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Influence of Chemical Control on the Floristic Composition of Weeds in the Initial and Pre-Harvest Development Stages of the Sunflower Crop

Elielton Germano dos Santos [1], Miriam Hiroko Inoue [1], Ana Carolina Dias Guimarães [2], Jennifer Stefany Queiroz Bastos [1], Ricardo Alcántara-de la Cruz [3,*] and Kassio Ferreira Mendes [4]

[1] Faculdade de Ciências Agrárias, Biológicas, Engenharia e da Saúde, Universidade do Estado de Mato Grosso, Tangará da Serra 78300-970, Brazil
[2] Faculdade de Ciências Biológicas e Agrárias, Universidade do Estado de Mato Grosso, Alta Floresta 78580-000, Brazil
[3] Centro de Ciências da Natureza, Campus Lagoa do Sino, Universidade Federal de São Carlos, Buri 18290-000, Brazil
[4] Departamento de Agronomia, Universidade Federal de Viçosa, Viçosa 36570-900, Brazil
* Correspondence: ricardo.cruz@ufscar.br

Abstract: The presence of weeds in the sunflower crop is one of the main factors linked to the low increase in productivity of this crop, and to determine the most appropriate management of weeds, it is essential to carry out a diagnosis through the phytosociological survey. The objective of this study was to assess the influence of chemical control on the phytosociological community of weeds in three areas cultivated with sunflower in the Parecis region (Brazil). The areas were treated with 2,4-D + glyphosate for desiccation; S-metolachlor was used for pre-emergence control in the three areas; meanwhile, sulfentrazone and flumioxazin were applied only in one area; and, finally, clethodim was applied for post-emergence weed management. Sampling was carried out at two different times, in the initial and pre-harvest stages (at 35 and 100 days after the emergence of the crop, respectively), using a quadrate, in which weeds were identified and quantified to determine the frequency, relative frequency, density, relative density, abundance, relative abundance, importance index, and similarity index between areas and times. Seventeen weed species were found in the sunflower crop (70.6% dicot and 29.4% monocotyledonous) in the two seasons, grouped into nine botanical families, with Poaceae being the most diverse family. The dicots *Tridax procumbens* and *Acanthospermum hispidium* were present in low frequency only in the initial stages of development of the sunflower crop. The weeds with the highest importance index values in the initial and pre-harvest stages were *Euphorbia hirta* (104 and 91%) and *Bidens pilosa* (45 and 66%, respectively), both belonging to the dicots group. These two species were present in the two evaluated periods and in the three experimental areas, demonstrating that there was a similarity index between them with values above 93%. These results of the phytosociological study may contribute to determining more efficient management strategies for weed chemical control in the sunflower crop.

Keywords: chemical control; *Helianthus annuus* L.; phytosociological survey; similarity index

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1. Introduction

The cultivation of sunflower (*Helianthus annuus* L.) is of great economic and social importance, particularly as a source of high-quality oil with excellent nutritional value for human and animal consumption [1,2]. Thus, with the growing demand for food worldwide, the production of high-quality and nutritious crops such as sunflower has become increasingly important. The global sunflower seed production reached 51 million tons in 2020, with Brazil being the second-largest producer [3]. However, during the early stages of development, sunflower plants grow slowly, resulting in low ground cover and providing favorable conditions for weed growth [4]. This makes weed interference one of the most significant challenges in sunflower production at this stage [5].

Weeds not only compete with sunflower plants for resources such as water, light, space, and nutrients but can also affect the crop quality and yield. Weeds can reduce sunflower yield by up to 80% in severe infestations of redroot pigweed (*Amaranthus retroflexus*) [6]. In addition, some weed species can act as hosts for pests and diseases that attack sunflower crops, further reducing yield and increasing management costs. Therefore, effective weed management is essential to maximize sunflower crop productivity and economic return for farmers.

To develop effective weed management strategies, it is crucial to conduct phytosociological surveys to identify and quantify weed populations and understand their dynamics in agricultural crops [7]. Phytosociological surveys also allow for a better understanding of the ecology of weed species present in a given area, such as their habitat preferences, competition with other species, and dispersal capacity. This information is crucial for developing more efficient weed management strategies, such as preventive, cultural, mechanical, physical, biological, chemical, or integrated management [8], and establishes the priority order of weed species to determine a control program [9].

Despite the significance of sunflower production in Brazil, information about the floristic composition of weeds, particularly in the Parecis region of Mato Grosso, one of the country's main producing areas [10], is limited. Furthermore, as an Asteraceae crop, several species of difficult-to-control weeds, such as *Conyza* spp. and *Bidens* spp., are common in Brazil, and herbicides authorized for use in other crops often have low tolerance [11]. Consequently, only a few herbicides, namely, alachlor, clethodim, diquat, imazamox, saflufenacil, S-metolachlor, and trifluralin, have been approved for sunflower production in Brazil [12]. The limited availability of herbicides for sunflower crop management has resulted in minimal research related to chemical weed control for this crop [13–15].

Therefore, this study aimed to evaluate the impact of chemical weed control on floristic and phytosociological parameters by identifying and quantifying weed species at two stages of sunflower crop development. By considering information from phytosociological surveys, this research aims to optimize weed management with herbicides in sunflower production.

2. Materials and Methods

2.1. Experimental Area

The phytosociological survey in the sunflower crop (tillage system) was carried out between March and June 2021 in three nearby areas located in the municipality of Diamantino, Parecis region, Mato Grosso, Brazil. The areas were separated and named experimental areas 1 (14°04′55″ S and 57°12′01″ W), 2 (14°05′38″ S and 57°12′59″ W), and 3 (14°09′30″ S and 57°18′23″ W) (Figure 1) [16]. All areas have had a history of sunflower cultivation for more than two years. The sunflower was sown mechanically in the second half of March, after the soybean harvest. The soil in the three areas was classified as Oxisol (*Latossolo Vermelho*) with a clayey texture.

According to the Köppen system, the municipality of Diamantino has an Aw climate, i.e., a hot and humid climate, with average annual temperature and precipitation of 24 °C and 1600–1800 mm, respectively [17]. The weather conditions during the experiments were recorded (Figure 2).

2.2. Chemical Control of Weeds

The 2,4-D + glyphosate mixture was applied for desiccation 12 days before sunflower sowing. In experimental areas 1 and 2, the dosages were 242 + 1080 g ha^{-1}, respectively, while in area 3, the dose of 2,4-D was adjusted to 363 g ha^{-1} because it was an area with more volunteer soybean (from remnant glyphosate-resistant soybean seeds). Pre-emergence management was carried out on the same day of sowing in all experimental areas with S-metolachlor (1152 g ha^{-1}). In experimental area 1, sulfentrazone (150 g ha^{-1}) and flumioxazin (50 g ha^{-1}) were added. Post-emergence management was carried out at 42 DAE with clethodim (96 g ha^{-1}) in all experimental areas. The management of insecticides and fungicides was carried out according to the needs and schedule of each property.

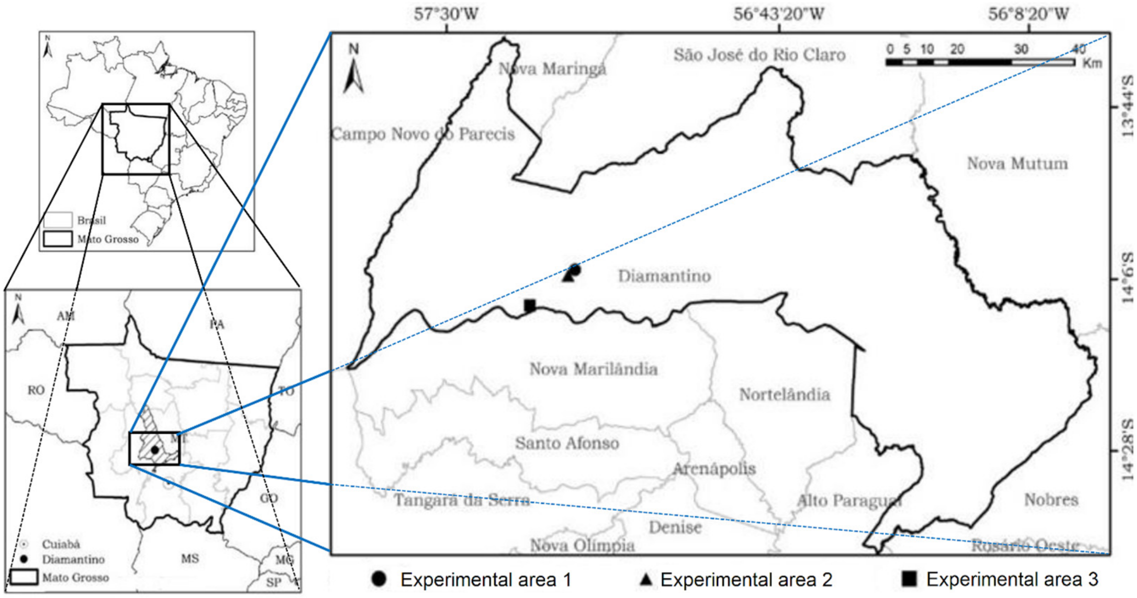

Figure 1. Descriptive map of three areas located in the municipality of Diamantino, Mato Grosso, Brazil. Source: SEPLAN [16].

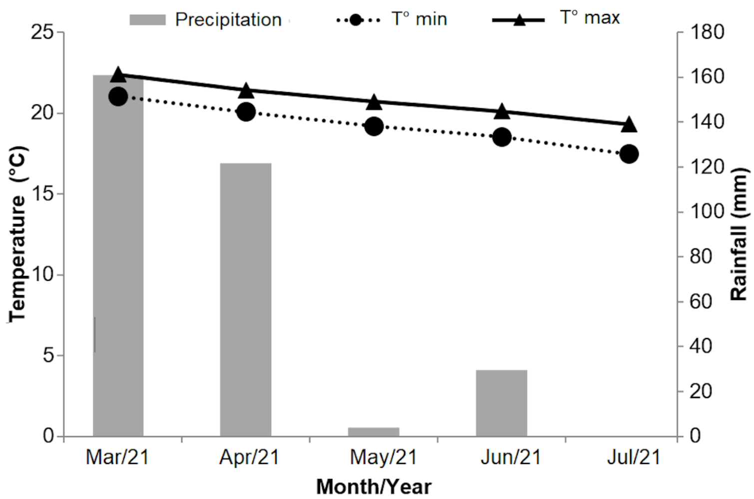

Figure 2. Monthly averages of precipitation and air temperatures (maximum and minimum) for the municipality of Diamantino, Mato Grosso, Brazil, between March and July 2021. Source: Data from the INMET [17].

2.3. Phytosociological Survey

The phytosociological survey was carried out at 35 DAE at the time of initial development of the sunflower and at pre-harvest at 100 DAE using the quadrate method [18]. A 0.5 × 0.5 m quadrate was dropped at random 160 times within each one-hectare area. In each sampled quadrate, the botanical families, species, and common names were quantified and identified using the manual of Lorenzi [19].

The frequency (1), relative frequency (2), density (3), relative density (4), abundance (5), relative abundance (6), and the importance value index (IVI) (7) were calculated and analyzed for the analysis of the weed population in the experimental areas using the following formulas [18,20,21]:

$$\text{Frequency} = \frac{number\ of\ quadrate\ in\ which\ the\ weed\ species\ was\ found}{total\ number\ of quadrate} \quad (1)$$

$$\text{Relative frequency } (\%) = \frac{Frequency\ of\ weed\ species \times 100}{total\ area\ of\ quadrate} \quad (2)$$

$$\text{Density} = \frac{number\ of\ quadrate\ in\ which\ the\ weed\ species\ was\ found}{total\ number\ of\ quadrate} \quad (3)$$

$$\text{Relative density } (\%) = \frac{Density\ of\ weed\ species \times 100}{density\ of\ all\ weed\ species} \quad (4)$$

$$\text{Abundance} = \frac{total\ number\ of\ individuals\ per\ weed\ species}{total\ number\ of\ quadrate\ containing\ the\ weed\ species} \quad (5)$$

$$\text{Relative abundance } (\%) = \frac{abundance\ of\ weed\ species \times 100}{total\ abundance\ of\ all\ weed\ species} \quad (6)$$

$$\text{IVI (\%) = Relative frequency + Relative density + Relative abundance} \quad (7)$$

In addition, the similarity index between areas (SIA) was calculated as follows [18,21]:

$$\text{SIA } (\%) = \frac{3 \times a}{b + c + d} \times 100 \quad (8)$$

where "*a*" is equal to the number of species common in the three areas; "*b*", "*c*" and "*d*" are the total number of species in the three areas compared.

The similarity index between seasons (SIS), which compares the similarity of the two seasons for each area, was also estimated by adapting the previous formula:

$$\text{SIS } (\%) = \frac{2 \times a}{b + c} \times 100 \quad (9)$$

where "*a*" is equal to the number of species common in both seasons, and "*b*" and "*c*" are equal to the total number of species found in the area during the two seasons evaluated. The data obtained were tabulated and discussed through descriptive analysis.

3. Results

Dicots comprised 70.6% of the 17 weed species found in sunflower crops in relation to monocots (29.4%) in the two periods [35 and 100 days after emergence (DAE)] and areas (1, 2, and 3) evaluated. The species found belong to 9 botanical families, with the families Poaceae (4 species), Fabaceae (3), Asteraceae (3), and Euphorbiaceae (2) composing the greatest floristic diversity. The identified weed species of the Poaceae family were: *Eleusine indica*, *Digitaria horizontalis*, *Sorghum halepense*, and *Urochloa plantaginea*. On the other hand, some species, such as *Tridax procumbens* (areas 1 and 2) and *Acanthospermum hispidium* (area 3), both from the Asteraceae family (dicots), were present only in the initial development stages of the sunflower crop (Table 1).

Table 1. List of weeds, distributed by family, class, species, common name, and area, occurring in the region of Parecis, Diamantino, Mato Grosso, Brazil, in two periods (initial and pre-harvest) in the sunflower crop.

Family	Class	Latin Name	Common Name	Area	Period
Poaceae	Monocot	*Eleusine indica* L. Gaertn	Goosegrass	1	Both
		Urochloa plantaginea (Link) R.D. Webster	Alexandergrass	1	Both
		Sorghum halepense (L.) Pers.	Johnsongrass	2	Both
		Digitaria horizontalis Willd	Jamaican crabgrass	2	Both
Fabaceae	Dicot	*Glycine max* (L.) Merr.	Volunteer soybeans	1, 2, and 3	Both
		Senna obtusifolia (L.) H.S. Irwin & Barneby	Sicklepod	2 and 3	Both
		Crotalaria spectabilis Röth	Crotalaria	3	Both
Asteraceae	Dicot	*Bidens pilosa* L.	Beggarticks	1, 2, and 3	Both
		Tridax procumbens L.	Buttons	1 and 2	Initial
		Acanthospermum hispidum DC	Starbur	3	Initial
Euphorbiaceae	Dicot	*Euphorbia heterophylla* L.	Poinsettia	1 and 2	Both
		Euphorbia hirta L.	Spurge	1, 2, and 3	Both
Convolvulaceae	Dicot	*Ipomoea purpurea* L. Roth	Morning glory	1 and 2	Both
Cyperaceae	Monocot	*Cyperus difformis* L.	Sedge	1	Both
Malvaceae	Dicot	*Sida rhombifolia* L.	Arrowleaf	2	Both
Amaranthaceae	Dicot	*Alternanthera tenella* Colla	Sanguinaria	3	Both
Commelinaceae	Dicot	*Commelina benghalensis* L.	Dayflower	1 and 3	Both

In addition to voluntary soybean occurring within three experimental areas, in areas 1 and 2, 10 and 9 species were identified in the initial and pre-harvest stages of sunflower development, respectively. In Area 3, only 8 and 9 weed species were identified, respectively. The total weed density of the three areas was 16.6 and 15.9 plants/m^2, respectively, in the initial and pre-harvest development of the sunflower (Figure 3). In area 1, the weed density was 3.8 plants/m^2 in both evaluation periods; however, in experimental areas 2 and 3, the density ranged from 5.2 to 7.3 plants/m^2 (Figure 4).

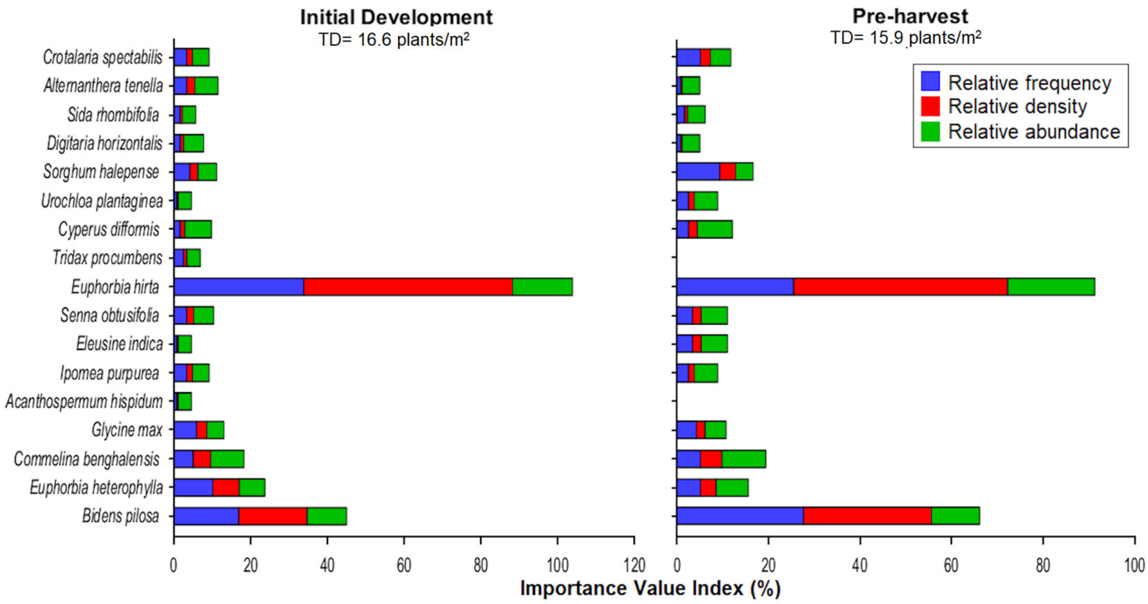

Figure 3. Importance value indices (IVI) (relative density, frequency, and dominance) of weeds found in the initial development and in the pre-harvest stages of sunflower in the three studied areas. TD = Total weed density. All results are presented in percentages (%).

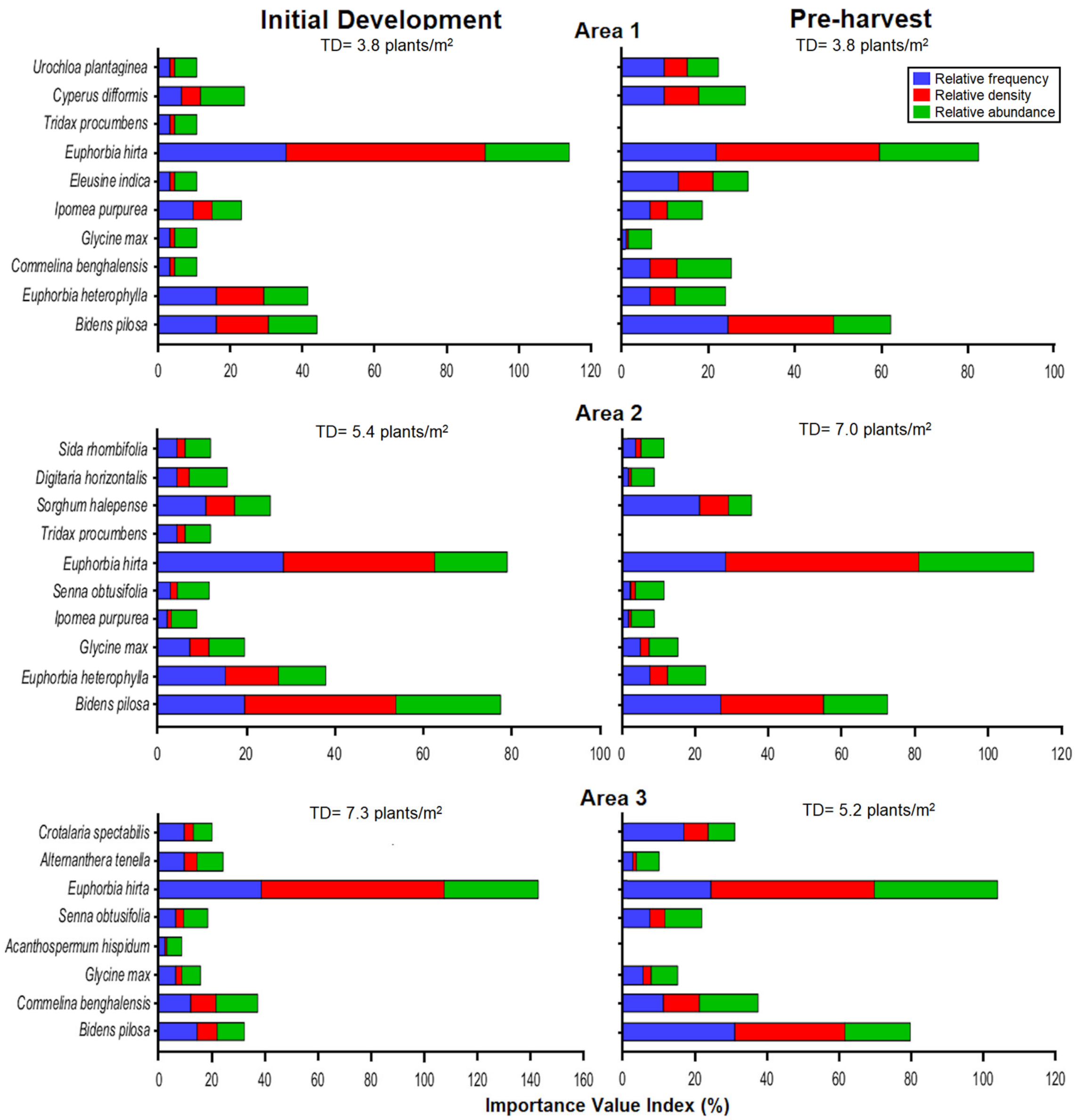

Figure 4. Importance value indices (IVI) (relative density, frequency, and dominance) of weeds were found in initial development [35 days after emergence (DAE) and pre-harvest (100 DAE)] in experimental areas 1, 2, and 3. TD = Total weed density. All results are presented in percentages (%).

According to the values of phytosociological indices, *Euphorbia hirta* presented the highest frequency, density, and abundance relative values, with importance value indexes (IVI) ranging from 79% to 142% in the initial development stages of the sunflower crop and from 82% to 113% in the pre-harvest period. *Bidens pilosa* had an IVI of 78% in the initial development only in area 2, but during the pre-harvest stages, this species was relevant in all three of the areas with IVIs that ranged from 63% to 80%. Weed species such as *Crotalaria spectabilis*, *E. indica*, *Euphorbia heterophylla*, and *S. halepense* became relevant in some areas or evaluation periods, but their IVIs hardly exceeded 40% (Figure 4). The global data of the study confirmed the relevance of *E. hirta* and *B. pilosa* in the three experimental areas, with IVIs of 104 and 45%, respectively, in the initial stages, and of 91 and 66% in the pre-harvest, i.e., these two species computed $\leq$150% of the IVIs for the two periods (Figure 4).

The similarity index between areas (SIA) of the weed species found in the sunflower cultivation areas was between 35.3% and 42.5% in the initial and pre-harvest development period, with only three weed species occurring in the three areas (Table 1), in addition to volunteer soybeans that were not included in the phytosociological survey. The weed community had a large variation from initial to end of crop cycle. When evaluating the similarity index between seasons (SIP) among the three experimental areas, the SIPs were 94.8%, 94.8%, and 93.3% in areas 1, 2, and 3, respectively. This occurred because the weed community hardly changed during the evaluation time within each experimental area.

4. Discussion

The Poaceae family presented the highest floristic diversity, but its relevance for sunflower cultivation was low, except for *S. halepense* in area 2, which had an IVI of up to 38% in the two evaluated seasons, which highlights the relevance of plant management weeds with selective herbicides for the sunflower crop to minimize the effects of interference [22]. On the other hand, the absence of *T. procumbens* and *A. hispidium* in the pre-harvest may be related to the low frequency of these species in the early stage of sunflower development, and due to the shading caused by the growth of the crop [23,24], preventing the development of these weeds during the season.

The lower weed density in experimental area 1 can be explained by the addition of sulfentrazone and flumioxazin herbicides for pre-emergent weed management. Reductions in the number of *Desmodium tortuosum*, *D. horizontalis*, *E. heterophylla*, *T. procumbens*, *Spermacoce latifolia*, and *Sida rhombifolia* plants were observed after application of flumioxazin at doses of 25 and 40 g ha^{-1} [25]. However, the higher weed density in area 3, which was the one with the lowest floristic diversity in the two evaluated periods, can be attributed to the less efficient weed management of desiccation, although the dose of 2,4-D was increased (from 242 to 363 g ha^{-1}) in this area. The weed densities quantified in the experimental areas were relatively low (from 3.8 to 7.3 plants/m^2); however, these densities are capable of affecting development and compromising sunflower productivity. Weed densities between 6 and 10 plants/m^2 reduced the dry weight of seeds, the number of achenes per head, the diameter of the stem and the head, and other sunflower parameters by 9% to 50%. On the other hand, plant height and number of hallow grains increased by 21% and 92%, respectively [26], to survive and evade weed interference.

Losses in sunflower productivity due to weeds are more evident in the initial stages of the crop (slow growth up to 40 DAE) [27], and weed control during this period is essential [5]. Despite variations in herbicide management in the evaluated areas, there was uniformity in relation to the high incidence of *E. hirta* and *B. pilosa* species, as well as voluntary soybean, frequently followed by *E. heterophylla*, both in the initial and pre-harvest periods. The high frequency of these weed species can be attributed to their wide adaptability to different agricultural environments. Sunflower was grown in succession to soybean, which favored the establishment of volunteer soybean plants from grain lost during harvest [28]. Volunteer plants, which generally have traits of resistance to herbicides such as glyphosate, can cause losses of up to 80% of productivity in the succession crop [29], which, in this case, is sunflowers. According to the study, herbicides used in pre- and post-emergence with modes of action different from glyphosate showed good control of volunteer soybeans in experimental areas cultivated with sunflower [30]. The use of different modes of action is an effective strategy in weed management and helps prevent the development of weed resistance to herbicides [31]. In addition, crop rotation, such as the use of sunflower after soybean cultivation, can also help reduce weed pressure in the field [32].

The use of S-metolachlor (1152 g ha^{-1}) for pre-emergent weed management did not efficiently control *E. hirta*, and this species presented the highest relative density indices in the initial development of sunflower in the three experimental areas. This herbicide has shown little efficacy against this species, since doses of up to 1680 g ha^{-1} have hardly controlled more than 60% of *E. hirta* [33], making it necessary to reassess the applied dose of S-metolachlor or, rather, the use of other pre-emergent herbicides. On the other hand, soil and climate conditions influence the behavior and effectiveness of herbicides [34], and, consequently, the weed population. During the season of the execution of this study, the rainfall was 28% below the average of the last 5 years for the Parecis region (Figure 2) [16], which possibly affected the efficiency of herbicides as well as the survival of the plants and weed species. Jursik et al. [35], using other herbicides of the acetamide chemical group, such as pethoxamid, also found that under drought conditions, the effectiveness of this pre-emergent herbicide decreased.

Weeds of the genus Euphorbia can cause yield losses of ≤80% due to allelopathic and competitive activity [36]. *B. pilosa* causes direct interference in the productive potential of crops due to competition, mainly because it is a species that presents rapid development and is highly prolific, producing up to three cycles per year, which gives the plant its presence throughout the year [37]. The presence of 15–40 plants/m^2 of *B. pilosa* during the critical period of sunflower cultivation can cause daily losses of 1.1 kg ha^{-1} in oil yield and 2.5 kg ha^{-1} in productivity [38]. These findings are extremely concerning, given that it is a short-cycle weed and that there are no options for selective products to apply in post-emergence in sunflower production [12], relying solely on the control of herbicides applied prior to crop emergence. In addition, sunflower is highly sensitive to herbicides such as clethodim [39], which was used post-emergence, favoring the frequency and density of *B. pilosa* and *E. hirta*, and consequently increasing the competition. Research studies have shown that the sensitivity of sunflower to clethodim can be affected by various factors such as the timing and rate of application, environmental conditions, and the sunflower cultivar used. For instance, a study by Brighenti et al. [40] reported that early post-emergence applications of clethodim at lower rates resulted in better sunflower tolerance than late applications or higher rates. Therefore, the results of this study show that, during the planning of weed control strategies, these dicot species should receive greater attention so that the effectiveness of weed management is guaranteed [41].

The SIA and SIS (estimates of the degree of similarity of the weed species community) range from 0 to 100%, with the maximum occurring when all species are common to both areas or seasons and the minimum occurring when there are no species in common [42]. The similar values of SIA (35–42%) and SIS (93–95%) showed that there was no difference in the floristic composition of weeds within and among areas from one evaluation period to the next. Values close to SIA were also found in the sunflower crop when comparing the Cerrado and Pampas regions, which ranged from 36 and 46% for the initial and pre-harvest periods, respectively [43]. A high SIS (>60%) was observed in guava orchards at different times [44]. The weed similarity index can also be used to evaluate the effectiveness of different weed management practices in different areas. For example, by comparing the similarity between weed communities before and after herbicide application, farmers can assess the efficacy of weed control and identify potential problems, such as the development of herbicide resistance [45]. This study has shown that weed communities can change over time and that management practices can have a significant impact on weed diversity and abundance.

5. Conclusions

Based on the results of this study, it can be concluded that the Poaceae family is the most prevalent weed family in the evaluated areas, followed by Fabaceae, Asteraceae, and Euphorbiaceae. This information is useful for farmers and weed management specialists to design effective strategies to control weed growth, particularly those in the Poaceae family. The fact that voluntary soybean, *Bidens pilosa*, and *Euphorbia hirta* were present in all areas and time analyzed, indicating their high indices of importance, also suggests that these species should be targeted in weed management plans. By taking these findings into consideration, farmers can implement more targeted and effective weed control measures, which can improve sunflower crop yield and quality, reduce crop loss due to weed competition, and ultimately contribute to the sustainable weed management.

S-metolachlor, applied in pre-emergence, hardly controlled *E. hirta* in the initial development stage of the sunflower crop, requiring the use of other pre-emergent herbicides, such as sulfentrazone and flumioxazin, which contributed to reducing the total plant density of weeds when applied in area 1. Furthermore, these herbicides significantly reduced the incidence of voluntary soybean. In general, the similarity indices showed low variation between areas and evaluation seasons, demonstrating the need for research with new herbicide molecules to be used in post-emergence sunflower production in order to reduce weed interferences until the harvest of the crop.

The results of this phytosociological survey provide a momentary assessment of the weed composition in sunflower producing areas of the Parecis region, Brazil, which can be used to minimize the damage caused by weed interference in the crop through the proper selection and timely application of herbicides.

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