado Comum do Sul (Mercosul). (2021). *Regulamento Técnico Mercosul de Identidade e Qualidade do Alho*. Retrieved from: https://normas.mercosur.int/simfiles/normativas/85147_RES_005-2021_PT_RTM%20Alho.pdf
Mudge, C. R., & Haller, W. T. (2009). Ornamental and row crop susceptibility to flumioxazyn in overhead irrigation water. *Weed Technology*, *23*, 89-93. https://doi.org/10.1614/WT-08-024.1
Patil, B. V., Naruka, I. S., Shaktawat, R. P. S., & Verma, K. S. (2016). Studies on growth, yield and quality of garlic (*Allium sativum* L.) as affected by herbicides and weeds. *International Journal of Bio-resource and Stress Management*, *7*, 1099-1103. https://doi.org/10.23910/ijbsm/2016.7.5.1540a
Siddhu, G. M., Patil, B. T., Bachkar, C. B., & Handal, B. B. (2018). Weed management in garlic (*Allium sativum* L.). *Journal of Pharmacognosy and Phytochemistry*, *7*, 1440-1444.
Sistemas de Agrotóxicos Fitossanitários (Agrofit). (2022). Retrieved from: https://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons
Sociedade Brasileira da Ciência das Plantas Daninhas (SBCPD). (1995). *Procedimentos para instalação, avaliação e análise de experimentos com herbicidas*. Londrina, PR: SBCPD.
Uzo, J. O., & Currah, L. (1990). In H. D. Rabinowitch (Ed.), *Onions and Allied Crops Volume II: Agronomy Biotic Interactions* (pp. 48-65). Boca Raton, LA: CRC Press. https://doi.org/10.1201/9781351075152
Wilkinson, A. D., Collier, C. J., Flores, F., & Negri, A. P. (2015). Acute and additive toxicity of ten photosystem-II herbicides to seagrass. *Scientific Reports*, *5*, 17443. https://doi.org/10.1038/srep17443