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Scientific Article

Response of sunflower genotypes to postemergence herbicides: phytosociology, selectivity, agronomic performance, and oil quality

Resposta de genótipos de girassol a herbicidas pós-emergentes: fitossociologia, seletividade, desempenho e qualidade do óleo

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ABSTRACT - Weed interference is a major constraint on sunflower productivity. This study aimed to identify and quantify the main weed species associated with different sunflower genotypes and to evaluate the effects of postemergence herbicide application on herbicide selectivity, agronomic traits, and oil composition under the edaphoclimatic conditions of Nova Andradina, MS, Brazil. The experiment was conducted in a randomized block design with a split-plot arrangement and four replications. The main plots consisted of three sunflower genotypes (Altis 99, Hélio 250, and BRS 323), while the subplots consisted of applications of fomesafen, clethodim, and chlorimuron-ethyl at 22 days after emergence (DAE), along with two controls (weeded and non-weeded). A phytosociological survey was conducted 20 days after crop emergence. Evaluations included visual phytotoxicity, plant height, head insertion height, head diameter, 1,000-achene weight, yield, and oil quality. The phytosociological survey revealed a predominance of species from the Poaceae family. *Cenchrus echinatus* had the highest relative importance values across the sunflower genotypes. Clethodim showed high selectivity and did not compromise agronomic traits. Fomesafen and chlorimuron-ethyl reduced plant performance, particularly in the BRS 323 genotype. Oil quality was not affected by the herbicide treatments. In conclusion, Poaceae species, particularly *C. echinatus*, predominated in the weed community. Clethodim proved selective and effective, whereas fomesafen and chlorimuron-ethyl reduced crop performance without affecting oil quality.

Keywords: *Helianthus annuus.* Weed community. Phytotoxicity. Chemical control. Crop yield.

RESUMO - A interferência de plantas daninhas é um dos principais entraves à produtividade do girassol. O objetivo deste estudo foi dentificar e quantificar as principais espécies de plantas daninhas associadas ao cultivo de diferentes genótipos de girassol, bem como avaliar os efeitos da aplicação de herbicidas em pós-emergência sobre a seletividade aos genótipos, os caracteres agronômicos da cultura e a composição do óleo, nas condições edafoclimáticas de Nova Andradina, MS. O experimento foi conduzido no esquema de parcelas subdivididas, distribuídas no delineamento de blocos casualizados, com quatro repetições. As parcelas foram constituídas por três genótipos de girassol (Altis 99, Hélio 250 e BRS 323) e as subparcelas pela aplicação dos herbicidas: fomesafen, clethodim e chlorimuron-ethyl, aos 22 DAE e mais duas testemunhas (com e sem capina). O levantamento fitossociológico foi realizado aos 20 dias após a emergência da cultura. Avaliou-se a intoxicação visual das plantas, altura de planta, altura de inserção do capítulo, diâmetro do capítulo, peso de 1.000 aquênios, a produtividade e a qualidade do óleo. O levantamento fitossociológico revelou predominância de espécies da família Poaceae. A espécie *Cenchrus echinatus* destacou-se com maiores valores de importância relativa nos genótipos. O clethodim apresentou alta seletividade, sem comprometer parâmetros agronômicos. O fomesafen e o chlorimuron-ethyl reduziram o desempenho das plantas, especialmente no genótipo BRS 323. A qualidade do óleo não foi impactada. Conclui-se que há predominância de Poaceae, com destaque para *C. echinatus*, sendo o clethodim seletivo e eficiente, enquanto fomesafen e chlorimuron-ethyl reduziram o desempenho sem afetar a qualidade do óleo.

Palavras-chave: *Helianthus annuus.* Comunidade infestante. Fitotoxicidade. Controle químico. Rendimento da cultura.

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INTRODUCTION

In recent decades, the expansion of global sunflower (*Helianthus annuus* L.) production has been driven primarily by the crop's adaptability to a wide range of soil and climatic conditions, combined with advances in genetic breeding that have resulted in cultivars and hybrids with high oil yields (MILADINOVIĆ et al., 2019; SANTOS et al., 2023a). Furthermore, because of its drought tolerance, sunflower is frequently cultivated in arid regions and under rainfed conditions, making it a promising oilseed crop, particularly in light of the challenges posed by global climate change (MILADINOVIĆ et al., 2019).

Against this backdrop of expanding production, sunflower stands out for its economic and nutritional importance, meeting a substantial portion of the global demand for vegetable oil, with annual production exceeding 58 million tonnes (ŠTEFANIĆ et al., 2023). Sunflower oil is widely recognized for its suitability for human consumption and is characterized by its light color, distinctive flavor, and high nutritional value (DULAIMY; ABDULKAFOOR; SARHEED, 2025). Additionally, it can be used for biodiesel production, further enhancing its strategic importance (SILVA et al., 2019). In Brazil, according to Conab (2025), the cultivated area in the 2024/25 season totaled 67.4 thousand hectares, with an average yield of 1,463 kg ha^{-1}, and the Central-West region stood out as a major production area.

Despite this favorable scenario, sunflower cultivation faces significant agronomic challenges, particularly regarding weed management. Weed interference is most critical during the early stages of crop development, when sunflower has lower competitive ability, thereby intensifying competition for light, water, nutrients, and space (HASSAN et al., 2025). In the absence of adequate weed control, yield losses can reach up to 58% (ŠTEFANIĆ et al., 2021).

Given this challenge, the adoption of efficient management strategies is crucial for minimizing the negative impacts of the weed community on crop productivity and quality (SANTOS et al., 2023b). However, in Brazil, sunflower cultivation still faces limitations regarding the availability of registered herbicides, particularly for the control of eudicotyledonous weeds. The crop's limited tolerance to postemergence herbicides restricts the available options; currently, only trifluralin, sethoxydim, and alachlor are registered in Brazil for chemical weed management in sunflower (BRASIL, 2025).

Nevertheless, beyond these regulatory limitations, a significant scientific gap remains: few studies have integrated the phytosociological characterization of weed communities associated with different sunflower genotypes with an evaluation of the effects of postemergence herbicides, not only on weed control but also on crop agronomic traits and oil composition. Thus, this study is innovative in integrating phytosociological analysis, agronomic performance, and oil quality across different sunflower genotypes and postemergence management strategies, providing a more comprehensive assessment of the effects of chemical weed control on sunflower.

In light of the above, this study aimed to identify and quantify the main weed species associated with different sunflower genotypes and to evaluate the effects of postemergence herbicide application on herbicide selectivity to the genotypes, crop agronomic traits, and oil composition under the edaphoclimatic conditions of Nova Andradina, MS, Brazil.

MATERIALS AND METHODS

Experimental site

The study was conducted at the Federal Institute of Mato Grosso do Sul (IFMS), Nova Andradina campus, MS, Brazil (Figure 1), on a dystroferric Red Latosol. Figure 2 shows the daily rainfall and temperature data recorded during the sunflower cultivation period.

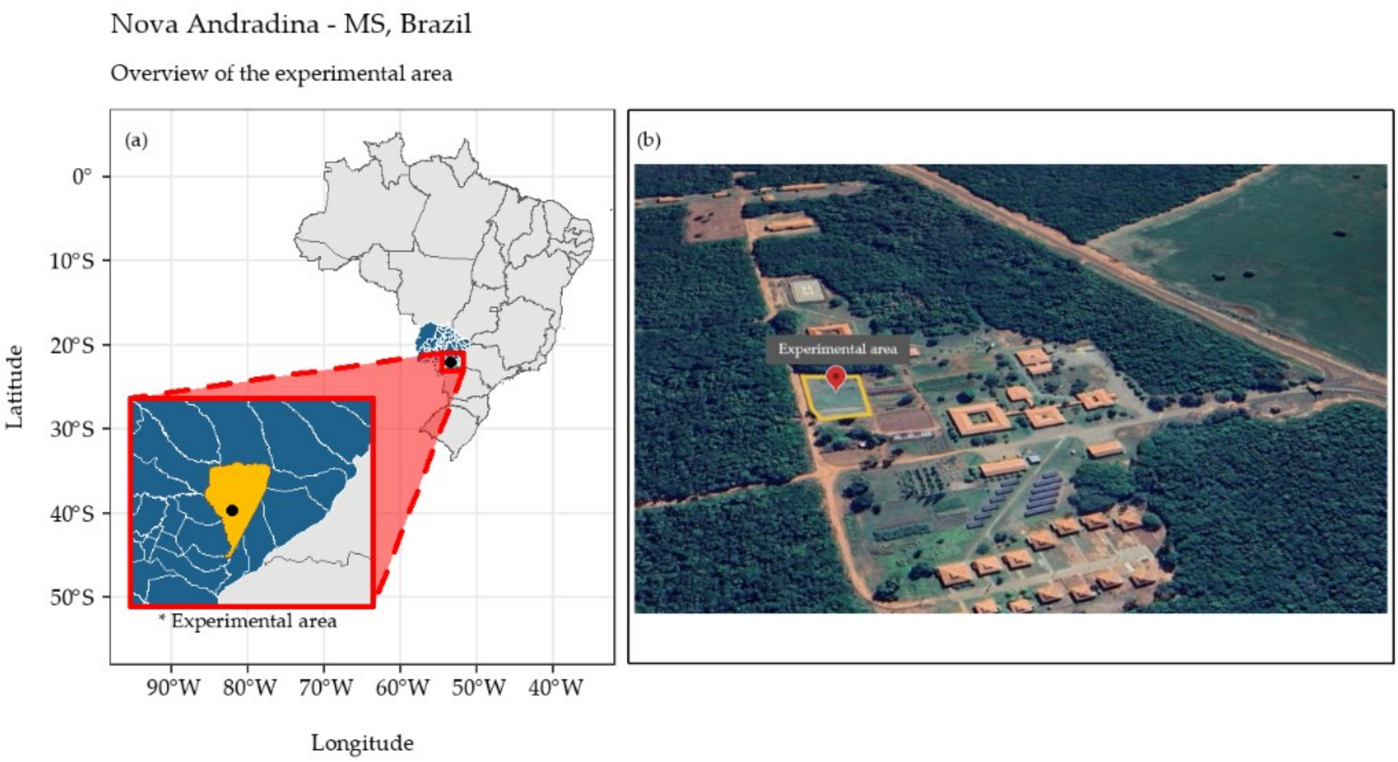

Figure 1. The experimental field is located at the Federal Institute of Mato Grosso do Sul (IFMS) in Nova Andradina, State of Mato Grosso do Sul, Brazil. The map was created using the *geobr* package and plotted in R. Image source: Google Earth.

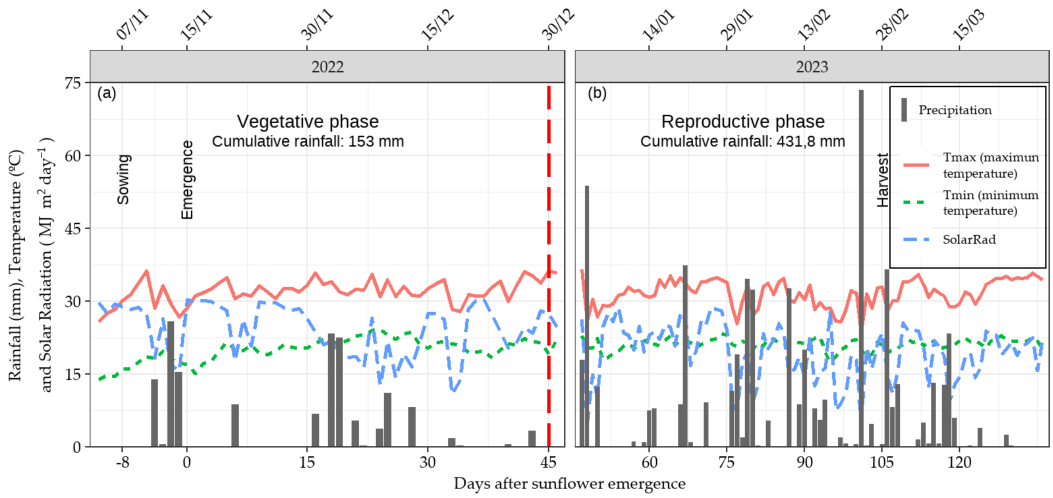

Figure 2. Meteorological data were obtained from the weather station at the Federal Institute of Mato Grosso do Sul (IFMS) in Nova Andradina, Mato Grosso do Sul State, Brazil. Dynamics of the climatic variables, including maximum and minimum air temperature, global radiation (lines), and rainfall, during 2022 (a) and 2023 (b). The vertical red dotted line indicates the transition from the vegetative to the reproductive phase.

Soil sampling and analyses

Soil samples were collected from the 0–20 cm layer to assess soil fertility and determine lime and fertilizer requirements. Chemical analysis of the 0–20 cm soil layer showed a pH (water) of 5.23; 31.73 mg dm^{-3} P; 0.07 cmolc dm^{-3} K; 1.9 cmolc dm^{-3} Ca^{2+}; 1.1 cmolc dm^{-3} Mg^{2+}; 0.0 cmolc dm^{-3} Al^{3+}; 2.1 cmolc dm^{-3} H + Al; a sum of bases of 3.07 cmolc dm^{-3}; base saturation of 43.70%; and 17.22 g dm^{-3} organic matter.

Sowing and crop management practices for sunflower genotypes

The experiment was conducted during a single growing season, with sowing performed on November 7, 2022. Seeds of three sunflower genotypes (Altis 99, Hélio 250, and BRS 323), obtained from Embrapa Soja in Londrina, Paraná, Brazil, were used. The crop was established under a no-till system, with black oat (*Avena strigosa*) used as the cover crop. The cover crop was desiccated with glyphosate applied at 3 L ha^{-1}. Each plot consisted of four 6-m-long rows spaced 0.45 m apart. The two central rows comprised the net plot area, excluding 1.0 m from each end.

At sowing, in-furrow fertilization consisted of 250 kg ha^{-1} of an 08-28-16 N-P_2O_5-K_2O formulation, supplemented with 20 kg ha^{-1} of monoammonium phosphate (10-52-00). Topdressing fertilization was performed 30 days after emergence by applying 40 kg ha^{-1} of N and K_2O to the soil using a 20-00-20 formulation.

After sowing, the necessary crop management practices were performed. Thinning was carried out 15 days after sowing, retaining the most vigorous plant at each planting point. During the experiment, periodic pest sampling was conducted to assess the potential for economic damage to the crop. When plants reached the R6 phenological stage (beginning of achene filling), the flower heads were bagged.

Phytosociological survey

The phytosociological survey was conducted 20 days after emergence (DAE), based on the critical period for weed control (CPWC) in sunflower. This timing was also selected to characterize the weed community before herbicide application. Weeds were identified and quantified using the quadrat method, with a 1.0 × 1.0 m quadrat. Four quadrat samples were collected for each sunflower genotype.

At each sampling point, the aboveground portions of the weeds were cut at ground level, collected, sorted by species into paper bags, and transported to the laboratory for species identification and quantification of individuals. Subsequently, the following phytosociological parameters were determined:

Frequency (F) = (number of quadrats containing the species × 100) / total number of quadrats;

Density (D) = total number of individuals of the species / number of quadrats;

Abundance (A) = total number of individuals of the species / number of quadrats containing the species;

Relative frequency (Fr) = (frequency of the species × 100) / total frequency of all species;

Relative density (Dr) = (density of the species × 100) / total density of all species;

Relative abundance (Ar) = (abundance of the species × 100) / total abundance of all species;

Importance value index (IVI) = relative frequency + relative density + relative abundance.

Weed species were identified based on morphological characteristics of the collected plants, with the aid of specialized literature and taxonomic keys. Comparisons with herbarium specimens were made when necessary.

Application of postemergence herbicides

The experiment was conducted in a randomized block design with a split-plot arrangement and four replications. The main plots consisted of three sunflower genotypes (Altis 99, Hélio 250, and BRS 323), while the subplots consisted of applications of fomesafen (250 g ha^{-1}), clethodim (96 g ha^{-1}), and chlorimuron-ethyl (20 g ha^{-1}) at 22 days after emergence (DAE), along with two controls (weeded and non-weeded) (Table 1). Herbicide rates and application timing were established based on product label recommendations and the study by Reis et al. (2014). At the time of herbicide application (22 DAE), air temperature was approximately 24–26°C, wind speed ranged from 0.6 to 1.1 m s^{-1}, and relative humidity was approximately 70%.

Table 1. Herbicides used, their common names, commercial products, and active ingredient (a.i.) rates applied per hectare.

Mechanism of Action*	Common name	Commercial Product	Rate (g a.i. ha^{-1})
PPO inhibitors	Fomesafen	Flex®	250
ACCase inhibitors	Clethodim	Select 240 EC®	96
ALS inhibitors	Chlorimuron-ethyl	Classic®	20

*PPO – protoporphyrinogen oxidase; ALS – acetolactate synthase; ACCase – acetyl-CoA carboxylase.

Herbicides were applied using a CO_2-pressurized backpack sprayer operated at a constant pressure of 3.0 kgf cm^{-2} and equipped with a boom containing two TT 110.02 nozzles spaced 50 cm apart. The application height was approximately 40 cm above the target, and the spray volume was 150 L ha^{-1}. Weed control in the weeded control plots was performed manually. Fomesafen and chlorimuron-ethyl were used exclusively for experimental purposes to evaluate their selectivity to sunflower and are not recommended for commercial use in this crop in Brazil.

Data on herbicide efficacy against weeds were not reported because the efficacy of the evaluated herbicides is well documented in the literature. Instead, this study focused on phytosociological characterization, herbicide selectivity, and the effects of the treatments on agronomic traits and sunflower oil quality.

Visual assessment of sunflower injury

Visual injury to sunflower plants was assessed at 5, 10, 15, 20, 25, and 30 days after herbicide application using a rating scale ranging from 0% (no visible injury) to 100% (plant death), according to the SBCPD (1995) methodology and based on the symptoms caused by the herbicides.

Morphological and agronomic characteristics of sunflower

At 32 days after treatment application, the following variables were evaluated: plant height (PH), measured from soil level to the apex of the head using a graduated ruler; head insertion height (HIH), measured from soil level to the point of attachment of the head to the stem; and head diameter (HD), measured with a measuring tape at the R5.5 stage (50% flowering).

At physiological maturity (R9), 1,000-achene weight (TAW), obtained by weighing and expressed in grams, and achene yield, extrapolated to kg ha^{-1} and adjusted to 13% moisture, were determined.

Sunflower oil extraction and fatty acid analysis

Sunflower oil was extracted using a Soxhlet apparatus with hexane as the extraction solvent. For each extraction, 100 g of finely ground sunflower seeds and 300 mL of hexane were used, with the heating temperature maintained at 60 °C. Extraction was performed for 6 h, and the resulting product was designated OG6 (sunflower oil obtained after 6 h of extraction). After extraction, the apparatus was allowed to cool to room temperature, and the solvent was subsequently evaporated using a rotary evaporator. The extraction was performed in triplicate (AOCS, 2017).

The following parameters were determined in the sunflower oil obtained from each treatment: oil yield (%), water content (%), acidity (mg KOH g^{-1}), specific gravity (g cm^{-3}), iodine value (g I_2 100 g^{-1}), and chemical composition. All analyses were performed according to protocols established by the American Oil Chemists' Society (AOCS, 2017).

Statistical analysis

Descriptive statistics were used to analyze the phytosociological survey data for the three sunflower genotypes. Importance value index data were presented as bar charts.

Phytotoxicity, yield-related traits, and oil quality data were subjected to analysis of variance. Initially, the Shapiro–Wilk test was used to assess the normality of residuals, and Levene's test was used to assess homogeneity of variances. Data that did not meet the assumption of normality were transformed using $\sqrt{(x + 1)}$. Means were compared using Tukey's test at the 5% probability level. Data on the chemical composition of oils from the three genotypes were analyzed using descriptive statistics (means), without presentation in tables or graphs, in accordance with the specific objectives of the study. SAS software was used for the analysis of variance, whereas SigmaPlot software was used to derive regression equations and generate the graphs.

RESULTS AND DISCUSSION

Phytosociological survey

At 20 days after emergence (DAE), seven weed species belonging to four botanical families were identified, with a predominance of monocotyledons (85.71%) over eudicotyledons (14.28%) (Table 2). Poaceae had the highest number of species across the three sunflower genotypes, accounting for 57.0% of the total and indicating greater adaptation to the experimental conditions. This result may be attributed both to the edaphoclimatic conditions of Mato Grosso do Sul, characterized by high temperatures and high light intensity, which favor species with C4 metabolism, and to the land-use history of the experimental area, which directly influences the composition of the soil seed bank.

Table 2. Phytosociological survey of weeds in three sunflower genotypes.

Genotype	Family	Species	Common name
Altis 99	Poaceae	*Cenchrus echinatus* L.	Southern sandbur
		Cynodon dactylon (L.) Pers.	Bermudagrass
		Eleusine indica (L.) Gaertn.	Goosegrass
	Commelinaceae	*Commelina benghalensis* L.	Benghal dayflower
	Malvaceae	*Sida glaziovii* K. Schum.	White sida
BRS 323	Poaceae	*Cenchrus echinatus* L.	Southern sandbur
		Cynodon dactylon (L.) Pers.	Bermudagrass
		Eleusine indica (L.) Gaertn.	Goosegrass
	Cyperaceae	*Cyperus rotundus* L.	Purple nutsedge
	Malvaceae	*Sida glaziovii* K. Schum.	White sida
Hélio 250	Poaceae	*Cenchrus echinatus* L.	Southern sandbur
		Cynodon dactylon (L.) Pers.	Bermudagrass
		Eleusine indica (L.) Gaertn.	Goosegrass
		Panicum maximum Jacq.	Mombasa grass
	Malvaceae	*Sida glaziovii* K. Schum.	White sida

Weed community composition is strongly associated with land-use history and the soil seed bank (LACERDA et al., 2020), which may help explain the predominance of Poaceae observed in this study and is consistent with the results reported by Marasca et al. (2021) for sunflower cultivation. Furthermore, because sunflower exhibits C3 photosynthetic metabolism, its lower photosynthetic efficiency under high-temperature conditions may favor competition from C4 species (SANTOS et al., 2017), further supporting the results obtained in this study.

Among the evaluated genotypes, differences in weed number and abundance were observed at 20 DAE (Table 3), with lower values recorded in the area cultivated with BRS 323 (23.75 plants m^{-2}) than in those cultivated with Hélio 250 (40.75 plants m^{-2}) and Altis 99 (51.00 plants m^{-2}). It should be noted that the phytosociological assessment was conducted at an early stage of crop development, which may have limited the expression of more pronounced differences among the genotypes.

The observed weed density may be related to factors such as land-use history, the soil seed bank, and environmental conditions during weed emergence (DATTA et al., 2017). Furthermore, early growth characteristics of the sunflower genotypes, such as emergence rate and leaf expansion, may influence the initial dynamics of the weed community. In this context, Santos et al. (2024), evaluating sunflower genotypes grown as a second crop in Nova Andradina, MS, reported that BRS 323 has an early maturity cycle. Under favorable conditions, rapid leaf expansion promotes earlier canopy closure, increasing shading during the initial stages of crop development and reducing light availability to weeds.

It is worth noting that light interception efficiency depends not only on plant height but also on structural and physiological characteristics of the canopy. These characteristics can intensify interspecific competition for light and restrict weed emergence and growth (SAVIĆ et al., 2025). Weed population density is a key factor determining the degree of interference with crops and is influenced by climate, crop cycle, genetic traits, and management practices (DATTA et al., 2017).

To characterize the weed community, relative density (RD), relative frequency (RF), and relative abundance (RA) were determined at 20 days after emergence (DAE) and used to calculate the importance value index (IVI) (Figure 3). *Cenchrus echinatus* had the highest IVI across all three sunflower genotypes, reaching 178.06 for Altis 99. Lopes et al. (2021) also reported a high importance value for this species in soybean crops and attributed this pattern to the soil seed bank, reinforcing the persistence and adaptation of *C. echinatus* in regional agricultural systems.

The IVI is a useful tool for defining more effective weed management strategies tailored to the conditions of each agricultural system. Accordingly, species with higher index values should be prioritized in weed control practices to reduce their populations and, consequently, minimize their impacts on crops (BATISTA et al., 2017).

Table 3. Phytosociological parameters of weeds associated with sunflower genotypes at 20 DAE. Number of individuals (NI), number of quadrats in which the species was present (NQ), frequency (F), density (D), and abundance (A).

Species	NI	NQ	F	D	A
		ALTIS 99			
Cenchrus echinatus	166	4	0.33	41.50	41.50
Commelina benghalensis	4	1	0.08	1.00	4.00
Cynodon dactylon	14	1	0.08	3.50	14.00
Eleusine indica	4	2	0.17	1.00	2.00
Sida glaziovii	16	4	0.33	4.00	4.00
TOTAL	204	12	1.00	51.00	65.50
		BRS 323			
Cenchrus echinatus	67	4	0.33	16.75	16.75
Cynodon dactylon	9	2	0.17	2.25	4.50
Cyperus rotundus	1	1	0.08	0.25	1.00
Eleusine indica	1	1	0.08	0.25	1.00
Sida glaziovii	17	2	0.17	4.25	8.50
TOTAL	95	10	0.83	23.75	31.75
		HÉLIO 250			
Cenchrus echinatus	111	4	0.33	27.75	27.75
Cynodon dactylon	7	1	0.08	1.75	7.00
Cyperus rotundus	3	1	0.08	0.75	3.00
Eleusine indica	2	1	0.08	0.50	2.00
Sida glaziovii	40	4	0.33	10.00	10.00
TOTAL	163	11	0.92	40.75	49.75

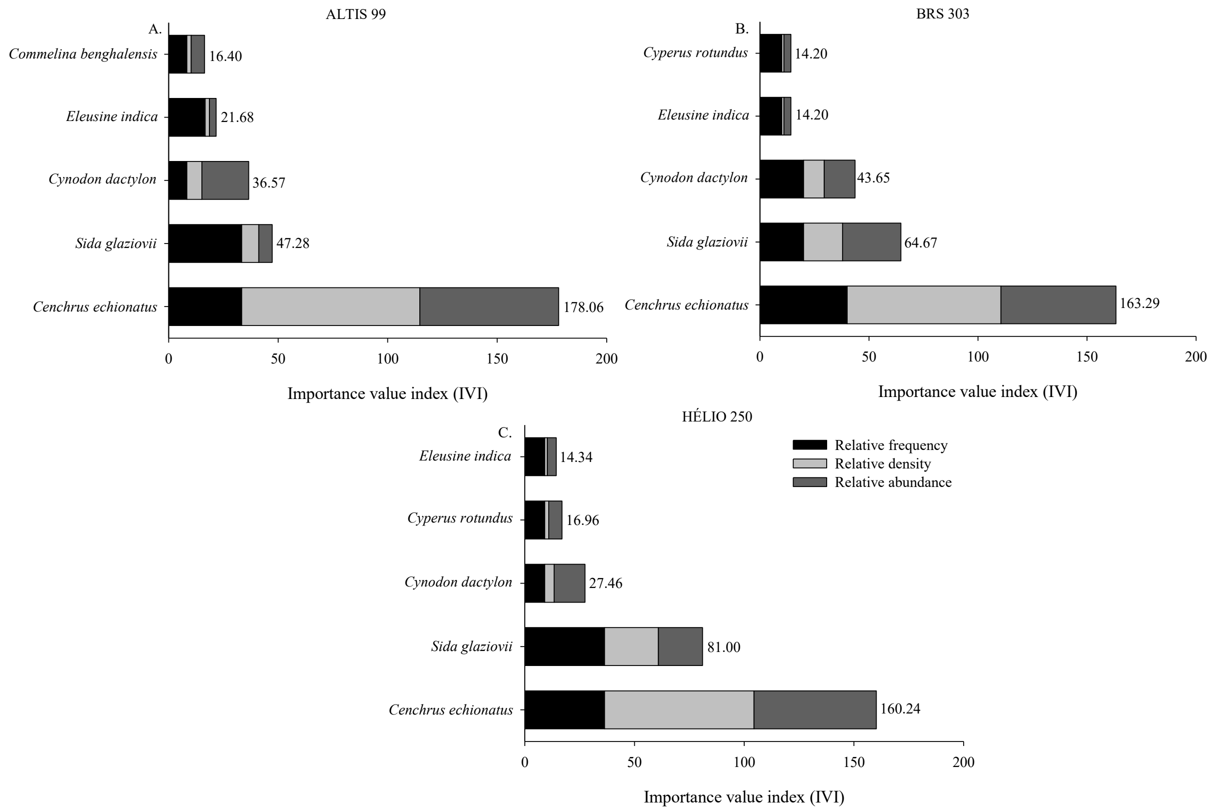

Figure 3. Importance value index of weeds (%) in sunflower genotypes, identified 20 days after sunflower emergence (20 DAE).

Phytotoxicity in sunflower plants

Herbicide treatments significantly affected phytotoxicity over time ($p \leq 0.05$) (Figure 4). Overall, fomesafen caused the highest levels of phytotoxicity, regardless of genotype, whereas clethodim caused no visible phytotoxicity in any of the evaluated genotypes, demonstrating high selectivity to sunflower.

For BRS 323 (Figure 4A), chlorimuron-ethyl caused the highest levels of phytotoxicity (approximately 75–85%), followed by fomesafen. For Altis 99 (Figure 4B), fomesafen resulted in the highest phytotoxicity levels, peaking at more than 80% at 20 DAA and differing from the other herbicide treatments. Similarly, for Hélio 250 (Figure 4C), fomesafen caused the greatest phytotoxicity, with the highest level observed at 15 DAA.

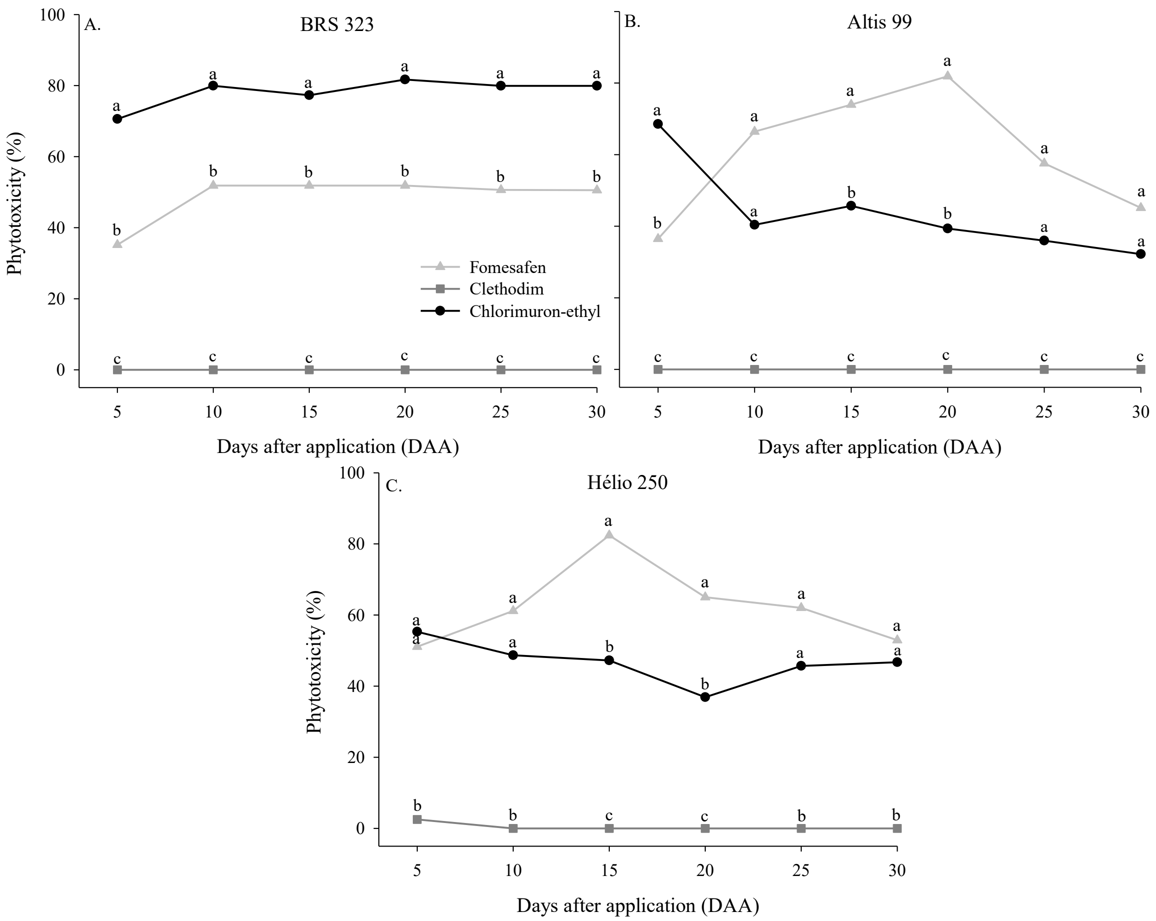

Figure 4. Phytotoxicity (%) of three sunflower genotypes (A: BRS 323; B: Altis 99; C: Hélio 250) at 5, 10, 15, 20, 25, and 30 days after application (DAA) of the postemergence herbicides fomesafen, clethodim, and chlorimuron-ethyl. Means followed by the same letter within each evaluation period do not differ according to Tukey's test ($p \leq 0.05$).

Clethodim was the only herbicide that caused no phytotoxicity symptoms in any of the sunflower genotypes, regardless of the evaluation time, demonstrating high selectivity to the crop. This response is related to its mode of action, which involves inhibition of the enzyme acetyl-CoA carboxylase (ACCase) and is particularly effective against grass species (DEVINE; DUKE; FEDTKE, 1992), explaining its widespread use for grass control in eudicotyledonous crops. From an agronomic standpoint, this result demonstrates the selectivity of clethodim to sunflower under the experimental conditions, particularly in an area where Poaceae species predominated, as observed in this study.

Conversely, chlorimuron-ethyl caused high levels of phytotoxicity among the evaluated genotypes, particularly in BRS 323, which exhibited values exceeding 70% from 10 days after application (DAA) onward, whereas Altis 99 and Hélio 250 showed lower sensitivity over time. This response is associated with its mode of action as an acetolactate synthase (ALS) inhibitor, which disrupts the synthesis of essential amino acids and consequently impairs plant growth (TRANEL; WRIGHT, 2002). Furthermore, variation in the response among genotypes suggests differences in herbicide tolerance, potentially associated with factors such as herbicide absorption, translocation, and metabolism. Although these mechanisms were not directly evaluated in this study, the results indicate that postemergence application of chlorimuron -ethyl may pose a risk of phytotoxicity to sunflower.

Morphological and agronomic characteristics of sunflower genotypes

A significant interaction ($p < 0.05$) between sunflower genotypes and herbicide treatments was observed for all morphological and agronomic traits (Table 4), indicating that crop response depended on the combination of these factors. Head insertion height (HIH) did not differ among herbicide treatments ($p > 0.05$) within each genotype, indicating greater stability of this trait under herbicide-induced stress.

Chlorimuron-ethyl caused the greatest growth reductions, resulting in the lowest plant heights, particularly for BRS 323 (17.25 cm), whereas clethodim resulted in values similar to those of the weeded control. A similar pattern was observed for head diameter (HD) and 1,000-achene weight (TAW), highlighting the negative effect of chlorimuron-ethyl on traits directly associated with yield potential. The lowest TAW was recorded for Altis 99 (9.50 g). Achene yield was the most sensitive variable, with significant reductions ($p < 0.05$) following chlorimuron-ethyl application across all genotypes (Figure 5). In contrast, clethodim did not reduce yield, further demonstrating its high selectivity to sunflower under the experimental conditions. This response is consistent with the selectivity of ACCase-inhibiting herbicides in many eudicot crops.

Table 4. Head insertion height (HIH) (m), plant height (PH) (cm), head diameter (HD) (cm), and 1,000-achene weight (TAW) (g) of three sunflower genotypes following postemergence application of three herbicides.

Parameter	Treatment	Genotype		
		BRS 323	Altis 99	Hélio 250
HIH	Weeded control	1.25 aA	1.18 aA	1.34 aA
	Non-weeded control	1.14 aA	1.10 aA	1.08 aAB
	Fomesafen	1.14 aA	1.08 aA	0.97 aB
	Clethodim	1.05 aA	0.91 aA	0.95 aB
	Chlorimuron-ethyl	1.10 aA	1.05 aA	1.04 aAB
PH	Weeded control	101.75 aA	103.50 aA	105.50 aA
	Non-weeded control	73.75 bB	103.50 aA	103.00 aA
	Fomesafen	49.25 bC	67.25 aB	70.75 aB
	Clethodim	92.00 aA	101.75 aA	95.00 aA
	Chlorimuron-ethyl	17.25 bD	54.25 aB	50.50 aC
HD	Weeded control	15.70 aA	12.50 aA	14.10 aA
	Non-weeded control	10.05 aB	7.87 aB	10.62 aB
	Fomesafen	11.30 aB	10.32 aAB	9.37 aB
	Clethodim	12.80 aAB	12.80 aAB	10.35 aB
	Chlorimuron-ethyl	5.45 bC	5.45 bC	10.40 aB
TAW	Weeded control	66.50 aA	48.00 bA	57.50 bA
	Non-weeded control	52.50 aB	24.75 bB	47.00 aAB
	Fomesafen	38.2 aC	20.50 bBC	32.50 aC
	Clethodim	42.00 aC	25.25 bB	42.75 aBC
	Chlorimuron-ethyl	43.50 aC	9.50 bC	49.00 aAB

*Means followed by the same lowercase letter within a row and the same uppercase letter within a column, for each evaluation, do not differ according to Tukey's test ($p > 0.05$).

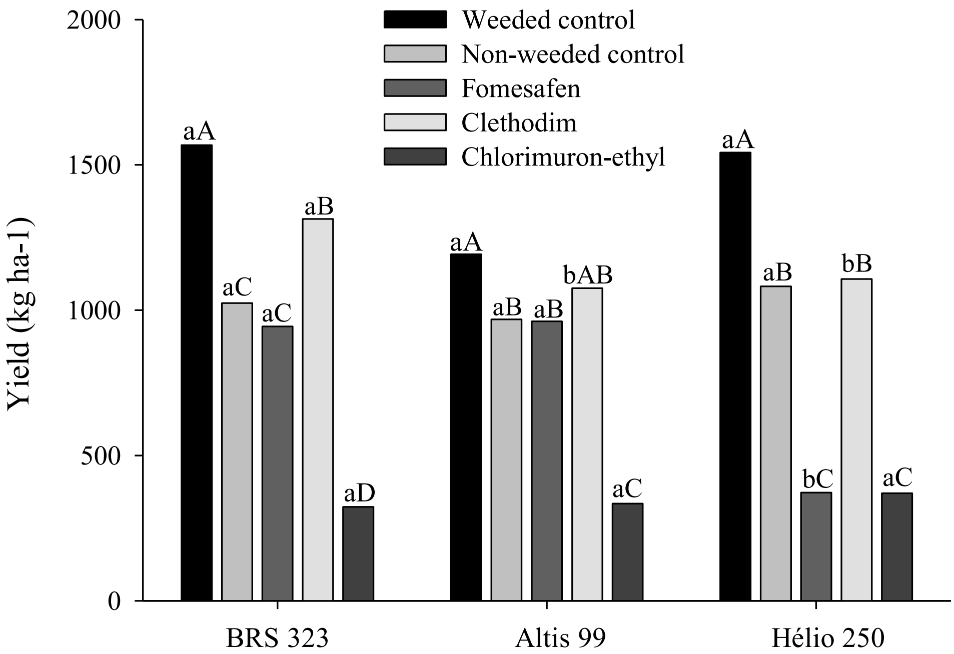

Figure 5. Yield (kg ha^{-1}) of three sunflower genotypes subjected to postemergence herbicide application. Means followed by the same uppercase letter do not differ among management treatments within each genotype, whereas means followed by the same lowercase letter do not differ among genotypes within each management treatment, according to Tukey's test ($p > 0.05$).

Although fomesafen negatively affected certain traits, such as plant height and 1,000-achene weight, in BRS 323 and Altis 99 (Table 4), both genotypes maintained yields close to 1,000 kg ha^{-1}, similar to those obtained under manual weeding (Figure 5) and approaching the Brazilian national average of 1,463 kg ha^{-1} (CONAB, 2025). This response may indicate some capacity for physiological compensation following herbicide-induced stress, possibly favored by reduced competition for resources resulting from weed control (HASSAN et al., 2025). Under manual weeding, yields ranged from 1,300 to 1,600 kg ha^{-1}. Although lower than the 2,407 kg ha^{-1} reported by Carvalho et al. (2021), these values were generally close to or above the national average of 1,463 kg ha^{-1} (CONAB, 2025), highlighting the influence of edaphoclimatic conditions and management practices on crop performance.

Oil quality

Linoleic (C18:2) and oleic (C18:1) acids were the major fatty acids in the oil extracted from the three sunflower genotypes, regardless of weed management treatment. No statistically significant differences were observed among treatments, indicating little variation in fatty acid composition. Linoleic acid content averaged approximately 50%, whereas oleic acid content remained around 28% across genotypes and management treatments. The minor fluctuations observed were less than 1%, indicating stability in the composition of the major fatty acids even following herbicide application.

These results indicate that the treatments had little influence on oil quality, with fatty acid levels remaining within the expected range for sunflower oil. Similar results were reported by Önemli and Tetik (2023), who observed no significant variation in linoleic and oleic acid contents among sunflower genotypes under different treatments and growing conditions.

Overall, no significant differences were observed in sunflower oil quality parameters among the weed management treatments or sunflower genotypes evaluated (Table 5). Variables such as oil yield (%), water content (%), acidity (mg KOH g^{-1}), specific gravity (g cm^{-3}), and iodine value (g I_2 100 g^{-1}) remained stable across the weeded and non-weeded controls and treatments with the postemergence herbicides fomesafen, clethodim, and chlorimuron-ethyl, regardless of genotype. These results indicate that, despite the effects of some treatments on plant growth and agronomic performance, the technological quality of the extracted oil was not compromised. The consistency of these parameters indicates that the evaluated treatments did not adversely affect final oil quality, an important characteristic for its potential use by the food and oleochemical industries.

Thus, herbicide selection should integrate crop selectivity, weed community management, and potential effects on sunflower yield and quality attributes, particularly in regions such as the Cerrado. Future studies should investigate the response to these herbicides under different edaphoclimatic conditions.

Table 5. Sunflower oil quality as affected by genotype and weed management.

Parameter	Herbicide	Genotype		
		BRS 323	Altis 99	Hélio 250
Oil yield (%)	Weeded control	18.84 aB	18.53 aA	17.69 bB
	Non-weeded control	17.46 bC	17.74 bB	18.70 aA
	Fomesafen	19.75 aA	18.83 bA	18.57 bA
	Clethodim	16.83 cD	18.52 aA	17.64 bB
	Chlorimuron-ethyl	18.47 aB	17.54 bB	17.48 bB
Water content (%)	Weeded control	0.35 aA	0.29 bC	0.32 abB
	Non-weeded control	0.26 bB	0.35 aB	0.35 aB
	Fomesafen	0.33 bA	0.41 aA	0.34 bB
	Clethodim	0.34 bA	0.34 bB	0.40 aA
	Chlorimuron-ethyl	0.26 bB	0.26 bC	0.42 aA
Acidity (mg KOH g^{-1})	Weeded control	0.65 aA	0.62 aA	0.65 aA
	Non-weeded control	0.63 aA	0.62 aA	0.65 aA
	Fomesafen	0.66 aA	0.61 bA	0.68 aA
	Clethodim	0.63 aA	0.62 aA	0.61 aA
	Chlorimuron-ethyl	0.67 aA	0.61 bA	0.67 aA
Specific gravity (g cm^{-3})	Weeded control	924.33 bA	922.33 cB	926.04 aA
	Non-weeded control	924.00 bA	921.66 cB	925.59 aA
	Fomesafen	924.67 bA	920.33 cB	926.50 aA
	Clethodim	922.33 cA	924.00 bA	927.41 aA
	Chlorimuron-ethyl	925.13 bA	922.00 cB	926.96 aA
Iodine value (g I_2 100 g^{-1})	Weeded control	134.63 aA	134.43 aA	134.30 aA
	Non-weeded control	133.86 bA	134.63 aA	133.06 cB
	Fomesafen	134.10 aA	130.46 cC	132.26 bB
	Clethodim	133.13 aA	133.13 aB	132.83 aB
	Chlorimuron-ethyl	132.03 aB	131.26 bC	132.00 aB

*Means followed by the same lowercase letter within a row and the same uppercase letter within a column, for each evaluation, do not differ according to Tukey's test ($p > 0.05$).

CONCLUSION

Phytosociological survey revealed a predominance of Poaceae species in the sunflower-growing areas, with the highest weed infestation observed in Altis 99 and the lowest in BRS 323. *Cenchrus echinatus* had the highest importance value indices across the evaluated genotypes. Among the herbicides tested, clethodim showed high selectivity to sunflower, causing no phytotoxicity or adverse effects on agronomic performance. In contrast, fomesafen and chlorimuron-ethyl reduced plant performance, particularly in BRS 323, although neither affected oil quality. Therefore, clethodim showed favorable selectivity under the experimental conditions, whereas the response to fomesafen, despite the initial phytotoxic effects observed, warrants further investigation before its potential use in sunflower can be considered.

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