

Weed control and fitosociology in cassava under pre-emergent herbicides and root quality

Controle de plantas daninhas e fitotoxicidade em mandioca sob herbicidas pré-emergentes qualidade das raízes

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Abstract: Background: Cassava (*Manihot esculenta*) is native from Brazil, widely cultivated across the country, and is the third largest source of food in the Brazilian tropical regions. Mechanical weeding is commonly used for weed control in cassava, which can be associated with herbicides.

Objective: To evaluate the weed control, phytosociology, yield, and sensory analysis of cassava treated with pre-emergent herbicides.

Methods: Two field experiments were conducted, with a randomized block design and four replications. The treatments consisted of the herbicides S-metolachlor, metribuzin, and clomazone applied after the planting of cassava cuttings, with additional weeding and weed-infested controls. The evaluation included weed control and phytosociology, plant height, number of leaves, and cassava yield. The roots were peeled and subjected to sensory evaluation using a multiple comparison discriminative test.

Results: The herbicides were effective in controlling most weeds, affecting phytosociology during cassava growth. *Richardia brasiliensis* was the most important weed specie when using clomazone and metribuzin. A significant improve in cassava yield was obtained when pre-emergent was applied, likewise at sensory root quality.

Conclusions: There is a difference in the control spectrum among herbicides, which leads to variations in the phytosociology of weed species. The importance value index for *Richardia brasiliensis* was higher for clomazone and metribuzin. The number of leaves per plant, plant height, cassava yield, and quality were greater in the herbicide-treated and weeding treatments compared to the untreated control.

Keywords: *Richardia brasiliensis*. Importance Value Index. *Manihot esculenta*. Clomazone. Metribuzin. S-metolachlor.

Resumo: Introdução: A mandioca (*Manihot esculenta*) é uma espécie nativa do Brasil, amplamente cultivada em todo o território nacional e a terceira fonte de alimento nas regiões tropicais. O controle mecânico de plantas daninhas é comumente utilizado, podendo ser associado ao uso de herbicidas.

Objetivo: Avaliar o controle de plantas daninhas, a fitossociologia, a produtividade e a análise sensorial da mandioca tratada com herbicidas pré-emergentes.

Métodos: Foram conduzidos dois experimentos de campo em delineamento em blocos ao acaso, com quatro repetições. Os tratamentos consistiram na aplicação dos herbicidas S-metolachlor, metribuzin e clomazone após o plantio das manivas, além das testemunhas capinada e infestada. As avaliações incluíram o controle e a fitossociologia das plantas daninhas, a altura e o número de folhas por planta e a produtividade da mandioca. As raízes foram descascadas e submetidas à análise sensorial por meio de teste discriminativo de comparação múltipla.

Resultados: Os herbicidas controlaram a maioria das plantas daninhas, alterando a fitossociologia durante o ciclo da cultura. A *Richardia brasiliensis* destacou-se como a espécie daninha mais importante nos tratamentos com clomazone e metribuzin. A aplicação de herbicidas pré-emergentes proporcionou aumento significativo na produtividade e na qualidade sensorial das raízes.

Conclusões: O espectro de controle entre os herbicidas é diferente, refletido nas variações da fitossociologia. O índice de valor de importância foi maior para *Richardia brasiliensis* para clomazone e metribuzin. O número de folhas, altura das plantas, produtividade e a qualidade das raízes foram superiores nos tratamentos com herbicidas e na testemunha capinada em relação à infestada.

Palavras-chave: *Richardia brasiliensis*. Índice de Valor de Importância. *Manihot esculenta*. Clomazone. Metribuzin. S-metolachlor.

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1. Introduction

Cassava (*Manihot esculenta* Crantz) is native to Brazil and plays a crucial role in the economy of various tropical countries. In Brazil, it is widely cultivated both for human consumption and as a raw material for the food and biofuel industries (Oliveira and Almeida, 2024). Due to its excellent adaptation to soil and climatic conditions, cassava has become the third largest food source in Brazil's tropical regions, following rice and maize (Suharko and Hudayana, 2020).

At the national level, the state of Pará has the largest cultivated areas of cassava, accounting for 20.97% of the total area, followed by Bahia (13.65%), Maranhão (10.74%), and Paraná in fourth place with 8.93%. The other states of Brazil collectively hold just over 45% of the total cassava-growing areas (Embrapa, 2018). However, cassava yield is significantly impacted by competition with weeds, which reduces the availability of essential resources such as water, nutrients, and light, thus impairing crop growth and development (Dje Bi et al., 2018).

Weed management is one of the most significant challenges faced by producers, requiring the adoption of strategies that integrate cultural, mechanical, and chemical methods (Ekeleme et al., 2016). The crop's slow initial development and low shading potential make it less competitive against weeds. Among the damages caused by weeds in cassava are reduced crop yield, increased production costs, harvesting difficulties, reduced quality of harvested roots, and shorter marketable shelf life (Peressin et al., 2022). Losses due to weed presence can reach up to 90%, depending on the duration of infestation and the density of weeds (Albuquerque et al., 2008).

Weed control in cassava has traditionally been carried out using mechanical weeding. Chemical control is applied in specific areas of cassava cultivation, with pre-emergent herbicides standing out for their ability to prevent the germination and early development of weeds shortly after planting (Albrecht et al., 2021). These herbicides are highly effective in controlling unwanted species, particularly during the early stages of crop growth. The use of pre-emergent herbicides can also enhance the effectiveness of post-emergent control methods (Salomão et al., 2021), reducing operational costs and minimizing the environmental impact associated with post-emergent herbicide use.

The application of pre-emergent herbicides requires careful management to ensure selectivity for cassava, thus avoiding phytotoxicity. The interaction between herbicide application and soil characteristics, such as pH, texture, and organic matter content, can also influence both the efficacy and safety of the herbicide for the cassava plant (Skaraboto et al., 2018). While chemical weed control is a common practice, improper application can lead to phytotoxicity, which directly impacts root quality (Rosa et al., 2020). Inappropriate herbicide use, lack of crop rotation, and poor management of fertilization and pest control can result in roots with lower commercial value (Cardoso et al., 2022).

Sensory analysis has emerged as an effective tool for assessing food quality, including cassava, due to its essential role in evaluating organoleptic characteristics such as flavor, texture, aroma, and appearance (Tagliapietra et al., 2021). This method allows for the identification of variations in the quality of cassava roots, which may be influenced by factors such as cultivation practices, post-harvest handling, and processing. Sensory analysis is particularly important in cassava, as research involving diverse consumer groups has identified seven key quality attributes of cooked cassava, including preparation, visual appearance, flavor, and texture (Iragaba et al., 2024). Sensory analysis plays a crucial role in ensuring quality standards and is essential for product improvement and consumer satisfaction.

The use of pre-emergent herbicides provides significant benefits in controlling cassava weeds. Therefore, the implementation of effective weed management programs is vital to ensure the sustainability of cassava production in the face of growing global demand for food and biofuels (Parmar et al., 2017). The aim of this study was to evaluate the effectiveness of pre-emergent herbicides in weed control, phytosociology, yield, and sensory analysis of cassava.

2. Material and Methods

The experiment was repeated in the 2018/2019 and 2019/2020 growing seasons in the city of Júlio de Castilhos, Rio Grande do Sul (29° 13' 37" S, 53° 40' 57" W; altitude of 529 m). A randomized block design with four replications was used. Before planting, the area was properly prepared with harrowing followed by the construction of raised beds, where 300 kg of the 5-20-20 fertilizer formulation was applied. In both experiments, cassava cuttings from the Vassourinha cultivar were used, buried at a depth of up to 5 cm. The experimental units consisted of plots measuring 15.36 m², containing 32 cassava plants, spaced 0.8 m between

plants and rows.

The treatment factor consisted of pre-emergent herbicides: S-metolachlor (1680 g i.a. ha⁻¹ - commercial product), clomazone (1080 g i.a. ha⁻¹ - commercial product), and metribuzin (480 g i.a. ha⁻¹ - commercial product) is important present the comercial herbicides used, along with a weed-free check (maintained with manual weeding) and an untreated control (weeds present throughout the entire crop cycle). The treatments were applied using a CO₂ pressurized backpack sprayer, calibrated to provide a spray volume of 150 L ha⁻¹, equipped with a 110.015 flat fan nozzle. The application was made over the planting line in the raised beds, one day after planting the cuttings.

The following variables were analyzed: weed control and phytosociology of the weed species present in the area, number of leaves, plant height, and cassava yield. Weed control was evaluated at 22, 29, and 43 days after application (DAA) for the 2018/2019 season and at 24 and 32 DAA for the 2019/2020 season. The following weed species were evaluated in the 2018/2019 season: goosegrass (*Eleusine indica*) (432 plants m⁻²), common pigweed (*Amaranthus deflexus*) (52 plants m⁻²), hairy beggarticks (*Bidens pilosa*) (120 plants m⁻²), and wild radish (*Raphanus sativus*) (368 plants m⁻²). In the 2019/2020 season, the following species were evaluated: Brazilian pusley (*Richardia brasiliensis*) (408 plants m⁻²), nutsedge (*Cyperus* sp.) (72 plants m⁻²), wild radish (68 plants m⁻²), and wild oat (*Avena sativa*) (62 plants m⁻²). A percentage scale was used for weed control evaluations, where 0 indicated no injury and 100 indicated complete plant death (SBCPD, 1995).

For phytosociology, weed surveys were conducted at 32 and 43 DAA for the 2018/2019 and 2019/2020 seasons, respectively. Random sampling was carried out for each experimental unit using a metallic frame with an internal area of 0.25 m². The number of individuals in each sample was counted, and the species were identified to genus and species level. Based on the data obtained, phytosociological variables were calculated according to the methodology proposed by Mueller-Dombois and Ellenberg (1976), using the following equations:

Relative Frequency (FR):

$$RF = \frac{\left(\frac{N^{\circ} \text{ samples with the species}}{\text{Total n}^{\circ} \text{ of samples}} \right) \times 100}{\text{Total frequency of all species in the treatment}}$$

Relative Density (DR):

$$DR = \frac{\left(\frac{N^{\circ} \text{ of plants of the species in sample}}{0,25 \text{ m}^2} \right) \times 100}{\text{Total density of all species in the treatment}}$$

Relative abundance (AR):

$$AR = \frac{\left(\frac{N^{\circ} \text{ of plants of the same species in the sample}}{N^{\circ} \text{ of samples with the species}} \right) \times 100}{\text{Total abundance of all species in the treatment}}$$

Relative importance Value Index (IVIR):

$$IVIR = FR + DR + AR$$

Relative Frequency (FR) determines the distribution of species in the samples; Relative Density (DR) represents the number of plants of each species per unit area; Relative Abundance (AR) demonstrates the concentration of species in the area. The Relative Importance Value Index (RIVI) determines the most important species present in the survey.

The evaluations of the number of leaves, plant height, and cassava yield were conducted in the 2019/2020 season, as they could not be evaluated in the 2018/2019 season due to drought, which prevented proper crop development. Plant height and number of leaves were assessed on the same day as harvest from five plants per plot, with plant height measured using a graduated ruler and the number of leaves counted directly on the same five plants. Harvesting was done by uprooting five plants per plot, separating roots with a length greater than 10 cm and a diameter of 2 cm or more.

For sensory analysis, the preparation of the roots followed the methodology of Tagliapietra et al. (2021), where 2 kg of cassava from each plot were peeled and frozen, then the roots were cooked and offered to participants. A total of 57 untrained judges, selected based on their availability and willingness to participate in the analysis, took part in the evaluation. A discriminative multiple comparison test was applied to assess how the roots treated with herbicides differed, for better or worse, in terms of the following attributes: flavor, texture, and appearance, compared to the weed-free check. A structured 5-point scale was used, where 1 and 5 indicated no difference and extreme difference compared to the weed-free check, respectively.

The analysis was performed in individual booths, and

the judges were presented with approximately 6 grams of each sample, coded with random three-digit numbers, on a tray. Along with the samples, a disposable cup with room-temperature filtered water was provided to cleanse the palate between samples to ensure proper sensory perception (Ferreira et al., 2000). Since this study involved experimentation with human participants, it was reviewed and approved by the Ethics Committee in Research at the Federal University of Santa Maria, under approval number 2.623.612.

Data was analyzed using the R software, with the ExpDes package (Healy, 1956). The data were subjected to analysis of variance, homogeneity of residual variances (Bartlett), normality of errors (Shapiro-Wilk), and mean comparison by Tukey's test ($p \leq 0.05$) when significant differences were detected.

3. Results and Discussion

Weed Control using pre-emergent herbicides

The results were consistent with the homogeneity (Bartlett) and normality (Shapiro-Wilk) tests. For the 2018/2019 growing season and the control variable, in all evaluation periods, the herbicides clomazone and S-metolachlor proved effective in controlling goosegrass (*Eleusine indica*), with no significant difference between them at 22 and 43 days after application (DAA) (Table 1). It is worth noting that clomazone provided control similar to the weed-free check at these same evaluation periods. The herbicide clomazone is selective for cassava under various cultivation conditions and soil types (Costa et al., 2013; Fontes et al., 2021), and its mixture with metribuzin provided more than 80% control of grasses and broadleaf weeds (Ekeleme et al., 2020).

Table 1. Control of different weed species in cassava crop evaluated at 22, 29, and 43 days after pre-emergent herbicide application (DAA). Júlio de Castilhos, 2018-2019 growing season.

Treatment	Goosegrass (<i>Eleusine indica</i>)	Common pigweed (<i>Amaranthus deflexus</i>)	Hairy beggarticks (<i>Bidens pilosa</i>)	Wild radish (<i>Raphanus sativus</i>)
22 DAA				
Weed-free check	100 a	100 a	100 a	100 a
Clomazone	97 ab	73 a	66 b	72 b
Metribuzin	0 c	80 a	72 b	16 c
S-metolachlor	94 b	78 a	26 c	5 d
Untreated control	0 c	0 b	0 c	0 d
CV ² (%)	3.57	31.60	23.64	16.19
29 DAA				
Weed-free check	100 a	100 a	100 a	100 a
Clomazone	96 b	86 ab	80b	68 b
Metribuzin	0 d	80 b	81 b	50 b
S-metolachlor	92 c	84 ab	61 c	12 c
Untreated control	0 d	0 c	0 d	0 c
CV (%)	2.67	15.76	12.11	26.28
43 DAA				
Weed-free check	100 a	100 a	100 a	100 a
Clomazone	96 ab	72 b	71 b	64 bc
Metribuzin	0 c	87 ab	86 ab	79 b
S-metolachlor	90 b	88 ab	35 c	47 c
Untreated control	0 c	0 c	0 d	0 d
CV (%)	9.79	21.08	17.60	20.73

¹Means followed by the same letter in the column, for each evaluation period, do not differ significantly by the Tukey test ($p \leq 0.05$).

²Coefficient of variation.

For the control of common pigweed (*Amaranthus deflexus*), no differences were observed between the herbicides, regardless of the evaluation period. The control of *Amaranthus hybridus*, *A. lividus*, *A. spinosus*, and *A. viridis* was also considered effective with the application of S-metolachlor and clomazone at rates of 1,000 and

720 g i.a. ha⁻¹, with control indices greater than 80% and 60%, respectively (Raimondi et al., 2010). On the other hand, the control of wild radish (*Raphanus sativus*) was ineffective with S-metolachlor application, regardless of the growing season, with analysis showing that this herbicide was only superior to the untreated control (Tables 1 and 2).

Table 2. Control of different weed species in cassava crop evaluated at 22 and 43 days after pre-emergent herbicide application (DAA). Júlio de Castilhos, 2019-2020 growing season.

Treatment	Wild radish (<i>Raphanus sativus</i>)	Brasilian pusley (<i>Richardia brasiliensis</i>)	Nutsedge (<i>Cyperus</i> sp.)	Wild oat (<i>Avena sativa</i>)
22 DAA				
Weed-free check	100 a	100 a	100 a	100 a
Clomazone	91 a	72 b	81 b	95 a
Metribuzin	86 a	79 b	86 ab	92 a
S-metolachlor	51 b	85 ab	95 ab	71 a
Untreated control	0 c	0 c	0 c	0 c
CV ² (%)	17.73	19.20	12.79	26.52
43 DAA				
Weed-free check	100 a	100 a	100 a	100 a
Clomazone	78 ab	59 b	64 b	92 ab
Metribuzin	71 b	66 b	79 b	81 bc
S-metolachlor	30 c	70 b	72 b	66 c
Untreated control	0 c	0 c	0 c	0 c
CV (%)	29.93	19.86	18.23	16.78

¹Means followed by the same letter in the column, for each evaluation period, do not differ significantly by the Tukey test ($p \leq 0.05$).

²Coefficient of variation.

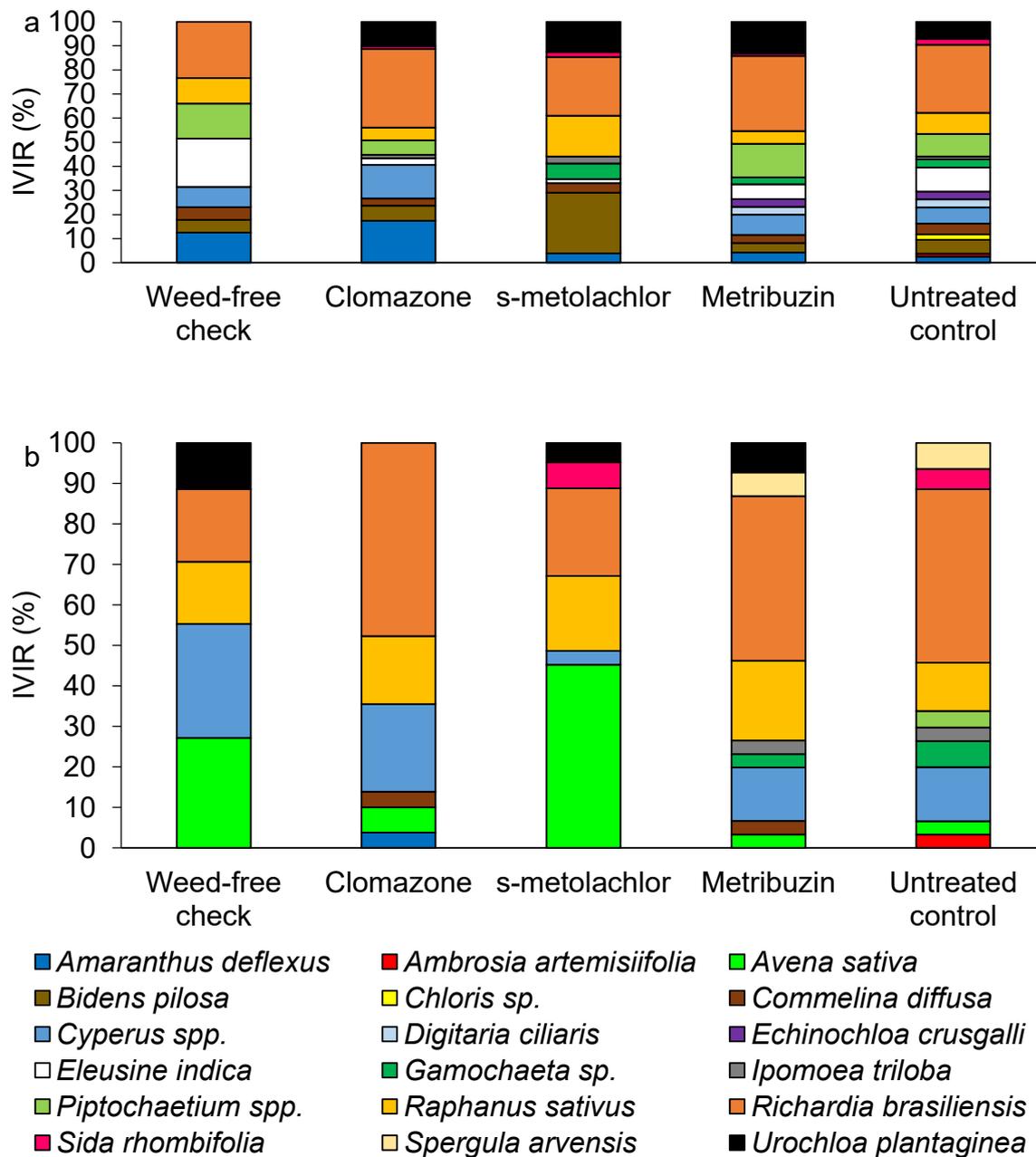
For the second growing season of the experiment (2019/2020), the application of the pre-emergent herbicides metribuzin and S-metolachlor provided similar control of wild radish at 22 and 32 DAA, with no significant differences between them, and both superior to S-metolachlor alone (Table 2). Furthermore, S-metolachlor was the only herbicide to provide control of nutsedge (*Cyperus* sp.) greater than 90%, although no significant differences were observed from the other herbicides in all evaluation periods (Table 2). The application of S-metolachlor in a pre-plant incorporation system resulted in a reduction of the dry mass of the aerial part of *Cyperus esculentus* by more than 64%, demonstrating its efficacy under the application conditions (De Cauwer et al., 2017). A similar result was observed for the control of Brazilian pusley (*Richardia brasiliensis*) and wild oat (*Avena sativa*), where, in most comparisons, no differences were found between the pre-emergent herbicides applied, and all were superior to the untreated control (Table 2).

Phytosociological survey

The phytosociology analysis identified sixteen weed species, belonging to nine different botanical families, in the 2018-2019 growing season. These included *Poaceae* (six species), *Asteraceae* (three species), and one species each from the families *Amaranthaceae*, *Brassicaceae*, *Commelinaceae*, *Convolvulaceae*, *Cyperaceae*, *Malvaceae*, and *Rubiaceae*. In the second growing season, 2019-2020, fourteen species from ten families were identified, as follows: three species from the

Poaceae and *Asteraceae* families each, and one species each from the *Amaranthaceae*, *Brassicaceae*, *Caryophyllaceae*, *Commelinaceae*, *Convolvulaceae*, *Cyperaceae*, *Malvaceae*, and *Rubiaceae* families. Based on the relative importance index (IVIR), Brazilian pusley emerged as the species with the highest values in both the 2018-2019 and 2019-2020 growing seasons for the untreated control, with values of 28.13 and 42.79, respectively (Figure 1). The IVIR identifies the species with the highest importance in the analysis, which was present at the sampling site (Mueller-Dombois and Ellenberg, 1976).

It was also observed that Brazilian pusley exhibited the highest IVIR values for the clomazone and metribuzin herbicides, regardless of the growing season (Figure 1), which explains the low control values observed (Table 2). This result is primarily related to the fact that the herbicides did not provide adequate control of the species at the applied doses, environmental conditions did not favor the control of this specie, and/or the herbicide's residual activity in the soil had ended, allowing reinfestation by the weed. This condition may be further exacerbated by the lack of a vegetative canopy, which favors the emergence of Brazilian pusley, as the presence of a canopy reduces the amount of light reaching the soil and can reduce the species' emergence by up to 90% (Gallon et al., 2018). The use of cover crops containing forage turnip and a dry mass of the aerial part exceeding 4 Mg ha⁻¹ reduced the IVIR of Brazilian pusley, supporting the need for a closed canopy to reduce the occurrence of this species (Grün et al., 2024).



When comparing herbicides, it is noteworthy that in the clomazone treatments, the IVIR for common pigweed and nutsedge was higher compared to those observed with S-metolachlor and metribuzin (Figure 1). This result reflects the low efficacy of clomazone in controlling these species. In contrast, the IVIR for wild radish did not vary substantially between the different herbicide treatments, suggesting that the uniform occurrence of this species may be linked to the cultivation of the species as a cover crop in the autumn-winter in the area (Grün et al., 2024). This can also be associated with the IVIR of wild oat in the second growing season. Therefore, it is pertinent to manage cover crops at the appropriate time, prioritizing the avoidance of seed production that could have negative impacts on subsequent

crops.

Cassava number of leaves, height and yield

For the number of leaves, it was observed that plots treated with the herbicides S-metolachlor and clomazone presented higher values compared to the weed-free check and metribuzin, although no significant difference was observed between the herbicides (Table 3). Both plant height and the number of leaves are important indicators of yield, as larger plants tend to have more leaves, which results in greater energy absorption and conversion into photoassimilates, ultimately leading to higher yield. The analysis of plant height did not show any difference between the herbicides

and the weed-free check (Table 3). This result demonstrates that both manual weeding and the use of pre-emergent herbicides minimized competition with the weed community, as these treatments promoted a 40% increase in plant height

compared to the untreated control (Table 3). This can be explained by the fact that pre-emergent weed control ensures good cassava development, allowing the crop to achieve up to 80% of its yield potential (Cardoso et al., 2022).

Table 3. Number of leaves, plant height, and cassava yield as a function of pre-emergent herbicide application. Júlio de Castilhos, 2019-2020.

Treatment	Number of leaves plant ⁻¹	Plant height (cm)	Yield (Mg ha ⁻¹)
Weed-free check	30.1 b	62.1 a	13.6 a
Clomazone	49.2 a	67.4 a	5.5 b
Metribuzin	43.3 ab	68.8 a	4.1 bc
S-metolachlor	49.4 a	77.4 a	5.9 b
Untreated control	6.6 c	41.9 b	0.6 c
CV ² %	57.11	30.93	42.75

¹Means followed by the same letter in the column do not differ significantly by the Tukey test ($p \leq 0.05$).

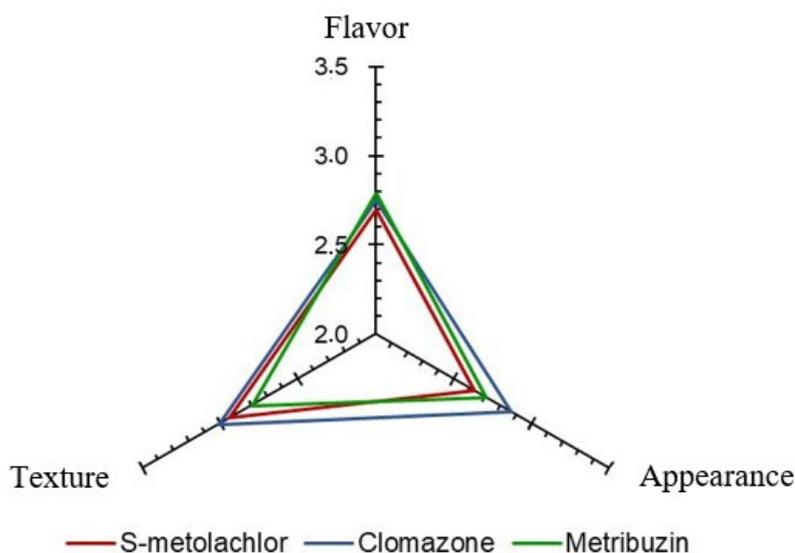
²Coefficient of variation.

The yield variable, assessed only in the second growing season due to climatic conditions in the first growing season, showed that the weed-free check promoted a 50% increase compared to the pre-emergent treatments (Table 3). This result is justified by the fact that even with the application of pre-emergents, some weed species remained in the area, negatively impacting cassava growth (Figure 1). However, the control promoted by the different herbicides (Table 2) resulted in approximately 90% higher yield compared to the untreated control (Table 3), confirming that the use of pre-emergent herbicides is a necessary practice for cassava cultivation. Competition with weeds can result in yield losses of up to 90% for cassava (Silva et al., 2012), a result clearly observed in the low yield of the weed-infested check. The application of clomazone,

diuron, and oxadiazon in the 'Aipim-Manteiga' cultivar did not promote any difference in yield compared to the weed-free check (Fontes et al., 2021).

Sensory analysis

In the sensory analysis, 57 panelists participated in the study, 40% of whom were female and 60% male, with most being young adults aged between 20 and 30 years. The ratings given by the panelists regarding the sensory aspects of cassava roots are presented in Figure 2. These results generally indicated that the three herbicides used showed similar behavior in all three sensory attributes analyzed (flavor, texture, and appearance).



Legend: 1 and 5 indicate no or extreme difference compared to the standard (weed free), respectively.

Figure 2. Sensory profile representing the average of the attributes flavor, appearance, and texture of cooked cassava roots based on different pre-emergent herbicides compared to the weed-free check. Santa Maria, 2020.

The mean values of the difference found in relation to the standard sample ranged from 2.63 to 3.01, with this difference being reported as positive by the panelists, meaning the roots were considered better than the weed-free check treatment. In a sensory test conducted on cassava roots subjected to different management practices, it was observed that the most accepted roots by the panelists were those that received the best management practices, including weed control through S-metolachlor application and manual weeding (Tagliapietra et al., 2021). This can be explained by the fact that any stress experienced by the crop alters its flavor, texture, and appearance (Lorenzi, 2012). Therefore, the use of herbicides helped prevent competitive stress from weeds, improving these attributes.

4. Conclusions

The pre-emergent herbicides S-metolachlor, clomazone, and metribuzin are effective in controlling most weed species. There is a difference in the control spectrum between the herbicides, leading to variations in the weed

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