CC BY

Research Article

Effectiveness of bicyclopyrone alone and in combination with hexazinone for controlling *Paspalum maritimum* Trind. in pre- and post-emergence[1]

Luis Eugênio Lessa Bulhões[2], Lucas Alceu Rodrigues de Lima[2], Leandro Lima Casado dos Santos[2], Antônio Barbosa da Silva Júnior[2], Renan Cantalice de Souza[2]

ABSTRACT

Ginger grass (*Paspalum maritimum* Trind.) is a perennial grass that is difficult to control due to the robustness of its rhizome system. This study aimed to evaluate the effectiveness of the bicyclopyrone herbicide in managing this species under greenhouse (0 to 740 g ha^{-1}) and field [untreated control, picloram alone, and picloram + hexazinone applied at pre- and post-emergence, with assessments at 15, 30, and 45 days after application (DAA) of the green cover index (Canopeo)] conditions. In the greenhouse bioassay, picloram provided 100 % of control starting from 185 g a.i. ha^{-1}. In the field, the pre-emergence application outperformed the post-emergence in all evaluations. At 15 DAA, there was a significant interaction, with the bicyclopyrone + hexazinone mixture standing out with the lowest coverage values: 7.1 % in pre- and 13.6 % in post-emergence, showing synergy between HPPD inhibitors and PSII. At 30 DAA, the mixture maintained the highest level of control; however, there was a linear increase in coverage for all the herbicide treatments due to rhizome regrowth and emergence of new seedlings. At 45 DAA, the reinfestation pressure evened out the plots, with no statistical difference between the treatments and the control. Bicyclopyrone (185 g ha^{-1}) is effective in a controlled environment, but, in the field, mixing it with hexazinone as a pre-emergence treatment is the best management strategy. The effective control lasts only up to 30 days, with coverage returning by 45 DAA, regardless of the application method.

KEYWORDS: Ginger grass, 4-hydroxyphenylpyruvate dioxygenase inhibitor herbicides, rhizomes.

RESUMO

Eficácia de biciclopirona isolada e em mistura com hexazinona no controle de *Paspalum maritimum* Trind. em pré e pós-emergência

O capim-gengibe (*Paspalum maritimum* Trind.) é uma gramínea perene de difícil controle, em função da robustez de seu sistema de rizomas. Objetivou-se avaliar a eficácia do herbicida biciclopirona no manejo da espécie em condições de casa de vegetação (0 a 740 g ha^{-1}) e de campo [testemunha sem aplicação, biciclopirona isolada e biciclopirona + hexazinona aplicadas em pré e pós-emergência, com avaliações aos 15, 30 e 45 dias após a aplicação (DAA) do índice de cobertura verde (Canopeo)]. No bioensaio em casa de vegetação, a biciclopirona proporcionou controle de 100 % a partir de 185 g i.a. ha^{-1}. No campo, a aplicação em pré-emergência foi superior à pós-emergência em todas as avaliações. Aos 15 DAA, houve interação significativa, destacando-se a mistura biciclopirona + hexazinona com as menores coberturas: 7,1 % em pré e 13,6 % em pós-emergência, evidenciando sinergismo entre inibidores de HPPD e FSII. Aos 30 DAA, a mistura manteve o maior nível de controle; contudo, observou-se incremento linear da cobertura em todos os tratamentos herbicidas devido à rebrota de rizomas e emergência de novas plântulas. Aos 45 DAA, a pressão de reinfestação nivelou as parcelas, sem diferença estatística entre tratamentos e testemunha. A biciclopirona (185 g ha^{-1}) é eficaz em ambiente controlado, mas, em campo, a mistura com hexazinona em pré-emergência constitui a melhor estratégia de manejo. O controle efetivo limita-se a 30 dias, com restabelecimento da cobertura até 45 DAA, independentemente da modalidade de aplicação.

PALAVRAS-CHAVE: Capim-gengibre, herbicidas inibidores de 4-hidroxifenilpiruvato dioxigenase, rizomas.

INTRODUCTION

Ginger grass (*Paspalum maritimum* Trind.) is a perennial, stoloniferous species that reaches heights between 50 and 100 cm and is characterized by the presence of very long rhizomes and stolons (Oliveira et al. 2013). It is an abundant plant, capable of forming dense populations in different environments, being found in sandy or humus-rich soils, dunes, human-modified fields, semi-evergreen forests, and disturbed areas, usually on flat to gently rolling terrain (Oliveira et al. 2013, Mello et al. 2016).

[1] Received: Apr. 06, 2026. Accepted: June 30, 2026. Published: July 29, 2026. DOI: 10.1590/1983-40632026v5685772.
[2] Universidade Federal de Alagoas, Campus of Engineering and Agricultural Sciences, Maceió, AL, Brazil.
E-mail/ORCID: lessabulhoes@gmail.com/0000-0003-3048-968X; alceulucasx2@gmail.com/0000-0002-7413-3303; leandrocasado.consult@gmail.com/0000-0002-7011-5837; antonio.barbosa@ceca.ufal.br/0000-0002-2513-7471; renan.souza@ceca.ufal.com.br/0000-0001-9022-3360.
Editor: Luis Carlos Cunha Junior/Data Availability Statement: Research data are only made available by authors upon request.

In the Northeast of Brazil, ginger grass stands out as one of the main weeds in sugarcane cultivation. When not controlled, this species forms large clumps, especially in sandy and/or low-fertility soils (Mello et al. 2016). In addition, *Paspalum maritimum* is recognized for its high ability to invade cultivated pasture areas, where it can form virtually pure colonies and dominate the vegetation in just a few years. Under these dominant conditions, even other weeds tend to disappear (Souza Filho 2006).

The control of *P. maritimum* is considered complex, mainly because of its morphological characteristics. It is a stoloniferous and rhizomatous plant, with upright or semi-upright growth, which helps it spread and persist in infested areas (Mello et al. 2016, Tenório Filho et al. 2023). Its underground system is made up of long, stiff rhizomes covered with short scales, which grow horizontally just below the soil surface (Mello et al. 2016).

Previous studies have shown that the use of metsulfuron-methyl (Mello et al. 2016), as well as the application of glyphosate combined with the flumioxazin herbicide (Tenório Filho et al. 2023), is an efficient and fast-acting option for controlling ginger grass. However, it is crucial to evaluate herbicides with different modes of action to help reduce the likelihood of resistant populations emerging (Lindley et al. 2020).

4-hydroxyphenylpyruvate dioxygenase-inhibiting herbicides (HPPD, EC 1.13.11.27) have established themselves as a promising tool in weed management. These compounds inhibit HPPD, an enzyme responsible for tyrosine metabolism, affecting the biosynthesis of plastoquinone and tocopherols and interrupting the carotenoid synthesis pathway, which causes leaf bleaching and necrosis, ultimately leading to the plant's death (Chen et al. 2024).

The unique nature of the molecular mechanism of action of HPPD makes these herbicides promising, as they have a low risk of resistance development and cross-resistance with other modes of action (Nan et al. 2023). These herbicides are widely used both at pre- and post-emergence, showing effectiveness in crops like corn, barley, oat, rice, sorghum, sugarcane, and wheat (Jhala et al. 2023).

Within this group, bicyclopyrone stands out as the newest herbicide in the triketone family, which includes mesotrione, tembotrione, benzobicyclone, and sulcotrione (Chen et al. 2018). Bicyclopyrone offers a great application flexibility, as it can be used both at pre- and post-emergence, being absorbed through roots and leaves, providing long-lasting control throughout the crop cycle (Lindley et al. 2020).

HPPD-inhibiting herbicides are also often used in combination with Photosystem II (PSII) inhibitors, a strategy that can result in a synergistic effect on weed control. This effect is attributed to the reduced availability of plastoquinone caused by HPPD inhibition, which enhances the action of PSII inhibitors on photosynthetic electron transport and increases photooxidative damage (Matringe et al. 2005, Jhala et al. 2023). However, the magnitude of this synergism depends on the herbicide combination, the weed species, and the application conditions (Fluttert et al. 2022).

In this context, the present study aimed to evaluate the efficiency of bicyclopyrone alone and in a mixture for controlling ginger grass (*Paspalum maritimum*) under greenhouse and field conditions.

MATERIAL AND METHODS

The experiment was carried out at the Universidade Federal de Alagoas, in Rio Largo, Alagoas state, Brazil (9º29'45"S, 35º49'54"W, and altitude of 127 m), between February and April 2024.

The study consisted of two bioassays: the first conducted in a controlled environment (greenhouse) and the second one under field conditions.

For the bioassay I, the experiment was set up in a completely randomized design, with four treatments and eight replications. The experimental units consisted of 500-mL pots filled with substrate until they reached a mass of 450 g. For planting, viable ginger grass rhizomes were selected (*Paspalum maritimum*), with 6 g of rhizomes being planted per pot. The treatments consisted of increasing doses of the biciclopyrone herbicide (0, 185, 370, and 740 g ha^{-1}) before the weed emergence, using a CO_2 pressurized backpack sprayer equipped with fan-type tips (Teejet XR 110 02-VS). The equipment was calibrated for an application rate of 150 L ha^{-1}. At 45 days after application (DAA), the count of living and dead plants was done to determine the control effectiveness.

For the bioassay II, the field experiment was conducted in an area of 180 m^2 (12 x 15 m) with record of high natural infestation of *P. maritimum*, adopting a randomized block experimental design in a 2 x 3 factorial scheme, with five replications

and 2-m² plots (1 x 2 m). The analyzed factors were two weed development conditions: pre-emergence (areas mowed with rhizomes left in the soil) and late post-emergence (adult plants in the vegetative stage, without flowering); combined with three herbicide treatments: bicyclopyrone (185 g ha^{-1}), a mixture of bencyclopyrone + hexazinone (175 + 221.7 g ha^{-1}) and an absolute control, without application. Before spraying within 48 hours, a 20-mm irrigation layer per plot was applied to ensure the plants' metabolic vigor. Evaluations were carried out at 15, 30, and 45 DAA, using a 0.50-m-sided frame to capture digital images, processed with the Canopeo software (contrast 1.0) to obtain the green cover index in percentage (%). The data were subjected to residual normality tests (Shapiro-Wilk) and variance homogeneity tests (Bartlett). Once the assumptions were met, an analysis of variance (Anova) was performed using the F test. When statistical significance was observed, the data from the bioassay I were fitted to the three-parameter logistic nonlinear regression model, as proposed by Streibig (1988): $y = y_0 + a/[1 + (x/b)c]$, where: y corresponds to the control percentage; y_0 is the starting value of the equation (intercept); x the herbicide dose; a the difference between the maximum and minimum points of the curve; b the dose that provides 50 % of the variable's response (C_{50}); and c the slope of the curve.

For the bioassay II, the averages of the qualitative factors (herbicides and application times) were compared using the Tukey test ($p < 0.05$). For the quantitative factor (evaluation times), the data were subjected to regression analysis, with linear models fitted ($p < 0.01$). The statistical analyses were carried out using the R software version 4.2.0 (R Core Team 2026).

RESULTS AND DISCUSSION

An adjustment of the data to the three-parameter logistic model was observed for the percentage control variable as a function of the doses applied. The dose of 185 g ha^{-1} of bicyclopyrone provided a control of 100 % for the ginger grass in the greenhouse, with no effectiveness gains from increasing the doses up to 740 g ha^{-1} (Figure 1).

The summary of the analysis of variance (Anova) for the ginger grass coverage index at 15, 30, and 45 DAA is shown in Table 1. At 15 DAA, a significant interaction ($p < 0.01$) was observed between herbicide management and application time. By 30 DAA, the coverage index was affected independently by the sources of variation. At the end of the evaluation period (45 DAA), the herbicide management and application time did not significantly influence the coverage index ($p > 0.05$).

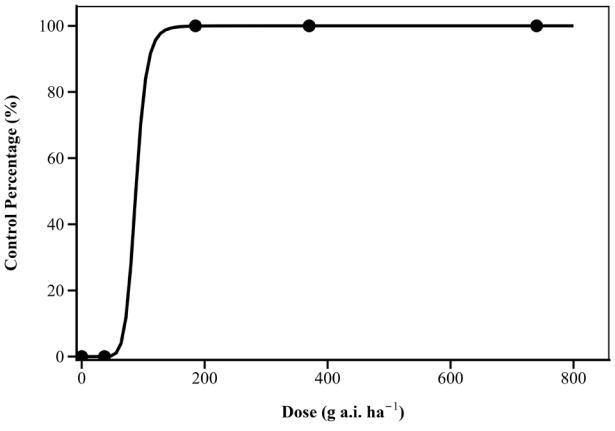

Figure 1. Control percentage of *Paspalum maritimum* at 45 days after application based on bicyclopyrone doses.

Table 1. Summary of the analysis of variance and coefficients of variation for the Green Cover Index (GCI) of ginger grass at 15, 30, and 45 days after application (DAA) under pre- and post-emergence herbicide management.

Source of variation	DF	Medium square		
		GCI 15 DAA	GCI 30 DAA	GCI 45 DAA
Block	4	20.83^{ns}	70.33^{ns}	84.00^{ns}
Treatment (I)	2	3,632.75**	2,612.24**	199.71^{ns}
Application (II)	1	2,751.95**	801.66**	558.66^{ns}
I x II	2	402.78**	113.00^{ns}	186.68^{ns}
Residue	20	14.99	77.80	153.97
Total	29			
Coefficient of variation (%)		12.83	19.49	21.19

DF: degrees of freedom. * Significant at 5 % of probability ($0.01 \leq p < 0.05$); ** significant at 1 %; ^{ns} not significant ($p \geq 0.05$).

It was observed that the placement of pre-emergence treatments resulted in lower infestation rates, when compared with post-emergence applications, regardless of the herbicide used at 15 DAA (Figure 2).

When analyzing the effect of the treatments within the time of post-emergence application, it was found that the control had the highest coverage rate (64.3 %). Applying bicyclopyrone alone significantly reduced this rate to 41.4 %, whereas the bicyclopyrone + hexazinone mixture showed the highest control effectiveness, resulting in only 13.6 % of coverage. A similar pattern was observed with the pre-emergence application, where bicyclopyrone + hexazinone had the lowest coverage value (7.1 %), statistically different from the other treatments.

Bicyclopyrone is an HPPD enzyme inhibitor, whereas hexazinone inhibits Photosystem II (PSII) (Woodyard et al. 2009, Lindley et al. 2020). Combining HPPD inhibitors with PSII inhibitors creates a synergistic effect (Matringe et al. 2005, Abendroth et al. 2006). HPPD inhibition lowers carotenoid levels, which are responsible for chlorophyll photoprotection (Matringe et al. 2005, Jhala et al. 2023). Without this protection, disrupting electron transport in PSII with hexazinone causes a massive buildup of reactive oxygen species, leading to cell death much faster and more efficiently than if they were used alone (Abendroth et al. 2006, Woodyard et al. 2009).

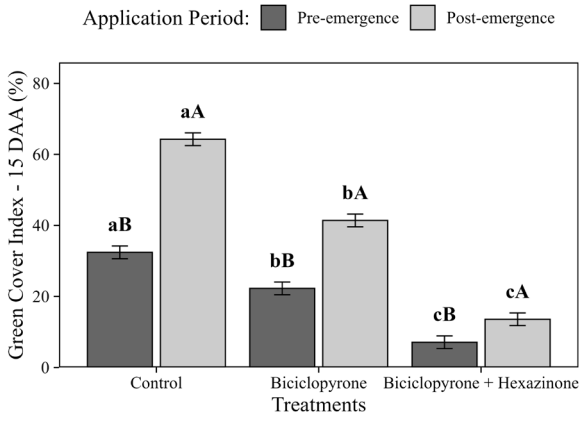

Figure 2. Green Cover Index of ginger grass (*Paspalum maritimum* Trind.) at 15 days after application (DAA) under pre- and post-emergence herbicide management. Means followed by the same lowercase letter among the herbicides and uppercase letter among the application times do not differ from each other according to the Tukey test at 5 % of probability ($p < 0.05$). Error bars represent the standard error of the mean.

When breaking down the interaction by the application time, it was found that all treatments showed a significant reduction in coverage index when applied in pre-emergence. For the treatment with bicyclopyrone alone, the pre-emergence application reduced infestation by 19.1 %, when compared to post-emergence. As for the bicyclopyrone + hexazinone mixture, the coverage index in pre-emergence (7.1 %) was lower than in post-emergence (13.6 %), results that show that the pre-emergence application boosts the herbicides' performance in controlling this species.

The higher efficiency of the pre-emergence treatments can be explained by the action of herbicides during the early stages of ginger grass development, before the formation of perennial structures like rhizomes. Grasses with rhizomes have a high capacity for regrowth once they become perennial, which significantly reduces the effectiveness of post-emergence applications (Gemelli et al. 2012). In addition, herbicides applied at pre-emergence act on the seed bank, creating a chemical barrier in the soil that reduces the emergence of new seedlings (Paven et al. 2025).

At 30 DAA, all treatments reduced the coverage index of ginger grass, when compared with the control. The use of the bicyclopyrone + hexazinone mixture showed the highest level of control, resulting in the lowest coverage index (30.35 %), statistically different from the application of bicyclopyrone alone, which had 42.96 % of coverage (Figure 3).

Regarding the application time, pre-emergence remained more effective than post-emergence in controlling the species. The average coverage rate for pre-emergence applications was 40.08 %, significantly lower than the 50.42 % observed when herbicides were applied at post-emergence. These results confirm the trend seen in the initial evaluations, reinforcing that the biological efficiency of the active ingredients is enhanced when applied before the weed emergence. This occurs because pre-emergence herbicides form an active layer in the soil, reducing the weeds' emergence and competitiveness in the early stages of the crop cycle, thereby extending the period free from weed interference (Silva et al. 2023, Bento et al. 2025).

At 45 DAA, the ginger grass coverage rates ranged from 44.45 to 64.95 %, with no significant differences between the sources of variation

(Figure 4). Although the bicyclopyrone + hexazinone treatment applied at pre-emergence showed the lowest absolute coverage value (44.45 %), it did not differ statistically from the control or the other treatments, indicating that, at 45 DAA, the reinfestation pressure evened out the experimental plots under the conditions of the study.

Despite its ability to provide initial weed control and help with residual soil management, the actual effectiveness of an herbicide like bicyclopyrone can decrease over time due to continuous reinfestation from the soil seed bank and the emergence of new seedlings, especially for highly persistent species (Chen et al. 2018).

Due to its high-water solubility and low retention in the mineral soil particles, hexazinone has a high mobility and leaching potential in the soil profile, moving to deeper layers after application (Chitolina et al. 2024). Studies with soil columns have shown that, when compared to less mobile herbicides such as diuron, hexazinone moves significantly more through the profile, which reduces its availability in the germination surface layer over time and may favor grass reinfestation (Reis et al. 2017).

When evaluating the effect of treatments and evaluation times on the ground cover index of ginger grass in pre- and post-emergence, a significant interaction ($p < 0.05$) between the sources of variation was observed according to the analysis of variance (Anova). For both application times, isolated effects of the sources of variation were also observed (Table 2).

In pre-emergence, the bicyclopyrone + hexazinone mixture showed the highest control effectiveness at 15 DAA (7.1 % of coverage), outperforming bicyclopyrone alone (22.3 %) and the control (32.4 %) (Figure 5). All pre-emergence treatments fit the linear regression model ($p < 0.01$), with bicyclopyrone alone standing out with the highest coefficient of determination ($R^2 = 0.77$). The bicyclopyrone + hexazinone mixture had the lowest daily coverage increase rate (1.24 %), showing a superior residual effect in delaying the emergence of *P. maritimum*.

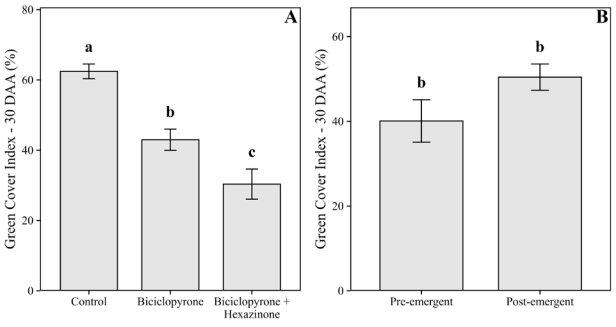

Figure 3. Green Cover Index of ginger grass (*Paspalum maritimum* Trind.) at 30 days after application (DAA) as affected by herbicide management (A) and application time (B). Means followed by the same lowercase letter on the bar do not differ from each other by the Tukey test at 5 % of probability ($p < 0.05$). The error bars represent the standard error of the mean.

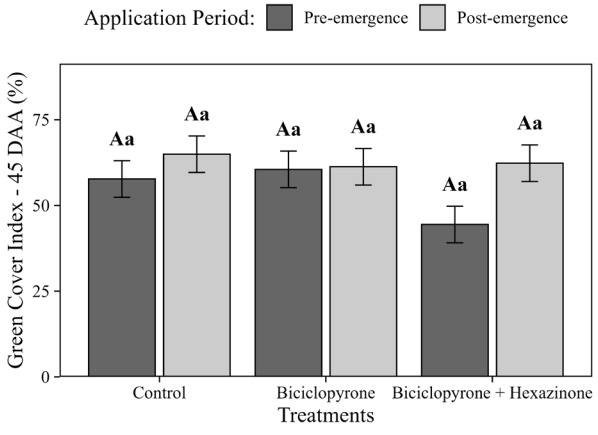

Figure 4. Green Cover Index of ginger grass (*Paspalum maritimum* Trind.) at 45 days after application (DAA) under pre- and post-emergence herbicide management. Means followed by the same lowercase letter among the herbicides and uppercase letter among the application times do not differ from each other according to the Tukey test at 5 % of probability ($p < 0.05$). Error bars represent the standard error of the mean.

Table 2. Summary of the analysis of variance and coefficients of variation for the Green Cover Index (GCI) of ginger grass as affected by herbicide management and evaluation times.

Source of variation	DF	Medium square	
		GCI Pre	GCI Post
Block	4	244.42^{ns}	67.08^{ns}
Treatment (I)	2	2,535.07**	2,585.18**
Evaluation time (II)	2	4,278.09**	2,006.82**
I x II	4	274.09*	739.36**
Residue	32	107.77	29.41
Total	44		
Coefficient of variation (%)		27.10	10.63

DF: degrees of freedom. * Significant at 5 % of probability ($0.01 \leq p < 0.05$); ** significant at 1 %; ^{ns} not significant ($p \geq 0.05$).

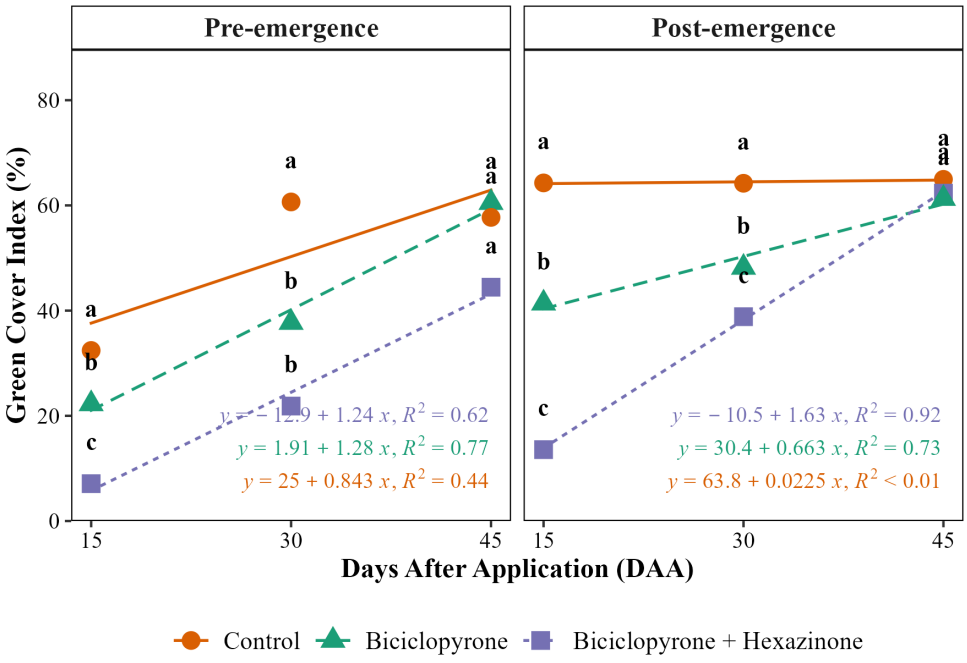

Figure 5. Green Cover Index of ginger grass (*Paspalum maritimum* Trind.) depending on herbicide management and evaluation time. Averages followed by the same lowercase letter within each evaluation time do not differ from each other according to the Tukey test at 5 % of probability ($p < 0.05$).

In post-emergence, the coverage rates were higher than in pre-emergence. At 15 DAA, the bicyclopyrone + hexazinone mixture (13.6 %) was statistically higher than bicyclopyrone alone (41.4 %) and the control (64.3 %). Unlike the other combinations, the control in post-emergence did not fit the linear model ($R^2 < 0.01$), and the coverage rate remained stable from the start of the evaluations. The herbicide treatments in post-emergence had the best statistical fits, with R^2 of 0.73 for bicyclopyrone and 0.92 for the bicyclopyrone + hexazinone mixture. However, considering bicyclopyrone + hexazinone, the rate of coverage recovery for the mixture in post-emergence (1.63 % per day) was higher than in pre-emergence (1.24 % per day), indicating a faster regrowth after the initial desiccation of the shoot.

This pattern of linear growth reflects the gradual loss of control provided by the herbicide due to the emergence of new seedlings and the limitation of the product's residual effect. Perennial species with rhizome systems, such as ginger grass and other perennial grasses, are notoriously difficult to control because the rhizomes remain in the soil and continuously produce regrowth after the initial desiccation of the above-ground parts (Gemelli et al. 2012, Lauenroth & Gokhale 2023). This limits the long-term effectiveness of single herbicide applications and favors a continuous increase in weed coverage over time, even after initially controlling the emerged individuals (Lauenroth & Gokhale 2023).

CONCLUSIONS

1. The 185 g ha^{-1} dose of bicyclopyrone controlled 100 % of the ginger grass in the greenhouse;
2. The biciclopirone + hexazinone mixture is more effective than using biciclopirone alone in controlling *Paspalum maritimum*;
3. Pre-emergence application is the most efficient technical strategy because it results in lower initial infestation rates and reduces the daily rate of increase in green coverage;
4. The period of effective control of the treatments is limited to about 30 days, with the residual effect ending and coverage being restored by 45 days after application, regardless of the application method.

REFERENCES

ABENDROTH, J. A.; MARTIN, A. R.; ROETH, F. W. Plant response to combinations of mesotrione and

photosystem II inhibitors. *Weed Technology*, v. 20, n. 1, p. 267-274, 2006.

BENTO, T. C.; SORNA, G. M.; MOURA, J. G. M. de; CANUTO, R. S. O. Herbicidas pré e pós-emergentes para o manejo de plantas daninhas na cultura do milho. *Foco*, v. 18, n. 9, e9671, 2025.

CHEN, L. J.; YING, R.-N.; WANG, X. Q.; XIE, D. T.; DONG, J.; LIN, H.-Y.; WANG, D.-W.; YANG, G. F. Discovery of triketone-indazolones as novel 4-hydroxyphenylpyruvate dioxygenase inhibiting-based herbicides. *Journal of Agricultural and Food Chemistry*, v. 73, n. 2, p. 1112-1121, 2024.

CHEN, Y.; HU, C.; DOOHAN, D. Safety of bicyclopyrone on several vegetable crops and efficacy of weed control. *Weed Technology*, v. 32, n. 4, p. 498-505, 2018.

CHITOLINA, G. D. M.; MENDES, K. F.; ALMEIDA, C. S.; ALONSO, F. G.; JUNQUEIRA, L. V.; TORNISIELO, V. L. Influence of soil depth on sorption and desorption processes of hexazinone. *Planta Daninha*, v. 38, e020217734, 2020.

FLUTTERT, J. C.; SOLTANI, N.; GALLA, M.; HOOKER, D. C.; ROBINSON, D. E.; SIKKEMA, P. H. Additive and synergistic interactions of 4-hydroxyphenylpyruvate dioxygenase (HPPD) and photosystem II (PSII) inhibitors for the control of glyphosate-resistant horseweed (*Conyza canadensis*) in corn. *Weed Science*, v. 70, n. 3, p. 319-327, 2022.

GEMELLI, A.; OLIVEIRA JÚNIOR, R. S. de; CONSTANTIN, J.; BRAZ, G. B. P.; JUMES, T. M. de C.; OLIVEIRA NETO, A. M. de; DAN, H. de A.; BIFFE, D. F. Biology aspects of *Digitaria insularis* resistant to glyphosate and implications for its control. *Revista Brasileira de Herbicidas*, v. 11, n. 2, p. 231-240, 2012.

JHALA, A. J.; KUMAR, V.; YADAV, R.; JHA, P.; JUGULAM, M.; WILLIAMS II, M. M.; HAUSMAN, N. E.; DAYAN, F. E.; BURTON, P. M.; DALE, R. P.; NORSWORTHY, J. K. 4-hydroxyphenylpyruvate dioxygenase (HPPD)-inhibiting herbicides: past, present, and future. *Weed Technology*, v. 37, n. 1, p. 1-14, 2023.

LAUENROTH, D.; GOKHALE, C. S. Theoretical assessment of persistence and adaptation in weeds with complex life cycles. *Nature Plants*, v. 9, n. 8, p. 1267-1279, 2023.

LINDLEY, J. J.; JENNINGS, K. M.; MONKS, D. W.; CHAUDHARI, S.; SCHULTHEIS, J. R.; WALDSCHMIDT, M.; BROWNIE, C. Effect of bicyclopyrone herbicide on sweetpotato and Palmer amaranth (*Amaranthus palmeri*). *Weed Technology*, v. 34, n. 4, p. 552-559, 2020.

MATRINGE, M.; SAILLAND, A.; PELISSIER, B.; ROLLAND, A.; ZINK, O. p-hydroxyphenylpyruvate dioxygenase inhibitor-resistant plants. *Pest Management Science*, v. 61, n. 3, p. 269-276, 2005.

MELLO, J. P.; SOUZA, R. C.; TIRONI, S. P. Controle químico em pós-emergência de capim-gengibre (*Paspalum maritimum* Trin.). *Ciência Agrícola*, v. 14, n. 1, p. 67-71, 2016.

NAN, J.; DONG, J.; CAO, J.-Q.; HUANG, G.-Y.; SHI, X.-X.; WEI, X.-F.; CHEN, Q.; LIN, H.-Y.; YANG, G. F. Structure-based design of 4-hydroxyphenylpyruvate dioxygenase inhibitor as a potential herbicide for cotton fields. *Journal of Agricultural and Food Chemistry*, v. 71, n. 14, p. 5783-5795, 2023.

OLIVEIRA, R. C. D.; SANTANA, S. H. D.; SILVA, A. S. D.; MACIEL, J. R.; VALLS, J. F. M. *Paspalum* (Poaceae) no Rio Grande do Norte, Brasil. *Rodriguésia*, v. 64, n. 4, p. 847-862, 2013.

PARVEN, A.; MEFTAUL, I. M.; VENKATESWARLU, K.; MEGHARAJ, M. Herbicides in modern sustainable agriculture: environmental fate, ecological implications, and human health concerns. *International Journal of Environmental Science and Technology*, v. 22, n. 2, p. 1181-1202, 2025.

R CORE TEAM. *R*: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2026.

REIS, F. C.; TORNISIELO, V. L.; PIMPINATO, R. F.; MARTINS, B. A.; VICTÓRIA FILHO, R. Leaching of diuron, hexazinone, and sulfometuronmethyl applied alone and in mixture in soils with contrasting textures. *Journal of Agricultural and Food Chemistry*, v. 65, n. 13, p. 2645-2650, 2017.

SILVA, T. S.; ARNESON, N. J.; DEWERFF, R. P.; SMITH, D. H.; SILVA, D. V.; WERLE, R. Preemergence herbicide premixes reduce the risk of soil residual weed control failure in corn. *Weed Technology*, v. 37, n. 4, p. 410-421, 2023.

SOUZA FILHO, A. P. S. Interferência potencialmente alelopática do capim-gengibre (*Paspalum maritimum*) em áreas de pastagens cultivadas. *Planta Daninha*, v. 24, n. 3, p. 451-456, 2006.

STREIBIG, J. C. Herbicide bioassay. *Weed Research*, v. 28, n. 6, p. 479-484, 1988.

TENÓRIO FILHO, L. C. J.; BULHÕES, L. E. L.; LIMA, L. A. R.; SILVA JÚNIOR, A. B.; CUNHA, J. L. X. L.; SOUZA, R. C. Eficiência do glifosato em associação com herbicidas inibidores da Protox no controle de *Paspalum maritimum* Trind. *Revista Científica da Faculdade de Educação e Meio Ambiente*, v. 14, n. 1, p. 295-306, 2023.

WOODYARD, A. J.; HUGIE, J. A.; RIECHERS, D. E. Interactions of mesotrione and atrazine in two weed species with different mechanisms for atrazine resistance. *Weed Science*, v. 57, n. 4, p. 369-378, 2009.