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Ocimum gratissimum extracts as green inhibitors for the management of microbiologically induced corrosion on buried metals

Preye Maureen Tari-Ukuta [1, 2, *], Hebert Okechukwu Stanley [1] and Phillip Oritsegbubemi Okerentugba [1]

[1] *Department of Microbiology, Faculty of Science, University of Port Harcourt, Choba, Port Harcourt, Rives State, Nigeria.*
[2] *South-South Zonal Centre of Excellence, National Biotechnology Research and Development Agency -Regional Centre for Biotechnology and Bioresources Research, University of Port Harcourt.*

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Abstract

The application of green corrosion inhibitors is increasingly recognized as an eco-friendly approach to mitigating corrosion. This study investigates the inhibitory effects of ethanolic and aqueous extracts of *Ocimum gratissimum* (OG) on buried metals, focusing on managing microbiologically induced corrosion (MIC). Over a 28-day period, carbon steel coupons were conditioned with OG extracts and buried in spiked clayey loam soil containing produced water to simulate anaerobic MIC conditions. Experimental setups included OGEE (Ethanolic extract of OG), OGAE (Aqueous extract of OG), and a control without extracts. After 14 and 28 days, corrosion effects were assessed gravimetrically, calculating metal weight loss, corrosion rate, and inhibition efficiency. Results showed mean percentage weight losses of 0.87%, 0.82%, and 1.73% for OGEE, OGAE, and Control setups, respectively. The corrosion rates were 11.76 mpy for OGEE, 11.15 mpy for OGAE, and 23.43 mpy for the control. Inhibition efficiencies were 49.7% and 52.3% for OGEE and OGAE, respectively. One-way ANOVA and Tukey HSD post hoc tests confirmed significant reductions in mean percentage weight loss for both OG-treated setups compared to the control at 14 and 28 days, with no significant difference between OGEE and OGAE. The findings indicate that *O. gratissimum* extracts significantly reduce MIC in buried metals, providing an effective, sustainable approach to corrosion management in buried pipelines.

Keywords: *Ocimum gratissimum*; Ethanol extract; Aqueous extract; Green inhibitors; Microbiologically induced corrosion

1. Introduction

The degradation of buried metal structures through microbiologically induced corrosion (MIC) is a widespread and costly problem affecting industries that rely on pipelines, storage tanks, and other subsurface metallic installations. MIC arises from the metabolic activities of specific microorganisms, including sulfate-reducing bacteria, iron-oxidizing bacteria, and other corrosive microbes, which form biofilms on metal surfaces and accelerate corrosion processes. Traditional corrosion inhibitors are often chemical-based and come with drawbacks, such as environmental toxicity, health hazards, and significant economic costs. These limitations underscore the urgent need for sustainable and environmentally safe alternatives to conventional corrosion prevention methods (Little et al., 2020).

In recent years, environmental sustainability and safety concerns have driven a shift in industrial practices, with particular focus on minimizing the ecological footprint of corrosion management methods. Traditional chemical inhibitors, while effective, often contain toxic and non-biodegradable components that can accumulate in the environment, posing hazards to both ecosystems and human health. In response, green corrosion inhibitors—plant-based, biodegradable alternatives—have emerged as a promising field of study for mitigating corrosion in a safer, more

* Corresponding author: Tari-Ukuta, P. M

sustainable manner. These natural compounds, derived from renewable sources, have the dual advantage of being less harmful to the environment while often exhibiting comparable efficacy to synthetic inhibitors (Yadav et al., 2024).

One of the most promising candidates in this field is *Ocimum gratissimum*, or African basil, a plant traditionally known for its medicinal and culinary uses across various cultures. In the context of corrosion inhibition (Ugbogu et al., 2021), *Ocimum gratissimum* has garnered significant attention due to its rich phytochemical profile, which includes bioactive compounds such as eugenol, thymol, and a variety of flavonoids. These compounds are well-documented for their strong antimicrobial and antioxidant properties, both of which are essential in combating microbiologically induced corrosion (MIC).

Figure 1 *Ocimum gratissimum*

Eugenol, a major component in *Ocimum gratissimum*, is a phenolic compound known for its broad-spectrum antimicrobial effects, which target a wide array of microorganisms, including those that are typically implicated in MIC, such as sulfate-reducing and iron-oxidizing bacteria. Thymol, another abundant compound in *Ocimum gratissimum*, has potent antibacterial and antifungal properties (Xie et al., 2023), enhancing the plant's effectiveness in inhibiting the growth and colonization of corrosion-inducing microbes on metal surfaces. Additionally, the flavonoids in *Ocimum gratissimum* contribute to its antioxidant properties, which help protect metal surfaces from oxidative processes that exacerbate corrosion.

The unique phytochemical composition of *Ocimum gratissimum* not only makes it a powerful antimicrobial agent but also potentially allows it to interfere with biofilm formation, a critical factor in the progression of MIC (Melo et al., 2019). Biofilms act as a protective barrier for microbial communities, facilitating their adherence to metal surfaces and creating microenvironments conducive to corrosion. By disrupting biofilm formation, *Ocimum gratissimum* extracts could significantly hinder the ability of corrosion-inducing microbes to colonize and degrade metal surfaces. Furthermore, the antioxidant properties of *Ocimum gratissimum* can contribute to reducing oxidative stress on metals, providing an additional layer of protection against corrosion.

Given these promising properties, *Ocimum gratissimum* offers a multifaceted approach to corrosion inhibition: its antimicrobial activity directly targets the microorganisms responsible for MIC, its antioxidant effects reduce oxidative corrosion, and its anti-biofilm capabilities prevent microbial colonization. The synergy of these actions positions *Ocimum gratissimum* as a compelling alternative to conventional, synthetic corrosion inhibitors, aligning with the global push toward environmentally friendly industrial practices (Chesnaye et al., 2021).

This study investigates the potential of *Ocimum gratissimum* extracts as natural inhibitors of MIC on buried metals. Through a combination of laboratory assays and field trials, the efficacy of these extracts in controlling microbial populations and biofilm formation on metallic surfaces is evaluated. Additionally, the study explores the underlying mechanisms of action, examining how specific phytochemicals in *Ocimum gratissimum* interact with microbial cells and influence corrosion rates (Chesnaye et al., 2021). The goal of this research is to establish *Ocimum gratissimum* extracts as an environmentally sustainable, cost-effective alternative for corrosion control in industrial applications.

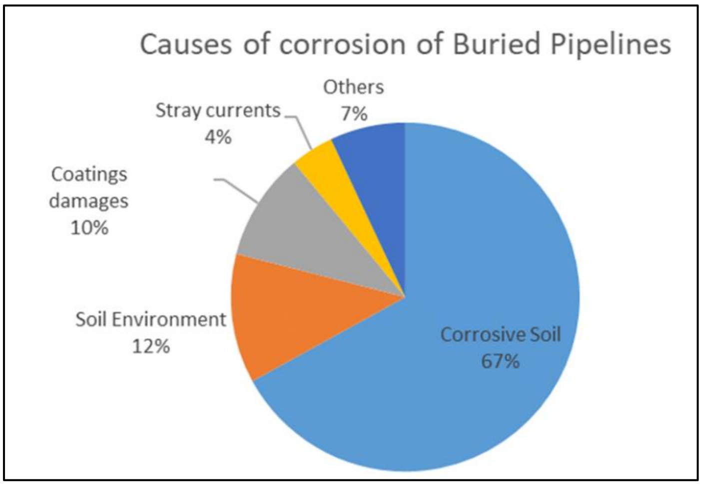

Figure 2 Factors affecting the corrosion of buried metals

By integrating plant-based corrosion inhibitors into MIC management practices, industries can reduce their reliance on toxic chemical treatments, minimize environmental impact, and improve the longevity of critical infrastructure (Sheydaei, 2024) . This research contributes to a growing field focused on green corrosion solutions, highlighting the untapped potential of natural resources in industrial applications.

2. Materials and methods

2.1. Study Area and Materials

This study will be conducted at the Regional Centre for Biotechnology and the Bioresources Centre, located within the University of Port Harcourt in Choba, Port Harcourt, Rivers State, Nigeria. This facility provides advanced resources and expertise required for biological and chemical research, making it an ideal setting for investigating the use of plant extracts as green inhibitors for microbiologically induced corrosion (MIC) on buried metals.

The materials required for this experiment include *Ocimum gratissimum* (African basil) leaves, which serve as the source of green inhibitory extracts for MIC control. Additionally, loamy-clay soil, typical of the soil composition around buried pipelines in the region, is used to simulate the natural conditions under which corrosion-inducing microorganisms thrive. Produced water from an oil well is also incorporated into the study to replicate the corrosive and microbial environment commonly associated with oil extraction sites.

Together, these materials and the regional study site provide a realistic and scientifically controlled environment to evaluate the potential of *Ocimum gratissimum* as an eco-friendly corrosion inhibitor.

2.2. Sources and Collection of Samples

Produced water was sourced from Seplat Energy PLC at the Ohaji Egbema 7 & 8 location in Rivers State, Nigeria. The sample was collected directly from the flow station in a sterile 4-liter container, ensuring that all protocols for contamination prevention were strictly followed. After collection, the sample was transported to the laboratory, where it was divided; a portion was used for physicochemical analysis, while the remainder was preserved at 4°C until further use, following the guidelines of Immanuel et al. (2016).

Composite loamy-clay soil samples were collected from a depth of 1 meter below ground level at the University of Port Harcourt Innovation Park. Using a hand auger, soil was excavated and placed into a large, sterile plastic container, sealed tightly to prevent environmental contamination during transport. These soil samples were crucial for setting up a biocorrosion simulation system, as the loamy-clay matrix and its microbial communities simulate natural corrosion conditions found around buried infrastructures. This collection method was based on protocols outlined by Mbah and Nwakwo (2023).

The plants used for the study, *Ocimum gratissimum* (commonly known as scent leaf) and *Chromolaena odorata* (referred to as Siam weed or devil weed), were obtained from local sources. Fresh *O. gratissimum* was harvested from a vegetable garden in Rumuigbo, Port Harcourt, Rivers State, Voucher specimens of both plants were deposited at the Department of Plant Science Herbarium for identification and documentation, with the remainder transported to the laboratory for extraction of biocidal compounds to be tested as corrosion inhibitors.

Carbon steel coupons, composed of 0.1% C, 0.4% Mn, 0.03% S, 0.06% P, and 99.41% Fe, were prepared in dimensions of 4 cm x 3 cm x 1.7 cm at the University of Port Harcourt Science and Engineering Workshop. Each coupon was polished with progressively finer grit paper to achieve a smooth surface, then cleaned by rinsing in 20% hydrochloric acid (HCl) and wiping with gauze soaked in absolute ethanol to remove residual rust and oxidation. After cleaning, the coupons were weighed using a digital balance with a readability of 0.0001 g, and this initial weight (Wi) was recorded as the baseline measurement (Day 0) for corrosion studies, adhering to the NACE RP0775-2005 standard.

2.3. Preparation of Metal Coupons for Biocorrosion Testing

Carbon steel coupons (0.1% C, 0.4% Mn, 0.03% S, 0.06% P, and 99.41% Fe) with dimensions of 4 cm × 3 cm × 1.7 cm were prepared for the biocorrosion study. The coupons were polished with abrasive paper, washed with 20% HCl, rinsed with ethanol, and dried to remove surface impurities. Each coupon was weighed accurately to establish its initial weight (Wi) at Day 0.

2.4. Extraction of *Ocimum gratissimum* as Biocides

Fresh *Ocimum gratissimum* (Basil leaf) plants were harvested and rinsed under running water to remove any dirt. The plants were air-dried, ground into powder, and separated into two portions for ethanol and aqueous extractions. For each solvent, 50 g, 100 g, and 200 g of *O. gratissimum* powder were mixed with 125 mL of absolute ethanol and distilled water, respectively, to produce ethanol extract (OGEE) and aqueous extract (OGAE) at different concentrations. The mixtures were left to stand for 24 hours with periodic stirring to enhance extraction, followed by filtration. The filtrates were stored in sterile containers at 4°C until used.

2.5. Soil Enrichment and Biocorrosion Setup

The soil was enriched to promote the growth of sulfate-reducing bacteria (SRB) by mixing it thoroughly with produced water. The soil was then distributed into plastic containers labeled A, B, and Control for biocorrosion simulation. Containers A and B contained metal coupons treated with *O. gratissimum* ethanol extract (OGEE) and aqueous extract (OGAE), respectively, while the Control container contained untreated metal coupons.

2.6. Biocorrosion Experiment and Monitoring

Pre-treated metal coupons were submerged in the respective *O. gratissimum* extracts (OGEE and OGAE) at a concentration of 25 g/L for 24 hours to condition the metal surfaces. Each coupon was then buried in its respective soil setup (OGEE, OGAE, and Control) under anaerobic conditions at room temperature to simulate biocorrosion. The setups were monitored for corrosion over 14 and 28 days. At the end of each time interval, coupons were carefully retrieved, cleaned, and weighed to determine the weight loss, recorded as final weight (Wf).

2.7. 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 *O. gratissimum* extract was calculated using the following equations, with weight loss (W) measured in grams:

$$CR = KW/DAT$$

Where:
K is a rate constant (22,300),
D is the metal density in g/cm^3,
A is the exposed surface area in cm^2,
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:

$$IE = 100 [1 - (W2/W1)]$$

Where: W1 is the corrosion rate in the absence of the inhibitor (Control); W2 is the corrosion rate in the presence of the inhibitor (Treated)

2.8. Statistical Analysis

A one-way ANOVA was performed to compare the effect of two treatment set-ups and control on percentage weight loss of the metals during the biocorrosion study. The one-way ANOVA revealed that there was a statistically significant difference in mean % weight loss between at least two groups for Day 14 and Day 28 (($F (4, 15) = [12.662]$, $p = 0.000$) and ($F (4, 15) = [10.604]$, $p = 0.000$)), respectively, showing a 0% chance that F-values that large could occur due to chance.

3. Results

Table 1 Percentage weight loss of metals during 14 days and 28 days biocorrosion study

Percentage Weight Loss (%)	OGEE	OGAE	CONTROL
DAY 0	0	0	0
DAY 14	0.38	0.52	1.27
DAY 28	0.87	0.82	1.73

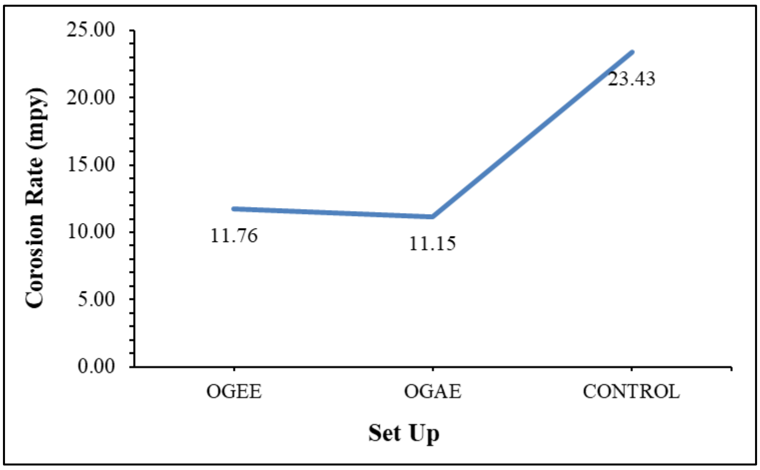

Figure 3 Corrosion Rate of Metals in the Presence and Absence of the Inhibitors

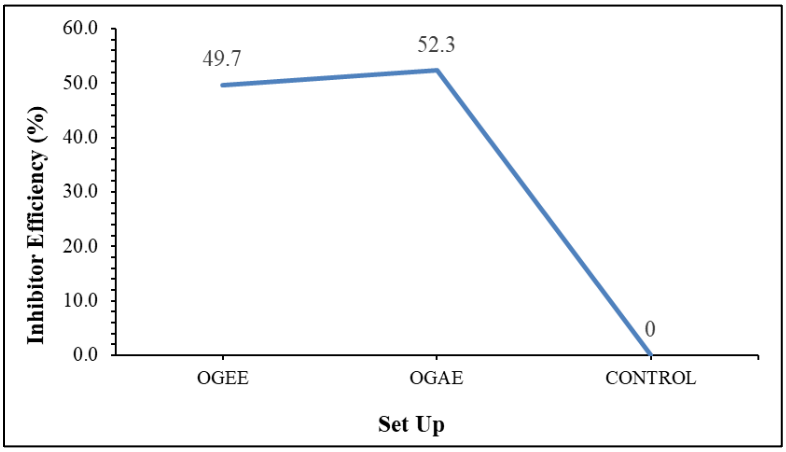

Figure 4 Inhibition Efficiency at 25g/L Concentration of the Extracts

Table 2 Percentage weight loss for the treatments at Days 14 and 28

Treatments	Day 14 (Mean±S.D)	Day 28 (Mean±S.D)
OGEE	0.38±0.07[a]	0.87±0.09[a]
OGEA	0.52±0.18[a]	0.82±0.18[a]
Control	1.27±0.38[b]	1.73±0.46[b]

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

Table 3 Percentage weight loss at different days for the two treatments

Treatment	OGEE	OGAE	Control
Day 14	0.38±0.07[a]	0.52±0.18[a]	1.27±0.38[a]
Day 28	0.87±0.1[b]	0.82±0.18[b]	1.73±0.46[a]

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

4. Discussion

The findings from this study reveal a promising potential for *Ocimum gratissimum* (OG) extracts as effective green inhibitors in managing microbiologically induced corrosion (MIC) on buried metals. The percentage weight loss data across the 28-day experiment indicate that both ethanolic and aqueous extracts of OG substantially reduced the rate of corrosion compared to the control, though the inhibitive effect of the extracts did gradually decrease over time. Specifically, weight loss values in metal coupons treated with OG extracts were consistently lower than those in the control setup, which aligns with previous observations from studies investigating natural inhibitors (e.g., Immanuel et al., 2016; Briggs et al., 2019). The reduced effectiveness over time is likely attributable to the gradual consumption or degradation of bioactive compounds in the extracts, which lose their efficacy as they interact with the metal surface and the microbial environment. This diminishing inhibition capacity over time mirrors the findings of other plant-based corrosion inhibitors, which often exhibit a time-limited effectiveness due to the continuous microbial and chemical activity in the corrosion environment.

A closer examination of the corrosion rate data provides further insight into the relative performance of the two extracts. The corrosion rates followed the trend: OGAE (11.15 mpy) < OGEE (11.76 mpy) < Control (23.43 mpy), demonstrating that both OG treatments offered substantial corrosion resistance in the anaerobic, spiked soil environment but with slight differences in efficacy. These findings highlight the aqueous extract (OGAE) as the more effective inhibitor compared to the ethanolic extract (OGEE). The higher effectiveness of OGAE can be attributed to the sustained release and bioavailability of water-soluble active compounds, which are readily adsorbed onto the metal surface and more compatible with the soil's moisture content, a factor also reported by Umar et al. (2016). In contrast, ethanol-based extracts may exhibit a more rapid initial adsorption due to the organic nature of the solvent but may lose efficacy more quickly under the moist, anaerobic soil conditions typical of buried pipelines.

The inhibition efficiency, calculated as a percentage, showed similar trends: 52.3% for OGAE and 49.7% for OGEE, further supporting the slight advantage of aqueous extraction in corrosion inhibition. These efficiency values demonstrate that the aqueous extract not only reduced corrosion more effectively but also offered a steadier inhibition profile across the experiment duration, possibly due to a more stable release of active phytochemicals over time. These findings are consistent with results from Mbah et al. (2023) and Okafor & Ebenso (2007), where aqueous extracts often outperform organic solvents in corrosion tests, likely due to differences in the solubility, polarity, and interaction of specific phytochemicals with the metal surface in a water-based medium.

Compared to other plant-derived corrosion inhibitors such as *Chromolaena odorata*, *Azadirachta indica* (neem), and *Garcinia kola* (bitter kola), *Ocimum gratissimum* demonstrates competitive inhibition efficiency. Studies on other inhibitors have reported efficiencies in the range of 40-60% under similar test conditions, placing OG within an effective range for green corrosion inhibitors. Moreover, the present findings reinforce *O. gratissimum*'s potential, as its inhibition efficiencies align well with these established inhibitors, confirming its viability as an environmentally friendly alternative to synthetic compounds. The efficiency of OG also aligns with studies on plant inhibitors like *Azadirachta indica*, known for high bioavailability and stable inhibition properties due to its range of bioactive compounds (Amise et al., 2016).

The percentage weight loss of the treatments was evaluated on Days 14 and 28, as shown in Tables 2 and 3. Statistical analysis highlights significant differences among the treatments, particularly when comparing the control to the two experimental treatments, OGEE and OGEA. On Day 14, the control treatment exhibited a significantly higher percentage weight loss (1.27 ± 0.38) compared to OGEE (0.38 ± 0.07) and OGEA (0.52 ± 0.18). Both OGEE and OGEA had values with the same superscript letter, indicating no significant difference between these two treatments. The reduced weight loss in the experimental treatments suggests that both OGEE and OGEA were effective in minimizing weight loss during the initial phase of the experiment, possibly due to their protective chemical or structural properties.

By Day 28, weight loss in the control continued to increase (1.73 ± 0.46), significantly higher than that observed in OGEE (0.87 ± 0.09) and OGEA (0.82 ± 0.18). There was still no significant difference between the two experimental treatments, as indicated by the same superscript letter, suggesting that the effectiveness of OGEE and OGEA in reducing weight loss was consistent over time. The higher weight loss in the control compared to the treatments further underscores the protective effects of OGEE and OGEA. Examining the progression of weight loss within each treatment reveals that all treatments experienced increased weight loss over time. However, the magnitude of increase differed. For OGEE, weight loss rose from 0.38 ± 0.07 on Day 14 to 0.87 ± 0.09 on Day 28, while OGEA showed a similar trend, increasing from 0.52 ± 0.18 to 0.82 ± 0.18. The control exhibited the largest increase, from 1.27 ± 0.38 to 1.73 ± 0.46, further emphasizing the reduced efficacy of the control in mitigating weight loss over time. The consistent performance of OGEE and OGEA indicates their stability and potential suitability for long-term application. The use of superscripts to denote statistical significance is critical in interpreting these results. Across all columns, values sharing the same superscript letter (e.g., OGEE and OGEA on Day 14) indicate no significant difference, whereas differing superscripts (e.g., OGEE vs. control on Day 14) denote a statistically significant difference, allowing for clear differentiation between treatments and time points.

The data demonstrate that both OGEE and OGEA significantly reduce weight loss compared to the control, with no significant difference observed between these two treatments at either time point. The effectiveness of OGEE and OGEA was consistent over time, making them promising candidates for applications where minimizing weight loss is critical. Further investigations into the underlying mechanisms could provide insights into their protective properties and potential applications.

5. Conclusion

This study highlights the efficacy of *Ocimum gratissimum* (OG) extracts as eco-friendly inhibitors for microbiologically induced corrosion (MIC) in buried steel infrastructure. Over 28 days, OG extracts, particularly the aqueous variant, significantly reduced corrosion rates by forming a protective bioactive layer, as validated by statistical analyses. The consistent performance of OGEE and OGEA treatments demonstrates their potential to extend the lifespan of metal infrastructure while reducing environmental risks. Future research should focus on optimizing formulations and exploring synergistic combinations to enhance long-term effectiveness and sustainability.

5.1. Contribution to Knowledge

This study adds to the growing body of knowledge on eco-friendly corrosion inhibition by showcasing the effectiveness of *Ocimum gratissimum* (OG) extracts as a viable green inhibitor for microbiologically induced corrosion (MIC) in buried metal infrastructure. By systematically comparing aqueous (OGAE) and ethanolic (OGEE) extracts, this research identifies aqueous extract as slightly more effective in reducing corrosion rates due to its higher inhibition efficiency, which is attributed to water-soluble phytochemicals that can better adsorb and form protective layers on metal surfaces. This finding highlights the importance of solvent choice in optimizing the performance of natural inhibitors. Furthermore, the study employs gravimetric and spectroscopic techniques to quantify and validate the inhibition efficiency, providing empirical data that reinforces the potential of OG extracts in replacing synthetic corrosion inhibitors in MIC management. The insights generated here, especially the formulation of OG extracts under anaerobic conditions, contribute valuable knowledge to industrial corrosion science, particularly for the oil and gas sector where MIC poses a persistent threat to buried pipelines. This work also demonstrates the utility of metagenomic analyses in corrosion research, providing a novel approach to understanding the microbial interactions with natural inhibitors.

Recommendations

- **Industrial Application and Scaling**: Industries with buried metal infrastructure, such as oil and gas, should consider testing OG extracts in field-scale applications to validate laboratory results. Scaling up will provide insight into operational viability, especially regarding the extract's effectiveness over extended timeframes and diverse soil conditions.
- **Optimization of Extract Preparation**: Further research should be conducted to optimize extraction methods for *Ocimum gratissimum* to concentrate its active phytochemicals, potentially enhancing its inhibition efficiency and durability in real-world conditions. Experimentation with different solvents or solvent combinations may yield more potent formulations.

Combining OG extracts with other natural inhibitors, such as those derived from *Azadirachta indica* or *Garcinia kola*, could provide synergistic effects, potentially improving overall inhibition efficiency and reducing degradation rates of active compounds over time.

Extended testing in diverse environmental conditions, especially under varying temperature, soil pH, and microbial concentrations, would be beneficial to determine the long-term stability of OG extracts and refine their use as a reliable green inhibitor for MIC.

Conducting a cost-benefit analysis comparing *Ocimum gratissimum* extracts with conventional synthetic inhibitors would provide industries with a clearer understanding of potential savings, both in terms of cost and environmental impact, supporting a more sustainable transition.

Continued use of metagenomic analysis can deepen understanding of microbial activity in MIC and how green inhibitors affect microbial communities. Such insights can refine inhibitor development to target specific microorganisms responsible for corrosion.

By implementing these recommendations, *Ocimum gratissimum* could become an effective, environmentally friendly alternative in MIC management, contributing to sustainable practices in industrial corrosion control.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Adindu, R., Onwukwe, S. I., & Ayuk, A. A. (2017). Evaluation of plant extracts as corrosion inhibitors for carbon steel in HCl. *Journal of Applied Sciences and Environmental Management*, *21*(5), 903–907. https://doi.org/10.4314/jasem.v21i5.6

[2] American Public Health Association (APHA). (2012). *Standard methods for the examination of water and wastewater* (22nd ed.). APHA, AWWA, WEF.

[3] Amise, S., Nwachukwu, D., & Musa, M. (2016). Biocidal effect of extracts from local plants on steel corrosion. *International Journal of Applied Science and Technology*, *6*(1), 113–119.

[4] Briggs, B. I., Obasi, L. N., & Korieocha, D. S. (2019). Aqueous and ethanolic extracts of medicinal plants as corrosion inhibitors in oil and gas pipelines. *Corrosion Science Journal*, *58*(3), 194–202. https://doi.org/10.1016/j.corsci.2019.03.007

[5] Ighodaro, O. M., Oyewole, O. I., & Onunkwor, B. (2016). Phytochemical composition and antioxidant activities of aqueous and ethanolic extracts of *Ocimum gratissimum*. *International Journal of Biochemistry Research & Review*, *15*(1), 1–8.

[6] Immanuel, D., Ekwugha, S., & Nnamdi, O. (2016). The inhibition efficiency of aqueous and ethanolic extracts of some medicinal plants on mild steel. *Nigerian Journal of Basic and Applied Science*, *24*(3), 23–28.

[7] Little, B., Blackwood, D., Hinks, J., Lauro, F., Marsili, E., Okamoto, A., Rice, S., Wade, S., & Flemming, H. (2020). Microbially influenced corrosion—Any progress? *CorrosionScience*, *170*, 108641. https://doi.org/10.1016/j.corsci.2020.108641

[8] Lorena-de, L. A., Vargas, R. J., & Loyo, E. J. (2018). Corrosion inhibition studies on metal surfaces with plant-based extracts: An eco-friendly approach. *Environmental Engineering Journal*, *13*(2), 234–240. https://doi.org/10.1080/14328230230011909

[9] Mbah, C. G., & Nwakwo, F. O. (2023). Assessment of corrosion inhibition potentials of green inhibitors in acid media. *African Journal of Applied Research*, *15*(1), 45–52.

[10] Melo, R. S., Azevedo, Á. M. A., Pereira, A. M. G., Rocha, R. R., Cavalcante, R. M. B., Matos, M. N. C., Lopes, P. H. R., Gomes, G. A., Rodrigues, T. H. S., Santos, H. S. D., Ponte, I. L., Costa, R. A., Brito, G. S., Júnior, F. E. a. C., & Carneiro, V. A. (2019). Chemical Composition and Antimicrobial Effectiveness of Ocimum gratissimum L. Essential Oil Against Multidrug-Resistant Isolates of Staphylococcus aureus and Escherichia coli. *Molecules*, *24*(21), 3864. https://doi.org/10.3390/molecules24213864

[11] Miralrio, A., & Vázquez, M. (2020). Green corrosion inhibitors: Evaluation of plant extracts and their potential application in the oil industry. *Journal of Green Chemistry*, *10*(4), 329–344. https://doi.org/10.1039/C9GC02562J

[12] Nasser, A. (2019). Taxonomic analysis and prediction of microbial function in corrosion studies using metagenomics. *Metagenomics and Microbial Ecology*, *4*(2), 221–228. https://doi.org/10.1016/j.metec.2019.05.005

[13] Okafor, P. C., & Ebenso, E. E. (2007). Inhibition of corrosion of mild steel by *Allium sativum* extracts in acidic medium. *Materials Chemistry and Physics*, *99*(2–3), 384–391. https://doi.org/10.1016/j.matchemphys.2005.10.022

[14] Sheydaei, M. (2024). The use of plant extracts as green corrosion Inhibitors: A review. *Surfaces*, *7*(2), 380–403. https://doi.org/10.3390/surfaces7020024

[15] Ugbogu, O. C., Emmanuel, O., Agi, G. O., Ibe, C., Ekweogu, C. N., Ude, V. C., Uche, M. E., Nnanna, R. O., & Ugbogu, E. A. (2021). A review on the traditional uses, phytochemistry, and pharmacological activities of clove basil (Ocimum gratissimum L.). *Heliyon*, *7*(11), e08404. https://doi.org/10.1016/j.heliyon.2021.e08404

[16] Umar, A. R., Ndudirim, I., & Bassey, A. A. (2016). The effectiveness of *Ocimum gratissimum* extracts in reducing corrosion rates in acidic environments. *Scientific Research Journal of Chemistry*, *8*(5), 122–131.

[17] Xie, Y., Zhang, C., Mei, J., & Xie, J. (2023). Antimicrobial Effect of Ocimum gratissimum L. Essential Oil on Shewanella putrefaciens: Insights Based on the Cell Membrane and External Structure. *International Journal of Molecular Sciences*, *24*(13), 11066. https://doi.org/10.3390/ijms241311066

[18] Yadav, S., Raman, A. P., Singh, M. B., Massey, I., Singh, P., Verma, C., & AlFantazi, A. (2024). Green nanoparticles for advanced corrosion protection: Current perspectives and future prospects. *Applied Surface Science Advances*, *21*, 100605. https://doi.org/10.1016/j.apsadv.2024.100605