IJMAAS
International Journal of Microbiology and Applied Sciences
ISSN 1115-4004 *Volume 4 issue 1 Jan, 2025* Research Article

Extracts of *Chromolaena odorata* as Effective and Nature-Friendly Inhibitors for the Management of Microbiologically Induced Corrosion on Buried Metals

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ABSTRACT

Microbiologically induced corrosion (MIC) poses significant risks to buried oil pipelines, leading to structural damage, leakages, environmental contamination, and substantial economic losses. With increasing regulatory restrictions on chemical biocides, there is an urgent need for eco-friendly and sustainable corrosion control strategies. This study investigates *Chromolaena odorata* ethanol extracts (COEE) and *Chromolaena odorata* aqueous extracts (COAE) as nature-friendly, low-cost inhibitors for managing MIC in buried metals. Mild steel coupons preconditioned with each extract were buried in a biocorrosion-simulating soil system with COEE, COAE, and control (no extract) setups. Gravimetric analysis at 14 and 28 days assessed the impact of the extracts on corrosion. Results showed that, by Day 28, the percentage weight loss for COEE, COAE, and control were 0.86%, 0.79%, and 1.73%, respectively, with corresponding corrosion rates of 11.74, 10.71, and 23.43 mpy. The inhibition efficiencies for COEE and COAE reached 50% and 53%, indicating substantial corrosion reduction. Statistical analysis with Tukey HSD confirmed significant differences in weight loss between treated setups and the control, with no significant difference between COEE and COAE, indicating comparable efficacy. These findings validate *C. odorata* extracts as promising, eco-friendly alternatives for MIC management in buried pipelines, offering effective corrosion protection with minimal environmental impact.

Keywords: Ethanol Extract; Aqueous Extract; *Chromolaena odorata*; Nature-Friendly; Microbiologically Induced, Corrosion.

Introduction

Microbiologically Induced Corrosion (MIC) represents one of the most pervasive and challenging forms of corrosion, especially in buried metal infrastructures such as pipelines, storage tanks, and underground utilities. This form of corrosion is catalyzed by the presence of microorganisms that interact with metal surfaces, causing accelerated degradation (Beech & Sunner, 2004; Little & Lee, 2015). These microorganisms include sulfate-reducing bacteria (SRB), iron-oxidizing bacteria (IOB), acid-producing bacteria (APB), and other microbial species that form biofilms on metal surfaces (Enning & Garrelfs, 2014). MIC is responsible for significant structural damage, leading to operational failures, safety hazards, and financial losses. The global economy is heavily impacted by MIC, particularly in industries reliant on the integrity of buried metal structures, such as oil and gas, water distribution, and telecommunications (Videla & Herrera, 2005).

As a result, mitigating MIC has become a top priority in material science and industrial engineering. Traditional methods for preventing MIC have largely relied on the use of synthetic chemical inhibitors. While these chemicals can be effective in reducing microbial activity and corrosion, they often pose significant environmental and health risks (Yahya et al., 2014). Many of these chemical inhibitors are toxic, non-biodegradable, and may accumulate in ecosystems, potentially leading to long-term environmental damage (Bardal, 2004).

Furthermore, their high cost and the growing demand for eco-friendly solutions have spurred a shift towards more sustainable, natural alternatives (Arockiasamy *et al*., 2015).

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In this context, plant-based extracts have emerged as promising candidates for the development of green corrosion inhibitors. These natural inhibitors offer several advantages over conventional synthetic options, including biodegradability, non-toxicity, and renewability, making them more aligned with modern sustainability goals (Ahamad & Quraishi, 2010).

One such plant that has gained attention in recent years for its potential as a natural corrosion inhibitor is *Chromolaena odorata*, commonly known as Siam weed. This fast-growing shrub is native to the tropical and subtropical regions of the Americas but has spread to other parts of the world, including Africa and Asia (Iwu et al., 1999). *Chromolaena odorata* has been traditionally used in folk medicine for its various therapeutic properties, including antimicrobial, anti-inflammatory, and antioxidant effects (Akintoye *et al*., 2015).

The plant is rich in bioactive compounds such as flavonoids, alkaloids, tannins, and terpenoids, which have been linked to its broad spectrum of biological activities (Okoli *et al*., 2007). Several studies have reported that these phytochemicals are responsible for the plant's ability to inhibit microbial growth, reduce inflammation, and prevent oxidative damage, all of which suggest that *Chromolaena odorata* could serve as an effective natural inhibitor against MIC (Sharma *et al.*, 2014).

The potential of *Chromolaena odorata* as an effective MIC inhibitor is rooted in its dual action: firstly, it can directly inhibit the growth and proliferation of corrosion-causing microorganisms, such as sulfate-reducing bacteria and iron-oxidizing bacteria, by disrupting microbial metabolic pathways and biofilm formation (Rao & Mulky, 2023). Secondly, its bioactive compounds can interact with metal surfaces, forming protective films that prevent microbial colonization and subsequent corrosion (Rajendran *et al*., 2010).

These bioactive compounds may also contribute to altering the electrochemical properties of the metal surface, reducing its susceptibility to corrosive processes. The combined antimicrobial and anticorrosive properties of *Chromolaena odorata* make it an attractive alternative to synthetic inhibitors, particularly in environments where microbial activity is a major driver of corrosion.

The shift towards more environmentally friendly approaches to corrosion management is particularly important in industries dealing with buried metals, where traditional chemical treatments may pose risks to both the environment and human health. As microbial corrosion processes often occur over extended periods, the use of natural inhibitors like *Chromolaena odorata* could provide long-term, cost-effective, and sustainable solutions to mitigate the effects of MIC. Moreover, the growing interest in green chemistry and sustainable industrial practices highlights the importance of exploring plant-based alternatives to traditional corrosion inhibitors.

This study aims to evaluate the effectiveness of *Chromolaena odorata* extracts as inhibitors for microbiologically induced corrosion on buried metals, focusing on their potential to prevent microbial growth and enhance metal protection. By exploring the secondary metabolite and the anti-nutrient composition of *Chromolaena odorata* with their mechanisms of action, this research contributes to the development of eco-friendly and sustainable corrosion inhibition strategies. Furthermore, the findings of this study could offer new insights into the use of plant-derived compounds as viable alternatives to synthetic chemical inhibitors in the fight against MIC, aligning with the broader goals of reducing environmental impact while maintaining the integrity of critical infrastructure.

Materials and Methods

Study Area and Materials

This research was conducted at the Regional Centre for Biotechnology and the Bioresources Centre, located within the University of Port Harcourt, Nigeria. This facility is well-equipped with advanced resources for biological and chemical analyses, making it an ideal setting for investigating the potential of plant extracts, specifically *Chromolaena odorata*, as green inhibitors against microbiologically induced corrosion (MIC) on buried metals.

The essential materials used in this study included *Chromolaena odorata* leaves, collected from randomly growing weeds in the University of Port Harcourt Innovation Park, as the primary source of bio-inhibitory extracts for controlling MIC. In addition, loamy-clay soil, a common soil type around buried pipelines in the region, was used to simulate natural corrosion-inducing conditions.

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Produced water, a complex mixture of organic and inorganic substances, such as salts, heavy metals, hydrocarbons, and various chemical additives, which contains high microbial loads and often a byproduct in the oil extraction industry, was incorporated to replicate the corrosive and microbial environment typically associated with oil infrastructure.

These materials and the selected study location provided a realistic, scientifically controlled environment for assessing *Chromolaena odorata* as an environmentally friendly corrosion inhibitor.

Sample Collection

Produced Water

Produced water was obtained from Seplat Energy PLC, specifically from the Ohaji Egbema 7 & 8 locations in Rivers State, Nigeria. Collection followed sterile procedures, using a sterile 4-liter container to prevent contamination during transport. Upon arrival at the laboratory, the sample was divided, with one portion analyzed for physicochemical properties and the rest stored at 4°C for use in the study, following the procedures of Immanuel et al. (2016)**.**

Soil Samples

Composite samples of loamy-clay soil were collected from a depth of approximately 1 meter at the University of Port Harcourt Innovation Park using a hand auger. The soil was collected in large, sterile containers and sealed tightly to prevent contamination during transport.

This soil was selected for its loamy-clay texture and microbial communities, which mimic natural corrosion conditions around buried pipelines, in line with protocols by Mbah et al. (2023).

Plant Collection and Identification

Fresh *Chromolaena odorata* leaves, commonly known as Siam weed, were harvested from local vegetation in Rumuigbo, Port Harcourt, Rivers State. Voucher specimens were deposited at the University of Port Harcourt's Department of Plant Science Herbarium for official identification and documentation. The remaining leaves were transported to the laboratory, where they were processed to extract biocidal compounds intended for corrosion inhibition.

Preparation of Metal Coupons for Biocorrosion Testing

Flat, rectangle-shaped carbon steel coupons obtained from the steel market were prepared at the University of Port Harcourt Science and Engineering workshop for biocorrosion testing. These coupons, composed of 0.1% carbon (C), 0.4% manganese (Mn), 0.03% sulfur (S), 0.06% phosphorus (P), and 99.41% iron (Fe), measured 4 cm × 3 cm × 1.7 cm. Each coupon was polished using progressively finer grit abrasive paper to achieve a smooth, uniform surface. Coupons were then cleaned with 20% hydrochloric acid (HCl) to remove surface oxides, rinsed with absolute ethanol, and dried thoroughly to prevent surface contamination. The cleaned coupons were weighed on a high-precision digital balance (AE ADAM Equipments, PW254) with a readability of 0.0001g, and the initial weights (Wi) were recorded as baseline measurements for the corrosion study, in accordance with National Association of Corrosion Engineers (NACE) RP0775-2005 standards.

Extraction of *Chromolaena odorata* Biocidal Compounds

To prepare the extracts, freshly harvested *Chromolaena odorata* leaves were washed under running water to remove any adhering dirt. The leaves were air-dried for 12 days in a well-ventilated area until a constant dry weight was achieved. Dried leaves were then ground into a fine powder using a locally fabricated mechanical grinder. Two separate extracts were prepared: an ethanol extract and an aqueous extract, using a concentration of 25g/L for the experiments.

For each extraction, 200g of *C. odorata* leaf powder were combined with 125 mL of absolute ethanol and another batch of *C. odorata* leaf powder (200g) were combined with 125 mL of distilled water, to create a concentration of 25g/L ethanol extract (COEE) and 25g/L aqueous extract (COAE) respectively**.** Each mixture was allowed to stand for 24 hours, during which it was stirred intermittently to enhance extraction. Following this, the mixtures were filtered using sterile Whatman N0.1 filter paper and the filtrates were collected in sterile containers. Samples of the test biocides were analyzed by high performance liquid chromatography and mass spectrometry (HPLC-MS) for identification and quantification of their phytochemical constituents.

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Phytochemical Analysis and Quantification of the *Chromolaena odorata* extract Using HPLC-MS

The phytochemical analysis of the *Chromolaena odorata* extract (test biocide) was performed using High-Performance Liquid Chromatography coupled with Mass Spectrometry (HPLC-MS) for identification and quantification of their phytochemical constituents. The system used was an Agilent 1290 Infinity II HPLC connected to an Agilent 6545 Q-TOF mass spectrometer. Chromatographic separation was carried out using an Agilent ZORBAX Eclipse Plus C18 column with dimensions of 4.6 × 150 mm and a particle size of 5 µm. The mobile phase consisted of water with 0.1% formic acid (Solvent A) and acetonitrile with 0.1% formic acid (Solvent B). A gradient elution program was implemented, starting with 10% Solvent B and increasing to 95% over 35 minutes at a flow rate of 0.4 mL/min. The injection volume was 5 µL, and the column temperature was maintained at 35°C. Detection was performed at a wavelength of 280 nm, chosen to capture the phenolic compounds in the extract.The mass spectrometer operated in electrospray ionization (ESI) mode, allowing analysis in both positive and negative ion modes. The capillary voltage was set at 3.5 kV, while the nebulizer pressure was 35 psi. The drying gas flow rate was 11 L/min, with a temperature maintained at 300°C. Mass spectral data were acquired within the range of m/z 100–1200. The spectral data were analyzed using Agilent MassHunter Workstation Software. The phytochemicals were identified based on their retention times, accurate mass measurements, and fragmentation patterns, which were compared to entries in the METLIN and HMDB databases. Quantification of the identified phytochemicals was achieved using external standards. Analytical replicates were conducted to ensure accuracy and reproducibility, with blanks and standard samples analyzed at regular intervals to validate the performance of the HPLC-MS system.

Soil Enrichment and Biocorrosion Setup

The loamy-clay soil samples were prepared for biocorrosion simulation by enriching them with produced water to encourage the growth of sulfate-reducing bacteria (SRB) and other corrosion-inducing microbes.

The enriched soil was then divided into three labeled containers: Container A, Container B, and Control. Containers A and B were treated with *Chromolaena odorata* ethanol extract (COEE) and aqueous extract (COAE), respectively, while the Control container contained untreated soil. This setup allowed for a controlled comparison between the treated soil environments and the untreated control, simulating natural biocorrosion conditions for the buried metal coupons.

Biocorrosion Experiment and Monitoring

To prepare the metal coupons for burial, each carbon steel coupon was pre-treated by immersing it in the *Chromolaena odorata* ethanolic or aqueous extracts at a concentration of 25 g/L for 24 hours. This conditioning step was included to allow a protective layer of the extract to form on the metal surface. After conditioning, each coupon was buried in its respective soil setup (COEE-treated, COAE-treated and Control-untreated) and kept under anaerobic conditions at room temperature to mimic the biocorrosion process.

The metal coupons were monitored over periods of 14 and 28 days to assess corrosion rates. At each interval, coupons were carefully removed, cleaned to remove any soil and extract residue, and weighed to determine the final weights (Wf). Weight loss (Wi – Wf) was recorded for each coupon to calculate the corrosion rate and assess inhibition effectiveness.

Calculation of Corrosion Rate and Inhibition Efficiency

Corrosion rate (*CR*) was calculated using the weight loss measurements (*Wi – Wf)* for each metal coupon. The inhibition efficiency (IE) of each *C. odorata* extract was calculated using the following equations, with weight loss (W) measured in grams:

$$CR = \frac{K \text{ x } (Wi - Wf)}{D \; x \; A \; x \; T}$$

Where:

- K is a rate constant (22,300),
- D is the metal density in g/cm³,
- A is the exposed surface area in cm²,
- T is the time of exposure in days.

The inhibition efficiency (IE) of each extract was calculated by comparing the corrosion rate in the treated setups to that in the control setup:

IE = 100 [1 – (*W treated / W control)*]

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Statistical Analysis

A one-way ANOVA was conducted to evaluate the statistical significance of differences in weight loss among the treatment groups (COEE, COAE, and Control) at Days 14 and 28. The analysis revealed statistically significant differences in mean percentage weight loss between groups, indicating that *Chromolaena odorata* extracts exerted a measurable effect on corrosion rates. The observed F-values were 12.662 (p = 0.000) and 10.604 (p = 0.000) for Days 14 and 28, respectively, showing a very low probability that these differences were due to random variation.

Results

The results of analysis and quantification of the identified phytochemicals of the *Chromolaena odorata* extract are presented in Table 1. The result of the Metal Weight Loss (g) for Biocorrosion Experiment with 25g/L of the Inhibitors is presented in Table 2. The result of the Percentage Weight Loss (Mean±S.D) of Metals during the Biocorrosion Study is presented in Table 3. The corrosion rate of metals in the presence and absence of the inhibitors and results of the inhibition efficiency at 25g/l concentration of the extracts are presented in Figures 1 and 2 respectively.

Table 1: Phytochemicals present in *Chromolaena odorata* extract

Compounds	***Chromolaena odorata***		**Compounds**	***Chromolaena odorata***	
Secondary Metabolites	**Ethanol extract**	**Aqueous extract**	**Antinutrients**	**Ethanol extract**	**Aqueous extract**
Total Alkaloids (g/100g)	15.370	12.583	Phytate (%)	3.057	3.717
Total Glycosides (g/100g)	3.616	3.879	Tannin (%)	3.764	1.892
Total Flavanoids (g/100g)	54.864	43.215	Oxalate (%)	1.609	1.957
Total Phenolics (g/100g)	259.953	242.824	Saponin (%)	0.947	1.479
Total Amino acids (%)	5.967	5.354	Trypsin-inhibitor (%)	2.285	1.734
Total Organic acids (%)	0.574	0.658			
Total Fatty acids (%)	31.349	28.05			

Table 2: Metal Weight Loss (g) for 14 Days and 28 Days Biocorrosion Experiment with 25g/L of the Inhibitors

	Metal Weight Loss (g)		
Duration of Burial (Day)	***Chromolaena odorata* ethanolic extract**	***Chromolaena odorata* aqueous extract**	**Control**
Day 14	0.344	0.407	1.065
Day 28	0.719	0.667	1.428

Table 3: Percentage Weight Loss (Mean±S.D) of Metals during 14 Days and 28 Days Biocorrosion Study

	Percentage Weight Loss of Metal (%)		
Duration of Burial (Day)	***Chromolaena odorata* ethanolic extract**	***Chromolaena odorata* aqueous extract**	**Control**
0	0	0	0
Day 14	0.41 ± 0.12^{a}	0.49 ± 0.13^{a}	1.27 ± 0.38^{b}
Day 28	0.86 ± 0.13^{a}	0.79 ± 0.19^{a}	1.73 ± 0.46^{b}

Values in the Table represent Mean ± standard deviation from 4 replicate experiments. Along the rows, values with similar superscripts letter are not significantly different whereas those with different superscript letters are significantly different

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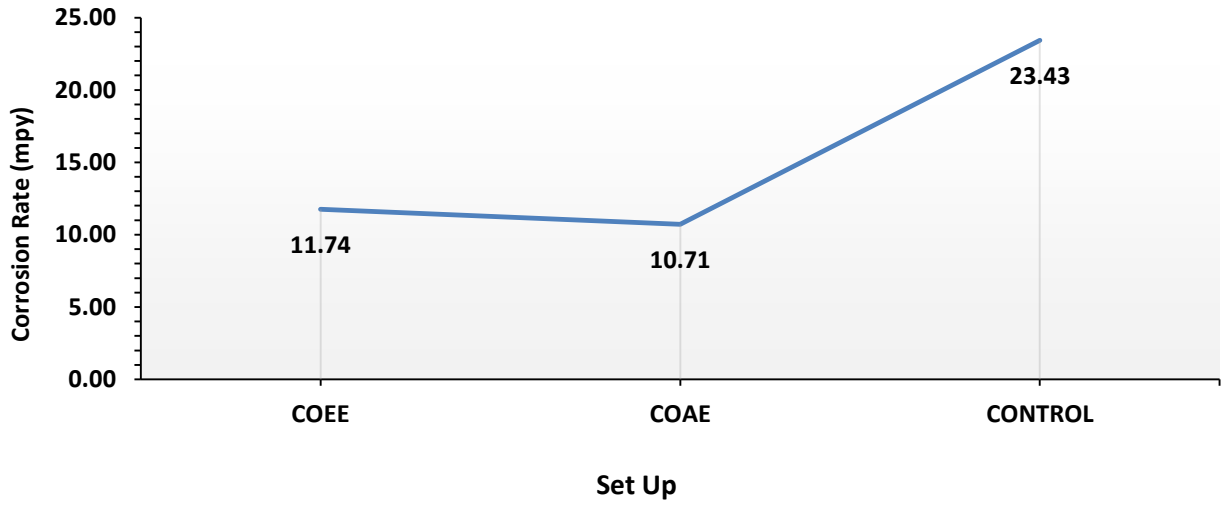

Figure 1: Corrosion Rate of Metals in the Presence and Absence of the Inhibitors
Key: COEE – *Chromolaena odorata* ethanolic extract; COAE – *Chromolaena aqueous* extract

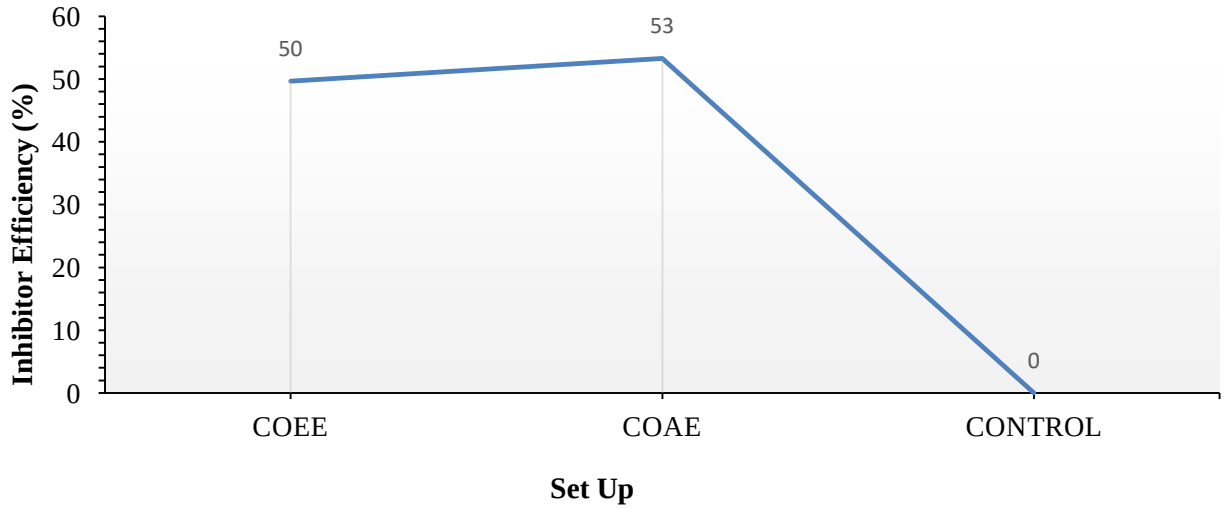

Figure 2: Inhibition Efficiency at 25g/L Concentration of the Extracts
Key: COEE – *Chromolaena odorata* ethanolic extract; COAE – *Chromolaena odorata* aqueous extract

Discussion

The findings of this study indicate a progressive increase in weight loss of metal coupons over time across all experimental setups, including those treated with *Chromolaena odorata* ethanol extract (COEE), aqueous extract (COAE), and the untreated control. This aligns with the established time-dependent nature of corrosion, where prolonged exposure to corrosive environments typically results in more significant metal degradation (Videla & Herrera, 2005; Enning & Garrelfs, 2014). The untreated control samples demonstrated the highest weight loss percentages, reaching 1.27% at 14 days and 1.73% at 28 days, which underscores the protective effect of the plant extracts in slowing corrosion rates. In setups treated with COEE and COAE, weight loss was consistently lower, with COAE at 0.49% and 0.79% at 14 and 28 days, respectively, and COEE showing 0.41% and 0.86% for the same intervals. This reduction in weight loss relative to the control highlights the efficacy of both extracts in mitigating metal degradation, a finding corroborated by similar studies using plant extracts as green corrosion inhibitors (Arockiasamy *et al*., 2015; Okafor & Ebenso, 2007).

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The gradual increase in weight loss over time, even in setups treated with COEE and COAE, can likely be attributed to the depletion of active inhibitory components in the extracts. As the bioactive compounds in *C. odorata*—including tannins, phenolics, and alkaloids—interact with the corroding metal surface, their availability diminishes, reducing their protective effect over extended exposure. This trend mirrors findings by Okafor and Ebenso (2007), who observed a similar pattern with *Carica papaya* extracts; they found that corrosion inhibition weakened as bioactive agents were consumed. The implication here is that *C. odorata* extracts may provide effective initial protection, but their efficacy could be sustained with either higher concentrations or periodic reapplication, particularly for prolonged use.

Corrosion rate analysis further confirmed the effectiveness of the extracts. By the 28-day mark, the corrosion rate ranking was COAE < COEE < Control, indicating that the aqueous extract offered slightly stronger corrosion inhibition than the ethanol extract. This difference in performance may be attributed to the specific bioactive compounds extracted by each medium. Aqueous extracts, known for their higher concentration of water-soluble compounds like tannins and phenolics, are recognized for forming stable, complex bonds with metal ions that create a barrier against corrosive agents (Rao & Mulky, 2023). These tannins and phenolics, well-documented for their corrosion-inhibiting properties (Rajendran et al., 2010), contribute to forming an insulating layer on the metal surface, reducing the oxidation and subsequent degradation processes (Sharma *et al*., 2014).

The lower corrosion rate (COEE - 10.71mpy; COAE - 11.74mpy) in the treatment setups with the inhibitors, showed that the phytochemicals in the ethanol and aqueous extracts of *C. odorata* employed in this study performed well in inhibiting the biocorrosion of the metal coupons, which was in contrast to the control setup without the inhibitors (no extract), that had a higher corrosion rate (23.43mpy).

The inhibition efficiencies recorded—53% for COAE and 50% for COEE at 25 g/L—indicate moderate but effective protection against corrosion, with the aqueous extract demonstrating a marginally higher efficiency. This slight advantage may be due to the higher concentrations of bioactive compounds like tannins in the aqueous extract.

Phytochemical secondary metabolites and antinutrients such as alkaloids, glycoside, flavonoids, phenolics, tannins, phytates, sapronins, etc. were detected in both ethanol and aqueous extracts of *C. odorata*. Secondary metabolites inhibit metal steel biocorrosion by interacting with the microbial community in the soil, changing the balance of microbial populations and reducing the overall activity of microorganisms that promote biocorrosion (Stanley et al., 2016, Rao and Mulky, 2023). Phenolics and flavonoids can act as chelatin agents, binding with metal ions and reducing their availability for corrosion reactions (Al-Amiery et al., 2023). Some secondary metabolites such as tannins, flavonoids, etc. can form complexes with metal surfaces, creating a protective layer that shields the steel from further corrosion (Al-Amiery et al., 2023). Tannins, specifically, are known to chelate with metal ions, blocking active sites on the metal surface and impeding further oxidation and corrosion (Yahya *et al*., 2014).

The phytochemical analysis of the *C. odorata* plant extracts used in this study, showed that the phenolic compounds in both the aqueous and ethanol extracts had the highest concentration amongst the other secondary metabolites. Phenolic can contribute to the formation of protective layer on the metal surface, thereby preventing the corrosion (Miralrio and Vázquez, 2020).

Another mechanism by which phenolic compounds contribute to the prevention of corrosion is by antimicrobial activity. This statement is corroborated by the report of Devab and Guibal (2020) which emphasizes that the natural antimicrobial activity of the plant, which results in minimizing biocorrosion phenomena, is usually associated to phenolic-based compounds contained in the plant extract. Additionally, phenolic compounds provide antioxidative properties that help reduce oxidation reactions, which also contributes to the inhibitive performance of the extracts (Ahamad & Quraishi, 2010).

These results place *C. odorata* within the performance range of other plant-based corrosion inhibitors, such as *Azadirachta indica* (neem) and *Carica papaya*, which exhibit inhibition efficiencies typically ranging between 40% and 80% depending on concentration, exposure duration, and environmental conditions (Beech & Sunner, 2004).

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The findings on *C. odorata* align well with existing literature on green corrosion inhibitors, suggesting that it could serve as an effective and eco-friendly option for corrosion management, though further refinement could enhance its effectiveness for industrial applications.

The promising outcomes observed for *C. odorata* extracts underscore their potential utility in industrial settings, particularly in the oil and gas sector, where buried pipelines and other metal structures are highly susceptible to microbiologically induced corrosion (MIC). With the plant's abundance in tropical regions, its cost-effectiveness, and its minimal environmental impact, *C. odorata* represents a practical solution for large-scale corrosion control. However, the observed decline in efficacy over time suggests that, in real-world applications, either increased concentrations or routine reapplication of the extracts may be necessary to maintain optimal protection, especially for prolonged exposure periods.

The findings from this study provide significant insights into the effectiveness of COEE and COAE as potential biocorrosion inhibitors. The results reveal the impact of these treatments on metal degradation over 14 and 28 days, compared to an untreated control. The percentage weight loss observed in the treated samples was substantially lower than that of the control, suggesting strong corrosion-inhibitory properties of both treatments. These results align with previous research highlighting the efficacy of plant-based extracts in mitigating corrosion through the formation of protective layers on metal surfaces (Kumar et al., 2020; Olasehinde et al., 2019).

On Day 14, the weight loss in samples treated with COEE and COAE was 0.344g and 0.407g respectively, which were significantly lower than the control value of 1.065g. This initial observation indicates that both treatments are effective in mitigating biocorrosion during the early stages. By Day 28, weight loss increased for all treatments, with COEE and COAE showing values of 0.719g and 0.667g, respectively, compared to 1.428g for the control. The progression in weight loss highlights the ongoing challenge of biocorrosion, even in the presence of inhibitors, but the treated samples continued to demonstrate significantly better resistance than the untreated control.

This aligns with findings from earlier studies suggesting that plant-derived inhibitors reduce corrosion by adsorbing on metal surfaces and slowing electrochemical reactions (Umoren & Solomon, 2015).

A one-way ANOVA confirmed that there were statistically significant differences between Day 14 and Day 28 for COEE ($p=0.002p = 0.002p=0.002$) and COAE ($p=0.040p = 0.040p=0.040$), reflecting the dynamic nature of corrosion over time and the treatments' role in slowing its progression. However, no significant difference was observed for the control ($p=0.173p = 0.173p=0.173$), indicating a steady and consistent degradation of metal in the absence of inhibitors. This distinction underscores the importance of COEE and COAE in mitigating the aggressive effects of the test environment, similar to findings in studies on green corrosion inhibitors for steel and other metals (Abiola et al., 2018). Between the two treatments, COEE demonstrated slightly better performance, with lower weight loss and a higher statistical FFF-value ($F=25.049F = 25.049F=25.049$) compared to COAE ($F=6.848F = 6.848F=6.848$). While both treatments showed similar efficacy on Day 14, COEE appeared more robust in reducing biocorrosion by Day 28.

This suggests that COEE may be a more effective inhibitor under the studied conditions, warranting further investigation into its composition and mechanism of action. Previous research has attributed variations in performance among plant-based inhibitors to differences in active compounds such as alkaloids, flavonoids, and tannins, which can impact adsorption efficiency and protective barrier formation (Verma et al., 2018). The findings emphasize the potential of COEE and COAE as practical solutions for managing biocorrosion. However, the observed increase in weight loss over time indicates that these treatments do not entirely prevent corrosion but rather slow its progression. This outcome highlights the need for optimization of these formulations to enhance their long-term effectiveness. Future studies could explore the performance of these inhibitors under varying environmental conditions and over extended durations to determine their broader applicability and durability. Additionally, mechanistic studies would be valuable in elucidating the specific biochemical or chemical interactions that contribute to their protective effects, as suggested by Shukla and Singh (2011).

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This research lays a foundation for the development of effective biocorrosion inhibitors and underscores their potential relevance in industrial applications where metal preservation is critical. Further refinement and testing of COEE and COAE could lead to the creation of optimized inhibitors with enhanced efficacy and practical utility across diverse conditions.

In conclusion, this study demonstrates that *Chromolaena odorata* extracts, both ethanol (COEE) and aqueous (COAE), effectively reduce metal corrosion in microbiologically induced environments. Over 14 and 28 days, both treatments significantly lowered weight loss compared to the control, with COAE showing slightly higher inhibition, likely due to its broader spectrum of polar phytochemicals. While the inhibitory effects diminished over time, suggesting depletion or modification of active compounds, the initial performance highlights their potential as eco-friendly, cost-effective alternatives to chemical inhibitors.

C. odorata's moderate inhibition efficiency (50–53%) situates it among other plant-based inhibitors like neem and papaya, making it a viable option for managing corrosion in industries such as oil, gas, and water utilities. Further optimization, including higher concentrations, improved extraction methods, and re-application strategies, could enhance long-term efficacy. These findings support the use of *C. odorata* as a sustainable solution to mitigate corrosion while reducing environmental and economic costs.

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