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Evaluation of *Aloe* Species–Based Botanical Treatments and Application Methods for Controlling Termite Infestations Associated With Maize Crop in Northwest Ethiopia

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ABSTRACT

Termites are among the most destructive soil-dwelling pests in tropical and subtropical agroecosystems. Maize growers in the Northwestern region of Ethiopia face a critical threat from termite damage, which directly weakens regional food security and causes significant yield loss. Therefore, this study was intended to evaluate *Aloe* species–based botanical treatments for sustainable termite control and soil health improvement in Northwestern Ethiopia with the objective to close the gap by investigating the efficacy of *Aloe vera* L. in controlling termite pressure in maize crops in Northwestern Ethiopia. A two-year field study (2023/2024 and 2024/2025) comprises 3 application methods of *A. vera* extract (solution, mulch, and powder) and 4 species of *A. vera* plants (*Aloe adigratana, Aloe barbadensis, Aloe berger*, and *Aloe laterita*) totally 12 treatments together with one control, summing up to 13 treatment combinations. They were arranged in a randomized complete block design (RCBD) with a factorial structure of 3×4 and three replications, and a hybrid variety of maize crop was used as a test crop. Analysis of variance showed that percentage of damaged plants per plot, termite population density (TPD), average damage severity per plot, and number of termite mounds per plot were significantly influenced by different treatments. A combined average mean of 93.98% of plant damage and high termite population was recorded from untreated control treatment; severe termite pressure was recorded. The most effective methods of application were mulch to suppress termite population as well as the number of mounds per plot. From *A. vera*, the plant species *A. adigratana* applied as a mulch shown as the superior treatment recorded the lowest TPD ($2.0\ m^{-2}$) and fewest termite mounds per plot (1.81%). Soil physiochemical properties like potential of hydrogen, organic carbon, available phosphorus, and cation exchange capacity were improved by the application of *A. adigratana* with a combination of mulch. Based on the current finding, *A. adigratana* in combination with mulch treatment offers smallholder farmers a cost-effective, nontoxic-to-environment, and effective way to stabilize yield in terms of quantity and quality.

1 | Introduction

Termites are among the most destructive soil-dwelling pests in tropical and subtropical agroecosystems. A number of methods for managing pests and plant-based solutions have gained popularity for their eco-friendly nature and minimal environmental impact [1]. *Aloe vera* L., a succulent plant recognized for its healing properties and ability to deter pests, is noted as a natural option for addressing termite infestations [2]. Around the world as well as in Ethiopia, *A. vera* species are regularly grown in arid and semi-arid areas because the nature of the plant species, long, thick cuticle, and toothed or serrated

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leaves allow this hardy plant to persist in arid environments. Without the need for harmful chemicals, *A. vera* plant species produce secondary metabolites, particularly its saponins and anthraquinones, which act as a natural deterrent by upsetting termite feeding cycles [3]. Organic chemicals, which are produced or released from *A. vera* plant species, are not harmful for human beings and do not harm the environment, but toxic chemical compounds released from chemical pesticides can harm human health and the environment by controlling termites [4]. The efficacy produced from *A. vera* is considered a natural insecticide, as different studies investigated [5]. According to these studies [6], the extracts produced from *A. vera* can harm termites and other insects because organic chemicals released from this plant disrupt their activities and feeding habits as well as their growth permanently. Moreover, studies indicate that it may be a useful natural remedy for termite infestation in both repelling and causing a lethal effect on termites [7]. Additionally, in Ethiopia, *A. vera* plant extracts reduce farmers' negative environmental effects, and currently they are efficient pest management plans and could have long-term effects that have safeguards for crops [8].

In Northwestern Ethiopia, grain harvest qualities and quantities are influenced by termite infestation and seriously damage maize yield [9]. Even though there is a large infestation of termites' pressure and a huge number of *A. vera* plant species in Northwestern Ethiopia, their function as well as application and soil health have not been investigated yet. This study seeks to close the gap by investigating the efficacy of *A. vera* L. in controlling termite pressure in maize crops in Northwestern Ethiopia. In this study, termite behavior, mortality rates, and ensuring maize harvest quality in terms of qualities and quantities were specifically evaluated for *A. vera* extracts on termites. This study also investigated the viability of incorporating *A. vera*-based solutions in the current farming methods in order to create more resilience and to create sustainable farming methods.

2 | Materials and Methods

2.1 | Description of the Study Area

The study was conducted over two consecutive main cropping seasons, 2023/2024 and 2024/2025, at the farmer's training center in the Zigem District, Awi Zone, Amhara National Regional State. The district is located 250 km from Bahir Dar, the capital city of the Amhara Region, in a southwestern direction, and 545 km from Addis Ababa in a northwestern direction. The experimental site is situated 45 km northeast of the district, at a latitude of 10°50′15″ N and a longitude of 36°38′40″ E.

2.2 | Research Site Weather Conditions

As shown in Figure 1, the topography of the area is relatively flat. According to traditional climate classification, most of the district falls under the dry Woine Dega agroecology, with an altitude range of 1150–1200 m above sea level and an annual rainfall range of 750–1200 mm. The rainfall pattern in the district is monomodal, with the main rainy season occurring from May to October, and more than 88% of the annual rainfall takes place between May and August.

As shown in Figure 2, the average minimum and maximum temperatures recorded in the district are 15 degrees Celsius and 35 degrees Celsius, respectively.

According to the District Office of Agriculture, the predominant soil type in the district is red soil, which covers approximately 80% of the total land area, with the remaining 20% consisting of clay soil. The main crops cultivated in the district, in order of significance, include maize, finger millet, *teff*, wheat, sorghum, legumes, and oilseeds. The agricultural system in the research area is based on a combination of crop and livestock farming. Maize, finger millet, *teff*, wheat, legumes, and oilseeds are the main crops grown in the area.

To characterize the soil of the experimental plot, soil samples were collected using an Auger from 24 representative points across the experimental field at a depth of 0–15 cm before sowing. These samples were thoroughly mixed to create one composite soil sample. This composite soil sample was air-dried for more than 2 days in a shaded area and ground to pass through a 2 mm sieve. At the Soil Chemistry Laboratory, Institute of Amhara Design and Supervision Works Enterprise Laboratory of Bahir Dar, analyses of different soil physiochemical properties were conducted to determine key physical and chemical properties such as soil texture, pH, available phosphorus, organic carbon content, cation exchange capacity (CEC), and total nitrogen using standard methods. As shown in Table 1 the clay soil composition is 22% sand, 29% silt, and 51% clay. Due to this information, the textural class of the experimental site is clay soil.



FIGURE 1 | Weather data of monthly average rainfall (mm).

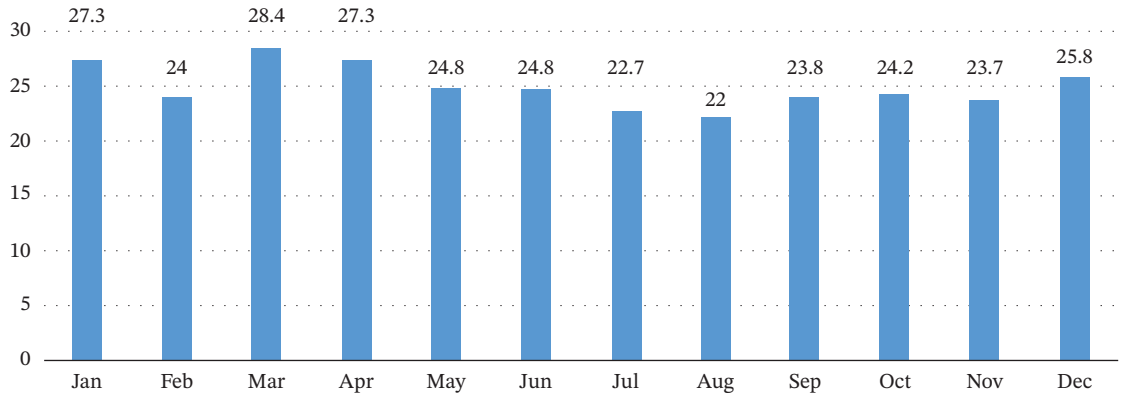


FIGURE 2 | Weather data of monthly average temperature (°C) at the research site.

TABLE 1 | Initial physical and chemical properties of experimental soil during the 2024 cropping season.

Soil characters	Values	Category
Particle size distribution		
Sand	22	
Silt	29	
Clay	49	
Textural class		Clay
pH (at 1:2.5 soil-to-water ratio)	6	Slightly acidic
Organic carbon (%)	0.65	Low
Total nitrogen (%)	0.21	Low
CEC (cmol(+) kg^{-1} of soil)	4.8	Low
Available P (mg kg^{-1} soil)	1.12	Low
EC (%) dS/m	0.041	Non-saline

Based on the laboratory result, the organic carbon content of the experimental site is 2.65%, which is classified as high carbon content [10].

As presented in Table 1, the pH level of the tested soil was slightly acidic at 6.0; the soil's CEC measured 24.8 cmol (+) kg^{-1}, which is classified as medium. In contrast, the EC was recorded at 0.041. According to the sources, soils with an EC lower than four are regarded as nonsaline and appropriate for growing cereals (Table 1). Additionally, the findings revealed that the soil contained total nitrogen and available phosphorus at levels of 0.21% and 18.12 mg kg^{-1}, respectively, both of which are considered low.

2.3 | Experimental Material

A hybrid maize (BH540) was selected as the experimental material, which was introduced by the *Bako* Agricultural Research Center and utilized for the research as a trial plant. The yield capabilities of BH546 at the research location were between 8 and 10 tons per hectare, whereas in the fields of farmers, the yield potential ranged from 5.5 to 6.5 tons per hectare.

2.4 | Experimental Treatments, Design, and Procedures

As illustrated in Table 2, there were factorial combinations involving three methods of *A. vera* application (*A. vera* extract in aqueous form, *A. vera* mulch using crushed leaves, and *A. vera* mixed with soil as a powder) and four species of *Aloe* (*Aloe adigratana, Aloe barbadensis,* also known as *A. vera, Aloe berger, and Aloe laterita*), resulting in a total of 12 treatment combinations alongside one control, summing up to 13 treatments. This was arranged in a randomized complete block design (RCBD) with a factorial structure of 3×4 and three replications.

The recommended spacing between rows was 75 cm, and within rows, 30 cm spacing for maize crops was employed for every experimental plot, and the black spacing was 1 m, and the spacing between the plots was 0.5 m for convenience of movement during different agronomic practices. The net plot size consisted of the two central rows, excluding the outer two rows on either side, which served as borders. The gross plot area measured 3 m × 4 m (totaling 12 m^2) and contained four rows. Consequently, the net plot dimensions were 4 m × 2.25 m (making 9 m^2). This resulted in 52 plants per plot (which is equivalent to 57,777 plants per hectare).

TABLE 2 | Treatment combinations used for the study.

Application method	*Aloe* species			
	S_1 (*Aloe adigratana*)	S_2 (*Aloe barbadensis*)	S_3 (*Aloe pirottae* Berger)	S_4 (*Aloe laterita*)
Solution (A_1)	A_1 x S_1 (T1)	A_1 x S_2 (T4)	A_1 x S_3(T7)	A_1 x S_4(T10)
Mulch (A_2)	A_2 x S_1(T2)	A_2x S_2(T5)	A_2 x S_3(T8)	A_2 x S_4(T11)
Powder (A_3)	A_3 x S_1(T3)	A_3x S_2(T6)	A_3 x S_3(T9)	A_3 x S_4(T12)
		Control (T13)		

Note: A = application method, T = treatment, S = *Aloe* solution, S = species.

Before establishing the experimental plots, the designated field was plowed four times using an ox-driven local plowing tool known as *Maresha*. The prepared land was then divided into plots based on the experimental treatments and was leveled by hand. Random assignments of the treatments were made for each replication, and as per the designated treatments, seeds were sown manually into open furrows on May 9, 2023, during the growing seasons of 2023/2024 and 2024/2025. A third of the urea and the complete recommended NPSBZn fertilizer were applied at the time of sowing and covered lightly with soil. Weeds were removed by hand, while all other agricultural practices were followed according to the recommended guidelines for maize cultivation.

2.5 | *A. vera* Preparation Methods

To prepare *Aloe* extract (aqueous solution), 0.05 tons of fresh leaves from each *Aloe* species (*A. adigratana, A. barbadensis*, and *A. berger*) were gathered, cleaned thoroughly to eliminate dust, chopped into smaller sections, and mixed with distilled water at a ratio of 1:10. The combination was subsequently filtered using a clean cloth to produce a transparent extract. The necessary volume of extract (2 L for each plot of 9 m^2) was then evenly sprayed around the base of each maize plant at the sowing and knee phases of growth, focusing on the root area prior to termite infestation.

To make powder, 0.05 tons of fresh *A. vera* leaves from the three species (*A. adigratana, A. barbadensis*, and *A. berger*) were gathered and washed thoroughly. The leaves were laid out in a single layer in a shaded, well-ventilated space to completely air-dry, which took about 3–7 days. After drying, the leaves were processed into a fine powder with a mechanical grinder. The powder has been stored until needed for use in a cool and dry sealed container. The required quantity of powder was calculated (2 kg per 9 m^2 or per plot) and evenly distributed around the base of each maize plant during sowing and at the knee stage, where termite activity is likely. Fresh *Aloe* leaves from both types were collected, cleaned, and then manually crushed until they were in smaller pieces. The crushed leaves were evenly placed around each maize plant at planting time, creating a mulch layer that was about 2–3 cm thick. Care was taken to ensure that the mulch did not touch the stems of the maize seedlings to avoid possible rotting. In the control group, no *Aloe* treatment was prepared or used.

2.6 | Data Collection

2.6.1 | Percentage of Damaged Plants per Plot (PDPP)

Crop health was calculated based on the percentage of termite-damaged plants using the formula as follows:

$$\text{percentage of damaged plants per plot} = \frac{\text{number of damaged plants/plot}}{\text{total number of plants/plot}} \times 100. \quad (1)$$

The total number of plants and the number of visibly termite-damaged plants in each plot were recorded before applying this calculation.

2.6.2 | Damage Severity (Average)

A scoring system has been used to assess root and stem damage severity by using a 0–5 scale, where zero designates *not at all damage* and five specifies *severe damage*. The signs of termite damage at each maize plant's roots and stems were inspected through uplifting the plant and by visual examination. The damage severity (average) score per plot has been calculated by means of the formula as follows:

$$\text{average damage severity per plot} = \frac{\text{the sum of severity scores for all plants}}{\text{total number of plants}} \times 100. \quad (2)$$

2.6.3 | Number of Mounds per Plot

The total number of mounds per plot has been counted and recorded during the field visit, and all plots have been assessed for destruction to clearly understand termite activities.

2.6.4 | Termite Population Density (TPD) (m^{-2})

TPD was estimated by measuring the area of the plot (m^2) and counting the number of termites found in randomly selected sampling locations within the plot, and the TPD was calculated by dividing the total number of termites observed by the total area sampled (9 m^2).

$$\text{Termite population density} = \frac{\text{Total number of termite observed}}{\text{Area sampled}\left(m^2\right)}. \quad (3)$$

3 | Results

3.1 | Postharvest Soil Properties

The analysis of soil physicochemical properties revealed significant improvements due to the application of *Aloe* species–based treatments across the two cropping seasons (Table 3). The untreated control plots exhibited strongly acidic conditions with

TABLE 3 | Soil properties of the experimental area after harvesting in the 2024 and 2025 cropping seasons.

Eco-green liquid fertilizer treatments	2024					2025				
	pH	OC (%)	TN (%)	CEC (cmol (+) kg^{-1} of soil)	Ava P (mg kg^{-1} soil)	pH	OC (%)	TN (%)	CEC (cmol (+) kg^{-1} of soil)	Ava P (mg kg^{-1} soil)
Adigratana ∗ mulch	6.68	2.96	2.16	6.66	1.72	6.86	3.69	6.96	6.96	2.72
Barbadensis ∗ mulch	6.56	2.73	1.16	5.87	1.46	6.79	3.52	6.75	5.88	2.46
Laterita ∗ mulch	5.88	2.38	1.19	5.74	1.74	5.99	2.44	6.02	5.88	2.45
Berger ∗ mulch	5.68	2.20	1.10	5.58	1.56	5.99	2.56	6.02	5.78	1.98
Adigratana ∗ powder	5.71	2.12	1.10	5.52	1.54	5.98	2.34	5.62	5.82	1.95
Laterita ∗ powder	5.26	2.03	0.92	5.44	1.44	5.71	2.46	5.75	5.74	1.94
Barbadensis ∗ powder	5.22	2.11	0.99	5.48	1.44	5.33	2.44	5.50	5.78	1.94
Berger ∗ solution	5.10	1.33	0.92	5.46	1.38	5.24	2.49	5.97	5.76	1.68
Adigratana ∗ solution	5.23	1.22	0.91	5.38	1.32	5.11	1.48	5.68	5.78	1.52
Barbadensis ∗ solution	4.92	1.21	0.99	5.22	1.28	5.00	1.48	5.68	5.72	1.48
Laterita ∗ solution	4.93	1.07	0.42	5.16	1.21	4.16	1.35	5.65	5.66	1.41
Berger ∗ powder	4.5	0.71	0.31	5.1	1.22	4.66	1.07	3.61	5.41	1.42
Control	4.21	0.66	0.22	5.00	1.2	4.22	0.99	3.4	5.40	1.4
Mean	**5.34**	**1.75**	**0.96**	**5.28**	**1.42**	**5.46**	**2.18**	**5.59**	**6.07**	**1.87**
SE±	**6.23**	**0.20**	**0.16**	**0.29**	**0.05**	**0.79**	**0.26**	**0.34**	**0.33**	**0.12**

Note: pH = soil reaction, CEC = cation exchange capacity (cmol (+) kg^{-1} soil), and AvP = available phosphorus (mg kg^{-1} soil). Bold values are not significant.
Abbreviations: OC = organic carbon, TN = total nitrogen.

a pH of 4.21, low organic carbon (0.66%), low total nitrogen (0.22%), and limited available phosphorus (1.20 mg kg^{-1}). In contrast, treated plots, particularly those receiving *A. adigratana* combined with mulch, showed marked enhancement in soil quality parameters. By the 2025 cropping season, soil pH increased to 6.86, organic carbon reached 3.69%, total nitrogen increased substantially, and available phosphorus rose to 2.72 mg kg^{-1}.

The observed improvements indicate a significant treatment effect over time, suggesting cumulative benefits of botanical amendments. The mean values across treatments also increased from 2024 to 2025 (organic carbon from 1.75% to 2.18% and CEC from 5.28 to 6.07 cmol (+)/kg), confirming a statistically meaningful enhancement in soil fertility attributes due to treatment application.

3.2 | Average Damage Severity (ADS)

The combined analysis of variance (ANOVA) indicated that ADS was significantly ($p < 0.05$) affected by the interaction between *Aloe* species and application methods. The untreated control plots recorded the highest ADS (42.65%), demonstrating severe termite damage under no treatment conditions (Figure 3).

In contrast, mulch-based treatments significantly reduced ADS, with *A. adigratana* ∗ mulch recording the lowest value (2.63%), followed by *A. laterita* ∗ mulch (6.80%), *A. berger* ∗ mulch (6.36%), and *A. barbadensis* ∗ mulch (8.68%).

Solution-based treatments exhibited comparatively higher ADS values (23.28%–31.95%), though still significantly lower than the control. Overall, the results demonstrate that mulch application significantly ($p < 0.05$) reduced termite damage severity compared to other methods.

3.3 | Number of Termite Mounds per Plot (NTMP)

The NTMP was significantly ($p < 0.05$) influenced by treatment combinations across both cropping seasons. The control plots consistently recorded the highest mound density (6.15 mounds per plot), indicating intense termite activity in untreated conditions (Figure 3).

Among treatments, *A. adigratana* ∗ mulch recorded the lowest NTMP (0.56), which was significantly different from the control 1.11. Other mulch treatments such as *A. laterita* ∗ mulch (1.02) and *A. berger* ∗ mulch (1.07) also significantly reduced mound formation.

Powder and solution treatments showed moderate effectiveness, with NTMP values ranging from 2.67 to 3.24, but these were statistically higher than mulch treatments (Table 4). The ANOVA results confirm that both the main effects and their interaction significantly influenced termite mound formation.

3.4 | PDPP

The PDPP was significantly ($p < 0.05$) affected by treatment interactions. The control treatment exhibited the highest damage levels, with 93.98% in 2024 and 79.90% in 2025, resulting in a combined mean of 86.94% (Table 5).

Mulch-based treatments significantly reduced PDPP, with *A. adigratana* ∗ mulch recording the lowest value (1.81%), followed by *A. laterita* ∗ mulch (11.92%), *A. berger* ∗ mulch (12.53%), and *A. barbadensis* ∗ mulch (13.76%). The LSD value (11.12) indicates that these reductions were statistically significant compared to the control.

Powder treatments resulted in moderate reductions (24.16%–27.16%), while solution treatments showed relatively higher

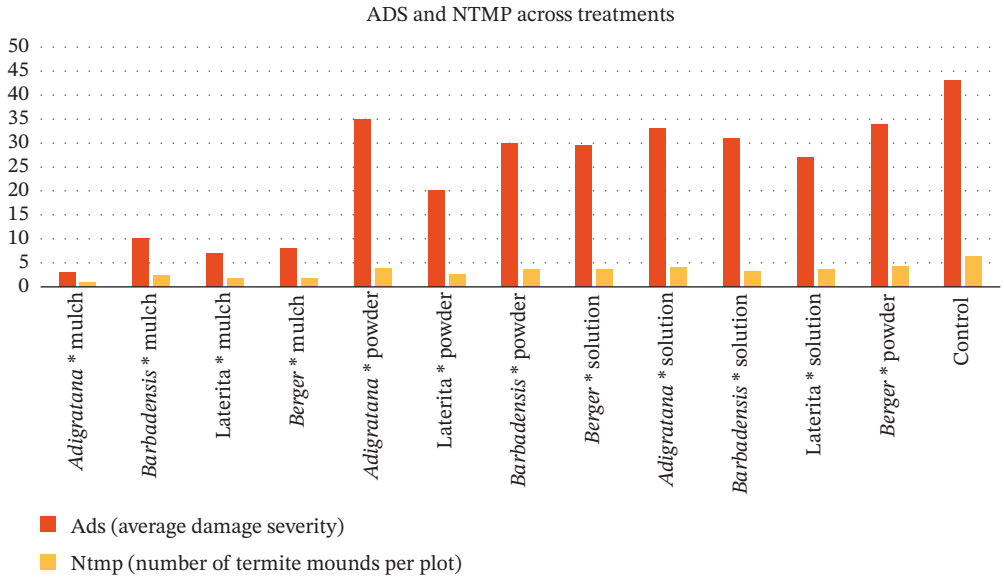


FIGURE 3 | Graphs showing the interaction effects of *Aloe vera* species and application methods on average damage severity and number of termite mounds per plot.

PDPP values (32.55%–56.03%), indicating lower effectiveness. The overall ANOVA confirms significant differences among treatments and highlights the superiority of mulch applications.

3.5 | TPD

TPD was significantly ($p < 0.05$) influenced by *Aloe* species and application methods. The control plots recorded the highest termite density, with 99.27 m^{-2} in 2024 and 25.8 m^{-2} in 2025, giving a combined mean of 62.54 m^{-2} (Table 5).

The lowest TPD was observed in *A. adigratana* ∗ mulch treatment (2.02 m^{-2}), which was significantly lower than all other treatments. Other mulch treatments also showed strong suppression, including *A. barbadensis* ∗ mulch (9.29 m^{-2}) and *A. laterita* ∗ mulch (12.60 m^{-2}).

TABLE 4 | Effect of *Aloe* species-based botanical treatments on termite damage severity (ADS) and number of termite mounds per plot (NTMP) in 2024 and 2025 cropping seasons.

Factors	ADS (%)			NTMP (m^2)		
	2024	2025	Combined mean (%)	2024	2025	Combined mean
Eco-green treatments						
Adigratana ∗ mulch	3.23^{d}	2.01^{c}	2.63^{d}	1.00^{ef}	0.11^{d}	0.56^{f}
Barbadensis ∗ mulch	10.46^{b}	6.90^{a}	8.68^{ab}	2.33^{de}	1.60^{ab}	1.97^{d}
Laterita ∗ mulch	7.106^{c}	6.50^{abc}	6.80^{bc}	1.83^{ef}	0.20^{d}	1.02^{ef}
Berger ∗ mulch	8.52^{cd}	4.20^{bc}	6.36^{c}	1.83^{ef}	0.30^{cd}	1.07^{ef}
Adigratana ∗ powder	34.54^{ab}	30.30^{a}	32.4^{ab}	3.83^{b}	1.50^{ab}	2.67^{c}
Laterita ∗ powder	19.93^{ab}	15.70^{a}	17.82^{a}	2.50^{cde}	1.90^{bc}	2.20^{cd}
Barbadensis ∗ powder	29.62^{ab}	25.50^{ab}	27.56^{ab}	3.67^{bc}	2.00^{bc}	2.84^{bc}
Berger ∗ solution	29.11^{ab}	21.50^{a}	20.31^{a}	3.67^{bc}	2.10^{ab}	2.89^{bc}
Adigratana ∗ solution	33.40^{ab}	30.50^{a}	31.95^{a}	4.00^{b}	2.10^{ab}	3.05^{b}
Barbadensis ∗ solution	31.29^{a}	25.90^{a}	28.50^{a}	3.33^{bcd}	2.30^{ab}	2.82^{bc}
Laterita ∗ solution	26.16^{ab}	20.40^{a}	23.28^{ab}	3.67^{bc}	2.80^{a}	3.24^{b}
Berger ∗ powder	33.66^{d}	30.00^{c}	31.83^{d}	4.33^{b}	4.00^{a}	4.17^{ab}
Control	45.37^{b}	39.90^{a}	42.65^{ab}	6.50^{a}	5.80^{a}	6.15^{a}
LSD (0.05)	11.28	5.60	8.44	1.18	1.03	1.11
SE±	3.99	1.98	2.98	0.42	0.36	0.39

Note: Means followed by the same superscript letter are not significantly different at the 5% level of probability according to least significant difference (LSD) test. ADS = average damage severity per plot, NTMP= number of termite mounds per plot.

TABLE 5 | Effect of *Aloe* species-based botanical treatments on percentage of damaged plants per plot (ADS) and termite population density in 2024 and 2025 cropping seasons.

Factors	PDPP (%)			TPD (M2)		
	2024	2025	Combined mean (%)	2024	2025	Combined mean (%)
Botanical treatments						
Adigratana ∗ mulch	2.61^{d}	1.01^{f}	1.81^{i}	3.83^{d}	0.21^{g}	2.02^{g}
Barbadensis ∗ mulch	21.23^{cd}	6.29^{ef}	13.76^{gh}	11.97^{c}	6.61^{ef}	9.29^{f}
Laterita ∗ mulch	17.33^{cd}	6.51^{def}	11.92^{h}	14.97^{c}	10.22^{de}	12.60^{ef}
Berger ∗ mulch	16.34^{cd}	8.72^{def}	12.53^{gh}	12.77^{c}	8.03^{ef}	10.40^{f}
Adigratana ∗ powder	32.88^{bc}	15.43^{def}	24.16^{fg}	26.83^{b}	11.35^{cde}	19.09^{de}
Laterita ∗ powder	37.15^{bc}	17.17^{de}	27.16^{ef}	26.07^{b}	11.79^{cde}	18.93^{de}
Barbadensis ∗ powder	34.72^{bc}	19.05^{e}	26.89^{ef}	25.63^{b}	10.20^{de}	17.92^{e}
Berger ∗ solution	43.59^{b}	21.51^{d}	32.55^{de}	27.00^{b}	12.11^{cde}	19.56^{de}
Adigratana ∗ solution	83.13^{a}	22.25^{cd}	52.69^{bc}	29.97^{b}	14.17^{bc}	22.07^{cd}
Barbadensis ∗ solution	86.96^{a}	25.09^{c}	56.03^{b}	29.77^{b}	14.68^{bc}	22.23^{cd}
Laterita ∗ solution	50.77^{b}	20.47^{ab}	35.62^{d}	28.10^{b}	14.98^{bc}	21.54^{cd}
Berger ∗ powder	46.92^{b}	30.09^{b}	38.51^{cd}	30.33^{b}	15.97^{b}	23.15^{c}
Control	93.98^{a}	79.90^{a}	86.94^{a}	99.27^{a}	25.8^{a}	62.54^{a}
LSD (0.05)	**13.02**	**9.22**	**11.12**	**1.18**	**1.03**	**1.11**

Note: Means followed by the same superscript letter are not significantly different at the 5% level of probability according to least significant difference (LSD) test. PDPP = percentage of damaged plants per plot, TDP = termite population density. Bold values are not significant.
Abbreviation: LSD = least significant difference.

Powder treatments showed moderate effectiveness (17.92–19.09 m^{-2}), whereas solution treatments recorded relatively higher densities (19.56–22.23 m^{-2}). The LSD (1.11) confirms significant differences among the treatments. The results clearly demonstrate that mulch-based applications significantly reduced termite populations compared to other methods.

4 | Discussions

4.1 | Postharvest Soil Properties of Experimental Sites

The essential physical and chemical characteristics of the soil analyzed were derived from the data of the control group from 2024, likely indicating the initial condition before any treatment (Table 3). This particular soil displayed notable acidity, evidenced by a pH near 4.21, extremely low organic carbon levels at 0.66%, very low total nitrogen at 0.22%, a moderate CEC of 3.00 cmol (+)/kg, and limited available phosphorus at 1.20 mg/kg. Beyond pest suppression, the decomposition of *Aloe* mulch enriched the soil, notably raising pH and organic carbon levels by the end of the 2025 season. The combined effect of *adigratana* and mulch combinations showed a remarkable increment, and the best result was recorded in all categories by the 2025 cropping season; and the level change in soil physical properties was recorded from a pH of 6.68, an organic carbon content of the soil increased to 3.69%, and available phosphorus was 2.72 mg/kg of soil and total nitrogen. Likewise, total nitrogen was significantly increased by the application of botanical-based treatments in the 2025 crop growing season. The result showed that the combined application of *adigratana Aloe* species in combination with the mulching method was more beneficial than other combinations; it might be due to the effectiveness of the application method and species of *A. vera adigratana* in temperature regulation, moisture retention capacity, and gradual nutrient release of the plant.

As compared to the 2024 cropping season, the 2025 cropping season shows a significant increment or improvement in organic carbon, CEC, and available phosphorus; this might be due to the lasting and additive benefits of amendments and organic matter accumulation in the soil. In summary, the careful application of these eco-friendly liquid fertilizers, especially in conjunction with mulching practices, successfully reduced soil acidity, increased organic matter content, improved nutrient availability, and enhanced the soil's ability to retain nutrients, thus providing an effective approach to rehabilitating unproductive and acidic soils for sustainable agricultural methods [11].

4.2 | ADS per Plot

The combined variance analysis revealed that applying various eco-friendly liquid fertilizer treatments significantly lowered the ADS per plot caused by termites in maize crops when compared to areas without treatment. As shown in Table 4 the vulnerability of the maize crop has been recorded from the untreated control treatment with ADS of 42.65%.

The interaction effect of *barbadensis* and mulch has been found to be the most effective mechanism to minimize damage severity of termites over maize crops and achieved 8.68% of ADS; however, the combination of *laterita* with mulch was recorded at 6.80% and followed by *Berger* in combination with mulch, which scored at 6.36%. Even the least performing mulch variation, *adigratana*, significantly outperformed the control, suggesting that the physical presence of the mulch is as vital as its chemical properties, reaching a combined mean of 2.63%. The solution

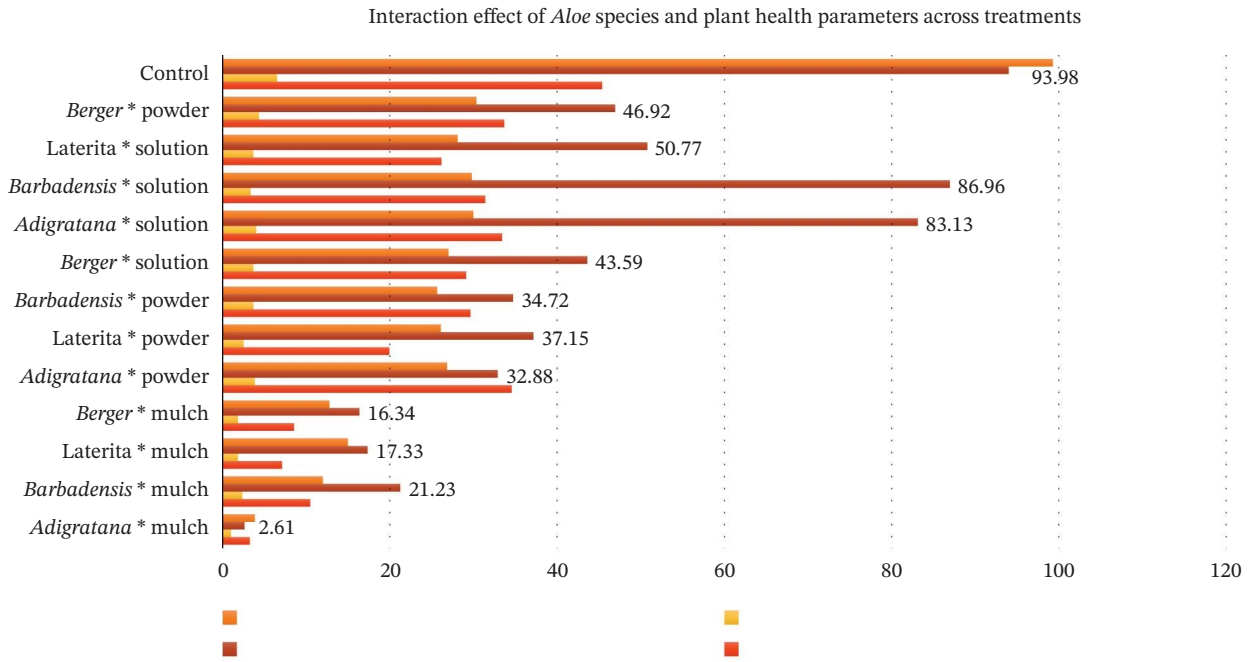


FIGURE 4 | Termite population density (TPD, m^2), plant damage percentage (PDPP), number of termite mounds per plot (NTMP), and aboveground damage score (ADS) were measured under different soil amendment and plant treatments.

method of application showed the most remarkable and significant reduction in the ADS of termites. The combined mean of ADS (23.28%) showed remarkable efficacy by the application of treatment *adigratana* in combination with solution and was closely followed by the *barbadensis* in combination with solution (28.5%) and the *laterita* solution combination (23.28%) [12], which recorded similar findings. The overall trend suggests that while all eco-friendly methods provided significant protection, the formulation type notably influenced the results; mulch treatments, particularly *barbadensis* mulch, produced the greatest reduction in damage severity, cutting it by almost 80% in comparison to the control. This comprehensive analysis validates the potential of specific botanical extracts and application methods as sustainable components of integrated pest management strategies, aiming to minimize termite damage in maize agriculture, thus supporting the protection of crop yields and farmers' income [13].

4.3 | NTMP

The ANOVA is shown in the 2024 and 2025 cropping season *A. vera* botanical-based treatment had a distinctly significant effect on the NTMP in the study area. The untreated control plots consistently recorded the highest termite presence, averaging 6.15 per plot, underscoring the severe pest concern when no actions were taken. In contrast, interaction, or the combined effect of *adigratana* and mulch, was the most effective method of treatment to control or minimize the number of mounds per plot, which produced the lowest average number of mounds (0.56), followed by the *laterita* and mulch combination and the *Berger* and mulch combination with an average of 1.02 and 1.07, respectively, whereas the combined effect of *barbadensis* with mulch recorded less effect on termite infestation as compared to others, but its number is 1.97, which means it is effective as compared to the control treatment. Generally, the application of all treatments has been effective or significantly affected the number of termites' populations in the studied plot area. Treatments utilizing both powdered and liquid forms of the eco-friendly agents exhibited greater variability in results but were generally more effective than the mulch options, though not to the extent of the leading mulch method. *Adigratana* (2.67) and *barbadensis* (2.84) in the form of powder, respectively, recorded moderate control as compared to other treatments. Liquid treatments, including *adigratana* ∗ solution (3.05) and latetita ∗ solution (3.24), reached similar levels of suppression. This is because of the combined effect of *adigrtatana* ∗ mulch created unfavorable conditions for the occurrence of termites in the applied area and created a physical barrier as well as the soil's potential for moisture retention capacity, which has been formed, and then termite colony establishment has been restricted. This is in line with the finding of Taslima et al. [14].

This remarkable reduction from over six mounds to just 0.56 highlights a crucial decrease in risk to crops, exhibiting the effectiveness of certain integrated pest management techniques in successfully and sustainably addressing termite issues in maize agriculture (Kiros & Dekebo, 2025).

4.4 | Damaged Plant per Plot (%)

The result of ANOVA showed that PDPP was significantly ($p < 0.05$) influenced by the combined effect of different botanical treatments (Table 5) during the 2024 and 2025 cropping seasons. The highest PDPP has been recorded from untreated or control treatment in 2024, and the highest damage level (93.98%) and total loss of maize crop have been observed, but in 2025 the loss was less as compared to the first year. This is because the residue remaining from the first year established the barrier for the occurrence of termites at the study plot.

Treatments involving *A. adigratana* Solution and *A. barbadensis* Solution also showed high damage levels (83.13% and 86.96%, respectively), which were statistically similar to the control's results. Conversely, mulch-based methods, particularly *adigratana* Mulch, proved to be the most effective, showing the lowest PDPP at just 2.61%. Other mulch applications and powdered treatments typically provided moderate safeguards, with PDPP results between 16.34% and 46.92%. In 2025, the overall termite pressure appeared to be reduced, as indicated by lower PDPP levels across all treatment groups. The control plot remained the most impacted, with a PDPP of 79.90%, although this figure was considerably lower than that of the previous year [15].

The combined effect of *adigratana* and mulch performed the best controlling mechanism of termite infestation in the studied area; hence, the lowest percentage of damaged (1.81%) maize seedlings or plants per plot has been recorded from the combination treatments received from *A. adigratana* and mulch treatment, even if the lowest damage percentage was recorded in both years, followed by the combined effect of *laterita* ∗ Mulch (11.92%), which consistently reduced the termite damage percentage and recorded the lowest damage percentage besides the *adigratana* and mulch combination compared to the heavily affected control treatment (86.92%). This result emphasizes that the application of botanical treatment of controlling mechanisms, especially *adigratana*, and mulch treatment minimized the highest rate of termite infestation in the area and the strong seasonal influences on termite damage and reveals the reliability of the genius controlling role of certain mulch-based treatments over both years. This finding is in line with the research finding [16].

4.5 | TPD m^2

During the 2024 season, the vulnerability of untreated plots was clear, with termite density peaking at 99.27 m^2, indicating a substantial termite presence in the absence of any treatment. Among the eco-friendly alternatives, solution-based treatments generally displayed greater termite population densities than those from mulch or powder. For instance, *A. adigratana* ∗ solution (29.97 m^2), *barbadensis* solution (29.77 m^2), and *laterita* solution (28.10 m^2) had relatively high TDP values, indicating their limited success in reducing termite populations that season. Mulching proved superior to powder or liquid applications; specifically, *A. adigratana* ∗ mulch suppressed population density to just 3.83 m^2 in the first year, dropping further to 0.21 m^2 in the second, compared to *barbadensis* mulch (11.97 m^2) and *Berger* mulch (12.77 m^2). Powder treatments showed average results, with *A. adigratana* ∗ powder (26.83 m^2) and *laterita* powder (26.07 m^2) decreasing termite density compared to the control, but they were not as effective as the mulch options.

During the growing season of 2025, there was a noticeable decline in TDP in all treatment groups, suggesting either a decrease in termite activity or enhanced effectiveness of the treatments applied.

ANOVA showed that the control treatment still received the highest (25.8 m^{-2}) rate of TPD per meter square of area; it confirmed that termites continued to flourish in the absence of any botanical treatments. However, the combined effect of mulch treatment with *adigratana A. vera* species provided the best treatment method; hence, the recorded TPD was 0.21 m^{-2} it exhibits very low termite density, while the combined effect of *A. barbadensis* ∗ mulch (6.61 m^{-2}) treatments received also recorded a reduced number of termites, followed by treatment with *Aloe barber* ∗ mulch (8.03 m^{-2}). Like that, treatment-using powder in combination with *A. barbadensis* (10.20 m^{-2}) and *laterita* (11.79 m^{-2}) showed moderate effectiveness of *A. vera* botanical-based termite control as compared to control treatment and solution methods; *barbadensis* in combination with solution (14.68 m^{-2}) and *laterita* in combination with solution (14.98 m^{-2}) applications showed or yielded relatively the highest value of TPD as compared to the other treatments.

In the absence of any treatment, the severity of termite infestation population density per plot has been repeatedly received the highest average TPD (62.54 m^{-2}) in both 2024 and 2025 years. Among treatments, the combined effects of *adigratana* and mulch (2.02 m^{-2}) had recorded the lowest overall TPD and performed the best method of termite control, followed by the combination of *barbadensis* ∗ mulch (9.29 m^{-2}) and *laterita* mulch (12.60 m^{-2}). The solution methods produced higher average TDP values, including *Berger* solution (19.56 m^2) and *adigratana* ∗ solution (22.07 m^2). The present finding was in line with the finding of Khan et al. [17], who stated that eco-friendly botanical treatments significantly reduced the number of termite population densities as compared to check or controlled treatments, whereas the solutions were the least effective overall throughout the seasons.

As the graphic structure clearly showed (Figure 4), different methods of treatments significantly lessened or decreased the damage to plant population and mound formation. Termites exert significant pressure and affirm their devastating role on maize crops; in the experimental plot, untreated control plots show the highest amounts across all metrics. Regarding treatment, the interaction effect of *A. adigratana* and mulch treatment resulted in a drastic decline in TPD, PDPP, NTMP, and ADS values at very low concentrations. This might be mulching that may create an unfavorable environment for termites' survival and activity, potentially via extended soil mulching for a longer time, changing the microclimates of the termite population in the soil, and releasing bioactive compounds like saponins and anthraquinones from the plant tissues [18, 19]. Even though their impacts were not as pronounced as that of *adigratana A. vera* species, other *A. vera* species for termite control have been also effectively used as a mulch. Termite activity and maize crop damage slightly decreased by the application of powder treatments; however, the application of a solution-based treatment was relatively less effective and often reached levels similar to the control treatment (Figure 4).

5 | Conclusions

In Northwestern Ethiopia, especially at the study area, the investigation showed that the existing infestation of termites leads to a major challenge to maize production in the farmers' fields and shows notably high damage levels, with numerous termite mounds per plot. Even if those mounds were a serious challenge for plowing the land, a substantial percentage of affected plants in the area leads to maize yield reduction, with a high or elevated number of termite population densities per unit of area in untreated control plots. This investigation shows the application of botanical-based termite control depends heavily on the

application methods as well as *A. vera* plant species, which was a clear winner for long-term protection of the maize crop in a successful way. Among all treatments tested, *A. adigratana* used as mulch repeatedly produced the most favorable results, showing the least average damage, the fewest termite mounds, the lowest percentage of damaged plants, and reduced TPD or intensity throughout both growing seasons.

Likely due to prolonged soil mulching or coverage and a continuous release of chemical active ingredient compounds from *A. vera* species, the mulching method of application was more effective than powder and liquid forms in preventing termite activity, and yearly decline in termite severity or population density per unit area also suggests that botanical-based treatments could have cumulative or lasting effects on maize crops in the study area. So *Aloe*-based botanical termite-controlling treatments, particularly using *adigratana A. vera* species in combination with the application method of mulching, offer an effective, environmentally friendly or safe, and sustainable approach to managing termite problems within the maize cultivation system.

6 | Recommendations

The current study strongly recommends the use of *Aloe*-based botanical treatments as an effective and sustainable strategy for termite management in maize production systems, particularly in Northwestern Ethiopia. Among the tested treatments, the application of *A. adigratana* in mulch form consistently demonstrated superior performance in reducing TPD, minimizing plant damage, and improving soil physiochemical properties. Therefore, smallholder farmers are encouraged to adopt this method as a cost-effective, environmentally friendly, and locally available alternative to synthetic pesticides. In addition, integrating *Aloe* mulch into existing farming practices can enhance soil fertility, moisture retention, and long-term crop productivity. Future research should focus on scaling up this approach across different agro-ecological zones, evaluating its economic feasibility, and exploring its compatibility with other integrated pest management strategies. Extension services and agricultural stakeholders should also promote awareness and provide training to farmers to facilitate the wider adoption of this eco-friendly technology.

Author Contributions

The author (Birhanu Gebeyehu Abebaw) conceived and designed the study, performed the experiments, analyzed and interpreted the data, and wrote the original draft of the manuscript. I also reviewed and edited the manuscript and approved the final version for submission.

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Conflicts of Interest

The author declares no conflicts of interest.

Data Availability Statement

The datasets generated and/or analyzed during the current study are not publicly available due to privacy considerations but are available from the corresponding author upon reasonable request.

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