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Efficacy Trial of *Chromolaena odorata* and Coconut Vinegar as an Alternative Herbicide

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ABSTRACT

This study evaluated the herbicidal efficacy of aqueous extracts from different parts of *Chromolaena odorata* (L.) enhanced with coconut vinegar for the control of common weeds under field conditions. Specifically, the study aimed to determine which plant part (leaves, roots, or stems) exhibited the greatest weed control efficacy compared with a positive control (sterile distilled water) and a negative control (glyphosate). The experiment was conducted using a Randomized Complete Block Design (RCBD) with five treatments and three replications. The treatments consisted of T1 – Sterile Distilled Water (positive control), T2 – *C. odorata* leaves + coconut vinegar + sterile distilled water, T3 – *C. odorata* roots + coconut vinegar + sterile distilled water, T4 – *C. odorata* stems + coconut vinegar + sterile distilled water, and T5 – Glyphosate (negative control). Results showed that the *C. odorata*-based formulations significantly suppressed weed growth compared with the untreated control. Seven days after application, Treatment 2 recorded the highest weed control rating among the botanical treatments (7.33 ± 0.58), followed by Treatment 4 (7.00 ± 1.00) and Treatment 3 (6.67 ± 1.15), while glyphosate achieved a mean rating of 8.00 ± 0.00. Fourteen days after application, weed control ratings declined for the botanical treatments, with Treatment 2 recording 5.33 ± 0.58, Treatment 4 recording 5.00 ± 1.00, and Treatment 3 recording 4.67 ± 0.58, whereas glyphosate achieved complete weed control (10.00 ± 0.00). Analysis of variance (ANOVA) revealed highly significant differences among treatments at both evaluation periods ($p < 0.001$). Tukey's Honestly Significant Difference (HSD) test indicated that all *C. odorata*-based treatments significantly outperformed the untreated control, while no significant differences were observed among the leaf, root, and stem extracts. However, glyphosate provided significantly greater weed control than the botanical formulations after 14 days. Among the weed species evaluated, *Cleome rutidosperma* was the most susceptible to the *C. odorata* extracts, whereas *Physalis angulata* was the least affected. The findings demonstrate that aqueous extracts of *C. odorata* enhanced with coconut vinegar possess promising herbicidal activity and can effectively suppress common weeds, particularly during the early stages of weed growth. Although their efficacy was lower than that of glyphosate over time, the comparable performance of the leaf, root, and stem extracts suggests that allelopathic compounds are distributed throughout the plant. These results highlight the potential of *C. odorata* as a sustainable botanical herbicide and provide a basis for further optimization of formulation, concentration, and application strategies for integrated weed management.

Keywords: Chromolaena odorata, allelopathy, botanical herbicide, coconut vinegar, weed management, glyphosate, bioherbicide.

INTRODUCTION

Weeds remain one of the major constraints to agricultural productivity because they compete with crops for sunlight, water, nutrients, and growing space. They also serve as alternate hosts for insect pests and diseases, interfere with irrigation and harvesting operations, reduce crop quality, and contaminate harvested produce with weed seeds. Consequently, uncontrolled weed infestations can cause substantial yield losses and increased production costs. Weed management commonly relies on tillage, hand weeding, and synthetic herbicides.

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Although synthetic herbicides provide rapid and effective weed control, their prolonged and indiscriminate use has raised concerns regarding environmental pollution, herbicide resistance, and adverse effects on soil health and biodiversity. Herbicides may alter soil microbial communities, affect nutrient cycling, contaminate water resources, and negatively impact non-target organisms (Haney et al., 2000; Johnsen et al., 2001; Duke & Powles, 2008).

These concerns have intensified the search for environmentally friendly alternatives, particularly plant-based herbicides that are compatible with sustainable and organic agriculture. Plants naturally synthesize a wide variety of secondary metabolites that function in defense and ecological interactions. Many of these compounds exhibit allelopathic properties, enabling plants to suppress the growth and development of neighboring species. This phenomenon, known as allelopathy, was first described by Molisch (1937) and later defined by Rice (1984) as the direct or indirect effect of one plant on another through the release of biologically active chemical compounds, or allelochemicals. These compounds may be released through root exudation, volatilization, leaf leaching, or decomposition of plant residues and can inhibit seed germination, root elongation, photosynthesis, nutrient uptake, and other physiological processes essential for plant growth (Inderjit & Duke, 2003; Cheng & Cheng, 2015).

One plant with considerable potential as a source of natural herbicides is *Chromolaena odorata* (L.) R.M. King & H. Robinson, commonly known as Siam weed or hagonoy. Native to tropical America, it has become one of the world's most invasive weeds due to its rapid growth, high adaptability, and strong allelopathic activity (Zachariades et al., 2009). The species suppresses surrounding vegetation not only through competition for resources but also through the release of phytotoxic secondary metabolites. Phytochemical studies have identified numerous bioactive compounds in *C. odorata*, including phenolic acids such as gallic, caffeic, chlorogenic, ferulic, and *p*-coumaric acids; flavonoids including quercetin, kaempferol, rutin, and luteolin; as well as terpenoids, sesquiterpene lactones, tannins, saponins, and essential oils (Phan et al., 2004; Taleb-Contini et al., 2007; Vijayaraghavan et al., 2017). These compounds have been reported to inhibit seed germination, reduce root and shoot growth, interfere with cell division, and disrupt photosynthesis and enzyme activities in susceptible plants, making *C. odorata* a promising source of botanical herbicides.

Among the different plant parts, the leaves generally contain the highest concentration of water-soluble phenolic compounds and flavonoids, resulting in stronger phytotoxic effects than stems or roots (Ambika & Jayachandra, 1980). Aqueous extracts of *C. odorata* have demonstrated inhibitory effects on the germination and seedling growth of several crop and weed species, suggesting their potential as an environmentally friendly weed management tool. Furthermore, combining these extracts with coconut vinegar, which contains acetic acid capable of rapidly damaging plant tissues, may enhance herbicidal efficacy through complementary modes of action (Webber et al., 2005).

Considering the abundance of *C. odorata*, its rich composition of allelopathic compounds, and the increasing demand for sustainable weed management strategies, this study was conducted to evaluate the herbicidal potential of aqueous extracts from the leaves, stems, and roots of *C. odorata*, both alone and in combination with coconut vinegar, as a potential organic herbicide.

METHODOLOGY

Preparation of Treatments

Fresh leaves, roots, and stems of *Chromolaena odorata* were collected from naturally growing stands within the study area. The plant materials were thoroughly washed with tap water to remove adhering soil and debris, air-dried under shaded conditions at ambient room temperature (27–30°C) for approximately 24 hours to remove surface moisture, and cut into strips measuring approximately 0.5 cm in length.

Separate extracts were prepared for the leaves, roots, and stems. Each extract consisted of 1 kg of fresh plant material mixed with 3 L of sterile distilled water, corresponding to a 1:3 (w/v) extraction ratio (approximately 0.33 g mL^{-1} of fresh plant tissue). The mixtures were placed in clean, covered plastic containers and allowed to

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stand for 72 hours at room temperature (27–30°C) under shaded conditions without direct sunlight. The containers were gently stirred twice daily to facilitate the extraction of water-soluble allelochemicals. After 72 hours, the extracts were filtered through a fine mesh cloth to remove plant residues and obtain the crude aqueous extracts.

Commercially available naturally fermented coconut vinegar (5% acidity) was used as an enhancer in the formulation. Coconut vinegar was incorporated based on its reported ability to lower the pH of the extract, potentially improving the extraction and stability of bioactive compounds while also contributing its own organic acids with possible herbicidal activity.

Experimental Design and Treatments

The experiment was laid out using a Randomized Complete Block Design (RCBD) with five treatments and three replications. The treatments were as follows:

- For Treatments 2–4, the final formulation consisted of **T1** – Positive Control (Sterile Distilled Water)
- **T2** – Chromolaena odorata leaves + Coconut Vinegar + Sterile Distilled Water
- **T3** – Chromolaena odorata roots + Coconut Vinegar + Sterile Distilled Water
- **T4** – Chromolaena odorata stems + Coconut Vinegar + Sterile Distilled Water
- **T5** – Negative Control (Glyphosate)

a 1:1:3 ratio of *C. odorata* crude extract, coconut vinegar, and sterile distilled water, equivalent to 1 kg of plant material extracted in 3 L of sterile distilled water, combined with 1 L of coconut vinegar. This formulation was uniformly mixed immediately before application. For the negative control, glyphosate was applied following the manufacturer's recommended rate of 30 mL L^{-1} of water.

Experimental Site and Environmental Conditions

The field experiment was conducted under natural environmental conditions during the cropping season. Throughout the experimental period, the site experienced typical tropical climatic conditions, with ambient temperatures ranging from approximately 28–33°C, relative humidity of 75–90%, and intermittent rainfall. No rainfall occurred immediately after treatment application; however, rainfall was observed approximately three days after spraying, minimizing the likelihood of immediate wash-off of the treatments. Environmental conditions were monitored throughout the study to ensure that treatment responses reflected normal field conditions.

Treatment Application

The experimental area was divided into plots measuring 1 × 1 m per replication, with 0.5 m alleys between plots. Weed species present in the field were identified, with the dominant species including *Cleome rutidosperma*, *Physalis angulata*, *Echinochloa colona*, and *Heliotropium indicum*.

The treatments were applied using a knapsack sprayer equipped with four flat-fan nozzles. Applications were conducted in the afternoon, when air temperature ranged from 25–30 °C. The field was visited daily for monitoring and data collection. Weed control effectiveness on individual species was assessed at 7 and 14 days after application. Weeds were considered killed when all tissues from the growing points to the soil surface were completely dead.

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Figure 1. The common weeds. **A.** Cleome rutidosperma **B.** Physalis angulata, **C.** Echinocloa colona, **D.** Heliotropium indicum

Data Gathered

Evaluation for weed control was conducted to the identified dominant weeds species in the area and was based on the percentage weed control using the ratings below.

Table 1. Weed control rating method described in Lanie *et al*. (1993), Lanie *et al*. (1994), Murray *et al*. (1994), Utulu (1998), Pritchard (2002), and Chuah *et al*. (2004).

Rate	**Percent of growth reduction**	**Description**
0	0	no weed control
1	1-10	very poor weed control
2	11-20	poor weed control
3	21-30	poor to deficient weed control
4	31-40	deficient weed control
5	41-50	deficient to moderate weed control
6	51-60	moderate weed control
7	61-70	weed control somewhat less than satisfactory
8	71-80	satisfactory to good weed control
9	81-90	very good to excellent weed control
10	91-100	complete weed control

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RESULTS AND DISCUSSION

After 7 Days of Application

Seven days after application, the plots treated with sterile distilled water alone (T1, positive control) exhibited no observable weed control, with a mean rating of 0.00 ± 0.00 (Table 2). In contrast, all *Chromolaena odorata*-based treatments demonstrated moderate herbicidal activity. Treatment 2 (*Chromolaena odorata* leaves + coconut vinegar + sterile distilled water) recorded the highest mean weed control rating among the botanical treatments (7.33 ± 0.58), followed by Treatment 4 (*C. odorata* stems + coconut vinegar + sterile distilled water) (7.00 ± 1.00) and Treatment 3 (*C. odorata* roots + coconut vinegar + sterile distilled water) (6.67 ± 1.15). The glyphosate treatment (T5) produced the highest numerical weed control rating (8.00 ± 0.00), corresponding to satisfactory to good weed control.

A one-way analysis of variance (ANOVA) revealed a highly significant effect of treatment on weed control ratings seven days after application ($F(4,10) = 60.50$, $p < 0.001$), indicating that weed control differed significantly among the treatments. Prior to ANOVA, the assumptions of normality and homogeneity of variance were evaluated. The residuals were normally distributed based on the Shapiro–Wilk test ($p = 0.101$), while Levene's test indicated homogeneous variances among treatments ($p = 0.534$). Since both assumptions were satisfied, no data transformation or non-parametric analysis was necessary.

To determine which treatments differed significantly, Tukey's Honestly Significant Difference (HSD) test was performed. The analysis showed that the sterile distilled water control (T1) differed significantly from all herbicide treatments ($p < 0.001$), confirming that the application of *C. odorata* extracts and glyphosate effectively suppressed weed growth compared with the untreated control. However, no significant differences ($p > 0.05$) were detected among Treatments 2, 3, 4, and 5. Although glyphosate produced the highest numerical weed control rating, its performance was statistically comparable with the *C. odorata*-based formulations. Likewise, the leaf, root, and stem extracts exhibited comparable herbicidal activity, suggesting that the different plant parts possess similar weed-suppressive potential under the conditions of the present study.

Among the weed species evaluated, Cleome rutidosperma exhibited the greatest susceptibility to the *C. odorata*-based treatments. The leaves rapidly developed necrotic lesions, turned brown, and eventually dried, while the stems remained green. In contrast, Physalis angulata, Echinochloa colona, and Heliotropium indicum exhibited only slight scorching along the leaf margins with limited injury to the remaining plant tissues. The greater sensitivity of *C. rutidosperma* may be attributed to its relatively broad and thinner leaves, which likely allowed greater retention and absorption of the aqueous allelopathic extract. Conversely, *E. colona*, a grass species, possesses narrow upright leaves with a waxy cuticle that may reduce spray retention and penetration. Similarly, differences in cuticle thickness and leaf surface characteristics of *P. angulata* and *H. indicum* may have limited the absorption of the active compounds, resulting in reduced herbicidal injury.

The herbicidal activity observed in the present study is consistent with the reported allelopathic properties of *C. odorata*, which contains bioactive secondary metabolites such as phenolic acids, flavonoids, tannins, alkaloids, and terpenoids. These compounds have been reported to disrupt membrane integrity, inhibit photosynthesis and respiration, interfere with enzyme activity, and induce oxidative stress, ultimately causing chlorosis, necrosis, and growth inhibition. The rapid foliar injury observed in the treated weeds suggests that the aqueous extracts primarily acted as contact herbicides, damaging exposed leaf tissues rather than being translocated throughout the plant.

Interestingly, no significant differences were observed among extracts prepared from the leaves, roots, and stems of *C. odorata*. This finding suggests that allelopathic compounds are distributed throughout the different plant organs rather than being localized exclusively in the leaves. Previous phytochemical studies have reported the presence of phenolics, flavonoids, and other secondary metabolites in various tissues of *C. odorata*, although their concentrations may vary among plant parts. The comparable efficacy observed in this study indicates that each plant organ contains sufficient quantities of bioactive compounds capable of suppressing weed growth.

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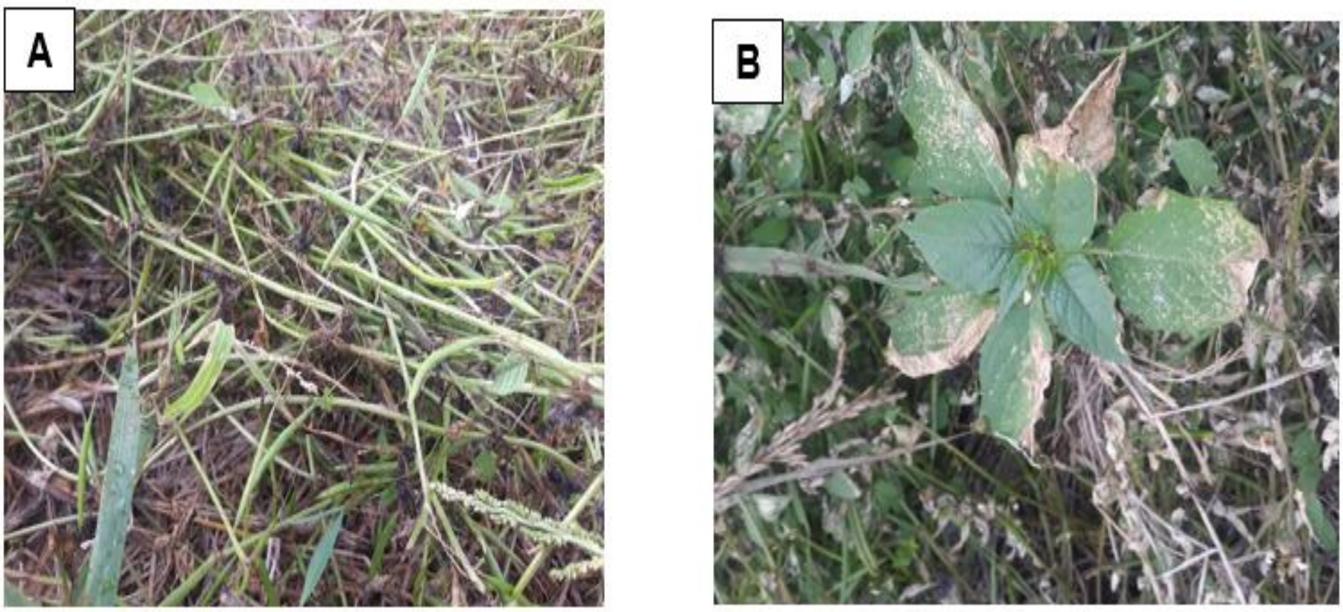
Although the *C. odorata*-based formulations demonstrated promising herbicidal activity, their effectiveness remained numerically lower than glyphosate. Rainfall occurring three days after application may have reduced the persistence of the extracts on the leaf surface through wash-off, thereby limiting absorption of the active compounds. Moreover, because aqueous *C. odorata* extracts function primarily as contact herbicides, they are unlikely to reach protected meristematic tissues or underground plant structures, allowing some weeds to survive despite visible foliar injury.

The findings indicate that *C. odorata* has considerable potential as a botanical herbicide. Future studies should investigate higher extract concentrations, optimize extraction procedures to maximize the recovery of allelochemicals, improve formulations through the use of natural surfactants or adjuvants to increase leaf retention and penetration, and evaluate combinations with other plant-derived herbicides possessing complementary modes of action. Furthermore, phytochemical characterization of the extracts, dose-response studies, repeated application schedules, and field evaluations under different environmental conditions are recommended to improve efficacy and support the development of *C. odorata*-based bioherbicides for sustainable weed management.

Table 2. Results after 7 days of application of the different treatments.

Treatment	***Mean ± SD***
T1 – Positive Control (Sterile Distilled Water)	***0.00 ± 0.00***
T2 – Chromolaena odorata Leaves + Coconut Vinegar + Sterile Distilled Water	***7.33 ± 0.58****
T3 – Chromolaena odorata Roots + Coconut Vinegar + Sterile Distilled Water	***6.67 ± 1.15****
T4 – Chromolaena odorata Stems + Coconut Vinegar + Sterile Distilled Water	***7.00 ± 1.00****
T5 – Negative Control (Glyphosate)	***8.00 ± 0.00****

Legend: ± standard deviation (SD). Asterisks indicate significant differences compared with the positive control (sterile distilled water) based on Tukey's Honestly Significant Difference (HSD) test following one-way ANOVA: ***** $p < 0.05$, ****** $p < 0.01$, ******* $p < 0.001$; ns = not significant.



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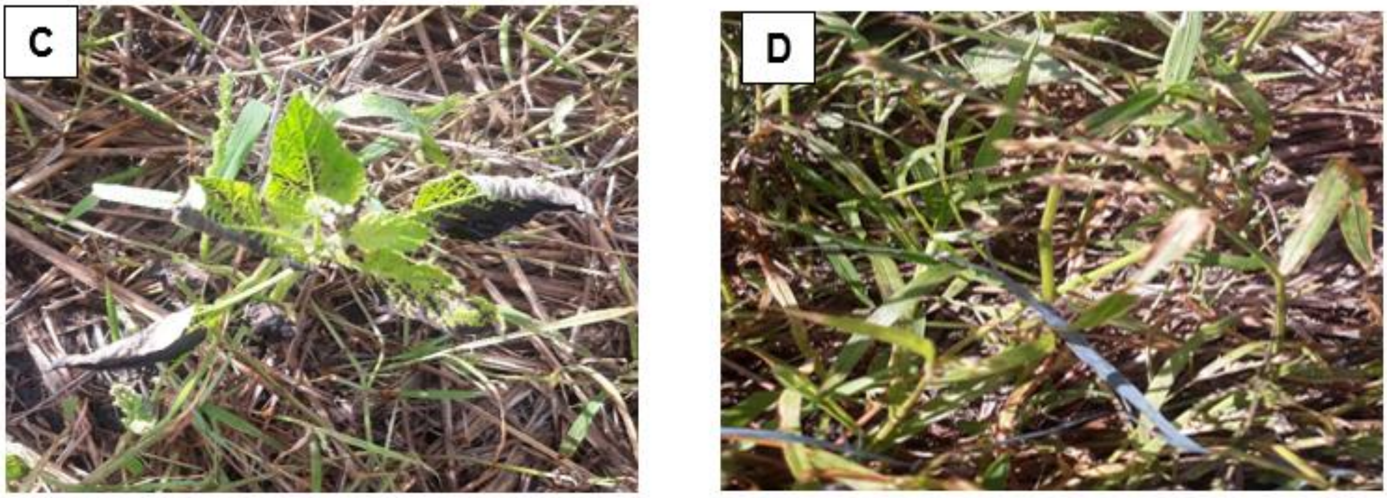

Figure 2. Common effects of the different treatments after 7 days of application. **A.** burned leaves of Cleome rutidosperma **B.** Scorched outer edges of the leaves of Physalis angulata **C.** Scorched outer edges of the leaves of Heliotropium indicum **D.** Scorched outer edges of the leaves of Echinocloa colona.

After 14 days of application

The one-way analysis of variance (ANOVA) revealed a highly significant effect of treatment on weed control ratings 14 days after application ($F(4,10) = 113.00$, $p < 0.001$), indicating that the herbicidal treatments differed significantly in their effectiveness over time. Subsequent multiple comparisons using Tukey's Honestly Significant Difference (HSD) test showed that all herbicide treatments significantly improved weed control compared with the sterile distilled water control ($p < 0.001$). Furthermore, glyphosate (T5) provided significantly greater weed suppression than the *Chromolaena odorata*-based formulations ($p < 0.05$), whereas no significant differences were observed among the leaf, root, and stem extracts ($p > 0.05$). These findings indicate that although the botanical formulations retained herbicidal activity after two weeks, their efficacy declined over time and remained inferior to the systemic herbicide glyphosate.

The reduction in weed control from seven to fourteen days suggests that the aqueous *C. odorata* formulations primarily function as contact herbicides rather than systemic herbicides. Contact herbicides rapidly damage exposed leaf tissues but exhibit limited translocation to underground structures or protected meristematic tissues. Consequently, mature weeds that retained viable growing points were able to regenerate after the initial foliar injury, explaining the observed regrowth of Cleome rutidosperma. In contrast, younger plants were completely desiccated because their growing tissues were more susceptible to the phytotoxic effects of the extracts. The gradual decline in herbicidal activity may also be attributed to the degradation of allelopathic compounds through environmental factors such as sunlight, oxidation, microbial activity, and rainfall, which reduce the persistence of the active ingredients under field conditions. The rainfall that occurred three days after application may have further contributed to the reduced residual activity by washing part of the extract from the leaf surface before complete absorption.

Despite the decline in efficacy, the leaf, root, and stem extracts continued to exhibit statistically comparable weed suppression, suggesting that allelopathic compounds are distributed throughout the different organs of *C. odorata*. Previous phytochemical studies have reported that phenolic acids, flavonoids, terpenoids, alkaloids, and tannins occur in both the aerial and belowground tissues of the plant, although their concentrations may vary among organs.

The comparable performance of the three botanical formulations indicates that each plant part contains sufficient quantities of bioactive secondary metabolites capable of suppressing weed growth.

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Although glyphosate achieved complete weed control after fourteen days, the *C. odorata*-based formulations still demonstrated appreciable herbicidal activity, highlighting their potential as environmentally friendly alternatives for integrated weed management. Their efficacy may be further improved through optimization of extract concentration, refinement of extraction procedures, repeated application schedules, incorporation of natural surfactants or sticking agents to enhance leaf retention and penetration, or combination with other plant-derived herbicides possessing complementary modes of action. Such improvements may increase the persistence and herbicidal effectiveness of the formulations under field conditions.

The present study was limited to the evaluation of a single extract concentration and formulation under one cropping season, and the concentrations of individual allelochemicals responsible for weed suppression were not quantified. Future research should investigate dose-response relationships, phytochemical characterization of the extracts, repeated application intervals, formulation stability, and efficacy under varying environmental conditions to support the development of more effective *C. odorata*-based bioherbicides for sustainable weed management.

Table 3. Results after 14 days of application of the different treatments.

Treatment	**Mean ± SD**
T1 – Positive Control (Sterile Distilled Water)	**0.00 ± 0.00**
T2 – Chromolaena odorata *Leaves + Coconut Vinegar + Sterile Distilled Water*	**5.33 ± 0.58***
T3 – Chromolaena odorata *Roots + Coconut Vinegar + Sterile Distilled Water*	**4.67 ± 0.58***
T4 – Chromolaena odorata *Stems + Coconut Vinegar + Sterile Distilled Water*	**5.00 ± 1.00***
T5 – Negative Control (Glyphosate)	**10.00 ± 0.00***

Legend: ± standard deviation (SD). Asterisks indicate significant differences compared with the positive control (sterile distilled water) based on Tukey's Honestly Significant Difference (HSD) test following one-way ANOVA: ***** $p < 0.05$, ****** $p < 0.01$, ******* $p < 0.001$; ns = not significant.

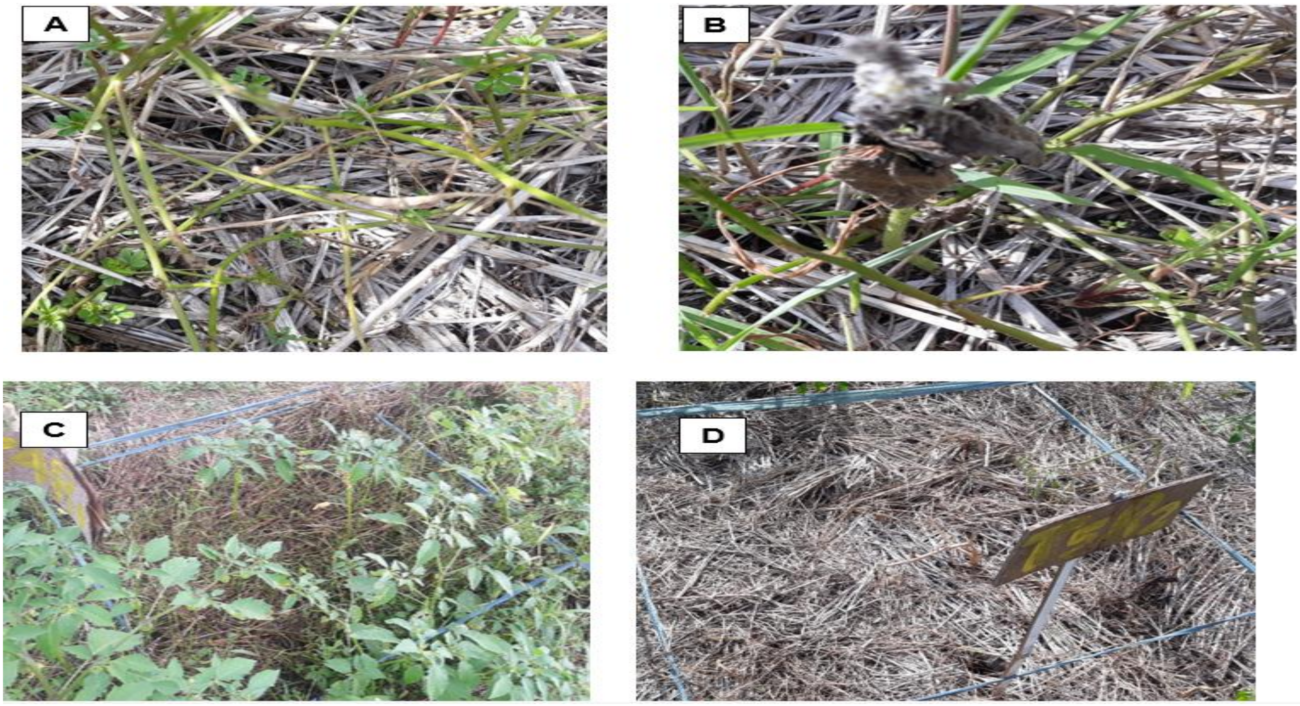

Figure 3. Common effects of the different treatments after 14 days of application. **A.** *Cleome rutidosperma* started to regrowth **B.** scorched leaves of young *Heliotropium indicum* **C.** No injury on *Physalis angulata* **D.** completely controlled weeds in treatment 5

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CONCLUSION AND RECOMMENDATION

Conclusion

The results of this study demonstrated that aqueous extracts of *Chromolaena odorata* combined with coconut vinegar possess herbicidal activity against common weeds under field conditions. Among the botanical treatments, the leaf extract (Treatment 2) consistently produced the highest weed control ratings, exhibiting slightly less than satisfactory weed control seven days after application and deficient to moderate weed control after fourteen days. Comparable herbicidal effects were observed for the root (Treatment 3) and stem (Treatment 4) extracts, indicating that bioactive allelochemicals are present throughout different plant parts of *C. odorata*. Statistical analysis further revealed that the *C. odorata*-based formulations significantly suppressed weed growth compared with the untreated control, although their efficacy remained lower than that of glyphosate after 14 days of application.

The botanical formulations produced visible herbicidal effects within 24 hours of application, with younger weeds exhibiting greater susceptibility than mature plants. Among the weed species evaluated, Cleome rutidosperma was the most susceptible to the treatments, whereas Physalis angulata showed the greatest tolerance. The decline in weed control from seven to fourteen days suggests that the aqueous extracts primarily function as contact herbicides, causing injury to exposed plant tissues but exhibiting limited systemic activity, thereby allowing regrowth from surviving meristematic tissues in some weed species.

Overall, the findings demonstrate that *C. odorata* has promising potential as a source of environmentally friendly botanical herbicides. Although its efficacy did not match that of glyphosate, the significant weed suppression observed supports its potential application as a component of integrated and sustainable weed management strategies aimed at reducing dependence on synthetic herbicides.

Recommendations

Based on the findings of this study, the following recommendations are proposed; The *C. odorata*-based formulations should be applied during dry, sunny weather, preferably in the afternoon, to maximize their effectiveness as contact herbicides and minimize losses due to rainfall or wash-off.

Future studies should evaluate different extract concentrations through dose-response experiments to determine the optimum concentration that provides maximum weed suppression while minimizing the amount of plant material required. Comprehensive phytochemical characterization of the leaf, stem, and root extracts should be conducted to identify and quantify the allelochemicals responsible for herbicidal activity and to better understand their mechanisms of action.

Further research should investigate improved formulations, including the use of natural surfactants, adjuvants, or sticking agents, as well as combinations with other plant-derived herbicides, to enhance leaf retention, penetration, persistence, and overall herbicidal efficacy under field conditions. Additional field trials should be conducted across different agroecological conditions, seasons, cropping systems, and a broader range of weed species to determine the consistency and general applicability of the botanical formulations under varying environmental conditions. Long-term studies should assess the environmental safety of *C. odorata*-based herbicides, including their persistence in soil, effects on soil microbial communities, beneficial insects, non-target plants, aquatic organisms, and overall ecosystem health.

Future research should also evaluate the economic feasibility, cost-effectiveness, and practical applicability of producing and using *C. odorata*-based herbicides, particularly for smallholder farmers, including analyses of production costs, labor requirements, availability of raw materials, and potential adoption compared with conventional herbicides.

Finally, future investigations should examine the effects of repeated applications, formulation stability during storage, and integration of *C. odorata*-based herbicides with other cultural, mechanical, and biological weed

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management practices to support the development of an effective and sustainable natural herbicide for integrated weed management programs.

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