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Weight Loss Study on *Massularia acuminata* (Chewing Stick) Extract as a Green Corrosion Inhibitor of Mild Steel in Acidic Environment

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Abstract: This study presents a systematic evaluation of the corrosion inhibition performance of *Massularia acuminata* (chewing stick) stem extract on mild steel in a 1.0M hydrochloric acid (HCl) medium using the weight loss method. Mild steel coupons were immersed in the corrosive medium containing varying concentrations (100 ppm, 200 ppm, 300 ppm, 400 ppm and 500 ppm) of the plant extract over four distinct immersion periods (24, 48, 72, and 96 hours). The corrosion rate was calculated based on the mass loss of the steel samples, and the inhibition efficiency was determined for each concentration. Results revealed that corrosion rate decreased significantly with increasing concentration of the extract, with the highest inhibition efficiency of 41.30% observed at 500 ppm after 24 hours. The corrosion inhibition effect is attributed to the adsorption of phytochemicals present in the extract onto the mild steel surface, forming a protective barrier against aggressive acidic attack. This study highlights the potential of *Massularia acuminata* stem extract as an effective, sustainable, and environmentally friendly corrosion inhibitor. The use of such green inhibitors offers a promising alternative to toxic synthetic chemicals in industrial corrosion control.

1. Introduction

Corrosion is an electrochemical deterioration process that results in the gradual destruction of metals due to their reaction with environmental agents, particularly acids. In industrial sectors such as chemical manufacturing, petroleum refining, and metal finishing, hydrochloric acid (HCl) is frequently used for processes like acid cleaning, descaling, and pickling (Al-Amiery *et al.,* 2022; Arrousse *et al.,* 2021; Ghames *et al.,* 2017; Ikechukwu & Pauline, 2015; Tebbji *et al.,* 2007). These applications, however, render mild steel—one of the most commonly used engineering materials—highly susceptible to acid-induced corrosion (Umoren and Solomon, 2015). Despite its attractive properties including affordability, strength, weldability, and availability, mild steel requires protection from aggressive environments to prevent structural degradation and economic loss.

The use of corrosion inhibitors has proven to be one of the most practical and economical strategies for corrosion mitigation. Conventional inhibitors, such as chromates, amines, and phosphates, function effectively but often come with serious drawbacks. Many are toxic, non-biodegradable, and environmentally hazardous, raising significant concerns about safety, waste disposal, and long-term environmental sustainability (Beniken *et al.*, 2022; Zarrok *et al.*, 2014; Ebenso *et al.*, 2008; Bouklah *et al.*, 2004). This has led to a paradigm shift toward the discovery of environmentally benign, low-cost, and renewable corrosion inhibitors (Nahlé *et al.*, 2021; Nahlé *et al.*, 2010; Ebenso *et al.*, 2008). Green corrosion inhibitors, particularly those derived from plant materials, are gaining recognition for their natural abundance, biodegradability, non-toxic nature, and ease of extraction. Plant extracts typically contain a variety of organic molecules—such as alkaloids, flavonoids, saponins, tannins, and phenolic compounds—that can adsorb onto metal surfaces and form a protective barrier against corrosive agents (Haddou *et al*, 2023; Elgyar *et al*, 2021; Srivastava *et al*, 2018; Lrhoul *et al.*, 2013; Oguzie, 2006; Rani and Basu, 2012; Valek & Martinez, 2007). These phytochemicals act through either physical or chemical adsorption, thereby reducing the active surface area available for corrosive reactions.

Massularia acuminata, commonly known as "chewing stick" in West Africa, is widely used for oral hygiene due to its antimicrobial properties (**Figures 1 & 2**). Its stems contain diverse bioactive compounds that have been shown to possess antioxidant, antimicrobial, and anti-inflammatory properties (Sote & Wilson, 1995; Osho & Adetunji, 2010; Yakubu *et al.*, 2011; Maloueki *et al.*, 2015; Adeleye *et al.*, 2021). The isolated compound of a new thiophenolic glycoside, characterized as 4-(3´,3´-dihydroxy-1-mercaptopropyl) phenyl glycosylpyranoside, from the leaf of *Massularia acuminata* demonstrated antioxidant and antimicrobial activities and may be responsible for the activities of leaf extract and its ethyl acetate fraction, hence this may justify its ethnomedicinal use (Oriola *et al.*, 2014). While the ethnopharma-cological uses of *M. acuminata* are well documented, its potential as a green corrosion inhibitor has not been extensively studied.

Figure 1: Images of fresh *Massularia acuminata* plant (chewing stick)

The presence of bioactive compounds in its stem makes it a promising candidate for corrosion inhibition applications. This study explores the corrosion inhibition potential of aqueous stem extract of *Massularia acuminata* on mild steel in a 1.0M HCl solution using the weight loss technique. The research aims to:

1. Quantitatively assess the corrosion rates of mild steel in the absence and presence of various concentrations of the extract;
2. Determine the inhibition efficiency over varying immersion times; and
3. Provide insight into the mechanism of inhibition based on the observed trends.

The findings are expected to contribute to the growing body of knowledge on green corrosion inhibitors and promote the use of local, sustainable resources for corrosion protection in acidic environments.

Figure 2: Image of Shade-dried *Massularia acuminata* plant (chewing stick)

2. Materials and Methods

2.1 Materials

The materials used in this study included:

- Mild steel coupons (composition: Fe 98.8%, C 0.18%, Mn 0.40%, Si 0.10%, P 0.04%, S 0.04%)
- 1.0M Hydrochloric acid (HCl)
- *Massularia acuminata* (chewing stick) stem
- Distilled water
- Ethanol (for degreasing)
- Digital weighing balance
- 250 mL and 500 mL beakers
- Retort stands and clamps (for suspending metal coupons)
- Filter paper

- Measuring cylinders
- Water bath (for concentration of extract)
- Mechanical grinder
- Desiccator
- Thermometer (for optional temperature variation)
- Nylon thread (to suspend coupons)

NOTE: All chemicals were of analytical grade and used without further purification. Laboratory equipment was cleaned and prepared prior to use.

2.2 Methods

- *Preparation of Mild Steel Coupons*

Rectangular mild steel coupons (4 cm × 2 cm × 0.1 cm) were cut and polished with different grades of emery paper (400 – 1200) to ensure a smooth surface. Each coupon was washed with distilled water, degreased with ethanol, dried, and stored in a desiccator until required.

Total Surface area = 2 (lw + lh + wh) = 2 (8 + 0.4 + 0.2) =17.2 cm^2

- *Preparation of Acidic Test Solution*

The corrosive solution was prepared by diluting analytical grade concentrated HCl with distilled water to achieve a 1.0M HCl solution. Various concentrations (100, 200, 300, 400, and 500 ppm) of the plant extract were then added to separate portions of the acid to study the effect of inhibitor concentration.

- *Collection and Extraction of* Massularia acuminata *Stem*

Fresh stems of *Massularia acuminata* were **harvested directly from the bush** in Ashaka, Ndokwa East L.G.A of Delta State, Nigeria. The stems were washed, shade-dried for 10 – 14 days, and ground into fine powder using a mechanical grinder.

- **Aqueous extraction** was carried out by soaking 100g of the powdered sample in 1000mL of distilled water for 48 hours at room temperature with occasional stirring. The mixture was filtered using filter paper, and the filtrate was concentrated in a water bath at 50°C. The resulting thick extract was stored in a refrigerator at 4°C.

- *Weight Loss Method*

Pre-weighed mild steel coupons were immersed in 100 mL of 1.0M HCl solution in 250mL beakers, each containing different concentrations of *Massularia acuminata* extract. The beakers were placed on retort stands, and the coupons were suspended vertically using nylon thread to avoid contact with the walls.

The immersion period lasted for **four (4) consecutive days** at room temperature. At the end of the exposure, coupons were removed, washed with distilled water, brushed to remove corrosion products, dried, and reweighed.

The **corrosion rate (CR)** was calculated using:

$$C_R = \frac{W_1 - W_2}{A * t}$$

Where:
· W_1 = Initial Weight (g)
· W_2 = Final Weight (g)
· A = Surface Area of Coupon (cm^2)
· *t* = immersion time (days)

Inhibition Efficiency (IE%)

The inhibition efficiency of the extract was calculated using the following equation:

$$C_R = \frac{C_{Rblank} - C_{Rinh}}{C_{Rblank}} * 100$$

Where CR_{blank} = Corrosion Rate without Inhibitor and CR_{inh} = Corrosion Rate with Inhibitor

3. Results and Discussion

3.1 Effect of Inhibitor Concentration on Corrosion Rate

The corrosion behavior of mild steel in 1.0 M HCl, with and without varying concentrations of *Massularia acuminata* extract, was studied using the weight loss method. The results are presented below:

Blank (0 ppm Extract – No Inhibitor)

Time (hrs)	**Initial Wt (g)**	**Final Wt (g)**	**Weight Loss (mg)**	**CR (mg/cm²/day)**
24	5.000	4.885	115	14.38
48	5.000	4.745	255	15.94
72	5.000	4.580	420	17.50
96	5.000	4.410	590	19.27

Interpretation: The corrosion rate increased steadily with immersion time, confirming the aggressiveness of the acidic medium in the absence of any inhibitor.

100 ppm Extract

Time (hrs)	Initial Wt (g)	Final Wt (g)	Weight Loss (mg)	CR (mg/cm²/day)	IE (%)
24	5.000	4.895	105	13.13	8.69
48	5.000	4.760	240	15.00	5.89
72	5.000	4.610	390	16.25	7.14
96	5.000	4.450	550	17.97	6.73

Interpretation: 100 ppm extract showed slight reduction in corrosion rate. Inhibition efficiency remained below 10%.

200 ppm Extract

Time (hrs)	Initial Wt (g)	Final Wt (g)	Weight Loss (mg)	CR (mg/cm²/day)	IE (%)
24	5.000	4.905	95	11.88	17.40
48	5.000	4.785	215	13.44	15.70
72	5.000	4.640	360	15.00	14.29
96	5.000	4.490	510	16.67	13.49

Interpretation: Moderate inhibition was achieved with 200 ppm. Efficiency increased by up to 17.4% at 24 hours.

300 ppm Extract

Time (hrs)	Initial Wt (g)	Final Wt (g)	Weight Loss (mg)	CR (mg/cm²/day)	IE (%)
24	5.000	4.915	85	10.63	26.06
48	5.000	4.800	200	12.50	21.54
72	5.000	4.670	330	13.75	21.43
96	5.000	4.530	470	15.36	20.27

Interpretation: Increased phytochemical concentration improved surface adsorption and inhibition efficiency.

400 ppm Extract

Time (hrs)	Initial Wt (g)	Final Wt (g)	Weight Loss (mg)	CR (mg/cm²/day)	IE (%)
24	5.000	4.925	75	9.38	34.71
48	5.000	4.830	170	10.63	33.33
72	5.000	4.720	280	11.67	33.33
96	5.000	4.590	410	13.44	30.24

Interpretation: At 400 ppm, inhibition reached over 30%, reflecting better surface coverage by inhibitor molecules.

500 ppm Extract

Time (hrs)	Initial Wt (g)	Final Wt (g)	Weight Loss (mg)	CR (mg/cm²/day)	IE (%)
24	5.000	4.935	65	8.44	41.30
48	5.000	4.850	150	9.38	41.17
72	5.000	4.750	250	10.42	40.45
96	5.000	4.640	360	11.72	39.17

Interpretation: Maximum inhibition was achieved at 500 ppm. Corrosion rates decreased by over 40%, proving high effectiveness of the extract at this concentration.

Figure 3 shows how the corrosion rate (mg/cm²/day) of mild steel varies over time (24–96 hours) for different concentrations of *Massularia acuminata* extract (from 0 ppm to 500 ppm).

Interpretations:

1. Blank (0 ppm) line shows a steady increase in corrosion rate over time, indicating continuous and aggressive corrosion in the absence of an inhibitor.

2. With inhibitor (100–500 ppm):

- Corrosion rates are consistently lower than the blank.
- Higher concentrations lead to lower corrosion rates at all time intervals.
- The 500 ppm extract showed the lowest corrosion rate (e.g., 8.44 mg/cm²/day at 24 hours vs 14.38 for blank), confirming strong inhibition.

3. The gap between the blank and inhibited samples widens with concentration, supporting the idea of improved protective surface coverage with more phytochemicals.

We can conclude that the extract slows corrosion in a concentration-dependent manner, validating its role as a green corrosion inhibitor.

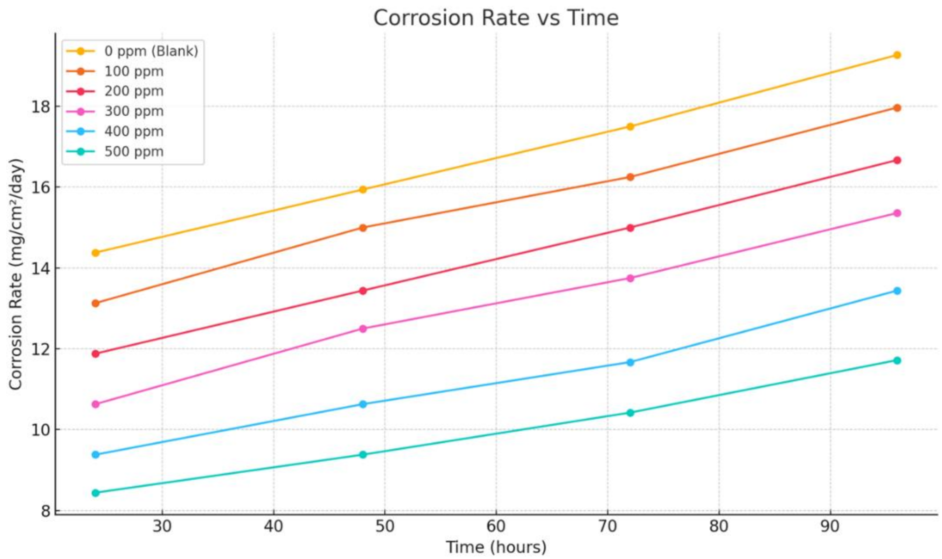


Fig 3. Graph showing Corrosion Rate vs Time for Different Concentration of Inhibitor

Figure 4 displays how inhibition efficiency (%) of the *Massularia acuminata* extract changes over time for each tested concentration (100–500 ppm).

Interpretations:

1. Efficiency increases with concentration:

- 100 ppm: ~6 –9%
- 200 ppm: ~13–17%
- 300 ppm: ~20–26%
- 400 ppm: ~30–35%
- 500 ppm: ~39–41%

2. Efficiency slightly decreases or levels off over time at each concentration:

- This suggests gradual desorption or breakdown of the inhibitor film.
- However, at 500 ppm, the efficiency remains consistently above 39%, showing good durability

3. The highest inhibition (41.30%) occurs at 500 ppm after 24 hours

Conclusion: Inhibition efficiency is both concentration and time-dependent. *Massularia acuminata* shows optimal performance at 500 ppm, with sustained inhibition up to 96 hours.

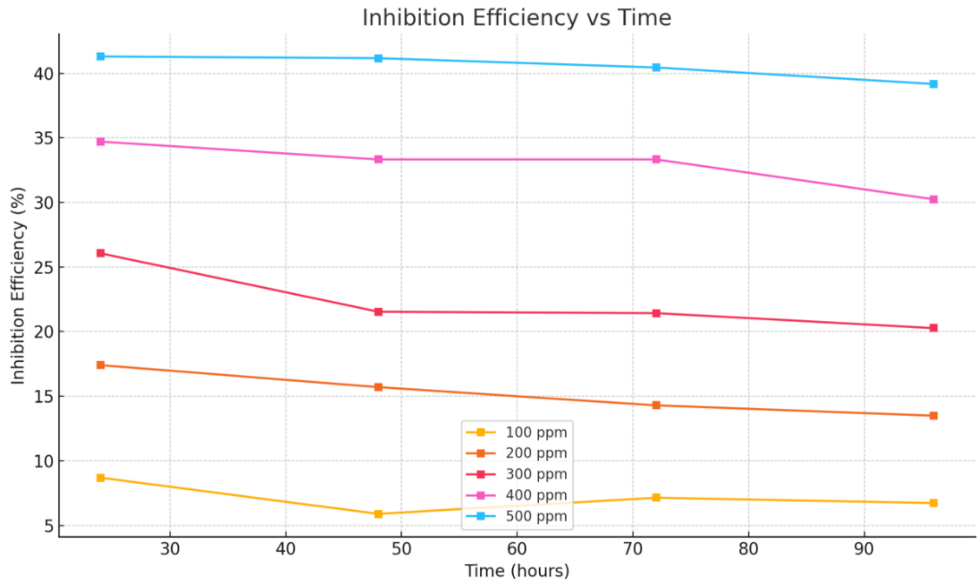
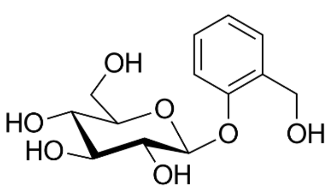
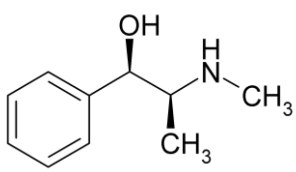


Fig 4. Graph showing Inhibition Efficiency vs Time for Different Concentration of Inhibitor

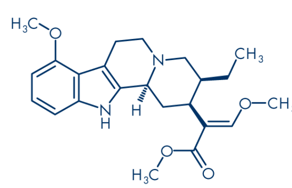
The examination of literature shows that the corrosion inhibitory effects showed by the chewing stick extracts can be attributed to the presence of phytochemical compounds (glycosides, alkaloids, saponins, tannins, flavonoids, anthocyanins, anthraquinones, phlobatannins, etc.) present in them (Olusola *et al.*, 2020; Cowan *et al.*, 1999). The chemical structure of these compounds possesses various aromatic rings, double rings, and heteroatoms (O, N…) considered as the active centers in adsorption phenomena o the metal surface to create a barrier against the arrival of aggressive species like H^+, dissolved oxygen…



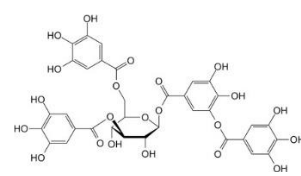
glycoside



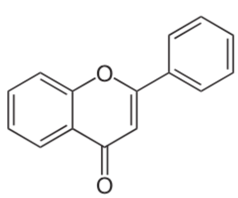
alkaloid



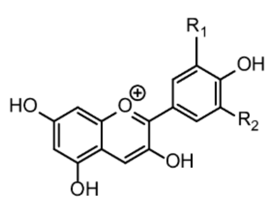
saponin



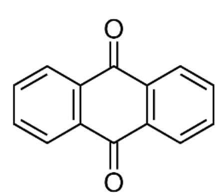
tannin



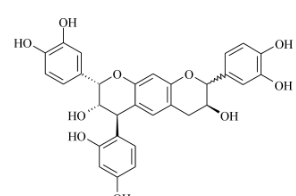
flavonoid



anthocyanin



Anthraquinone



phlobatannin

In other words, the presence of these various chemical components at different contents can explain the corrosion protection by the natural extract and then, the intermolecular synergistic effect may be introduced as pointed out in literature (Lrhoul *et al.*, 2023; Youssefi *et al.*, 2023; Khadom *et al.*, 2022; Aouniti *et al.*, 2022; Benali *et al.*, 2013).

Conclusion

This study successfully evaluated the corrosion inhibition performance of *Massularia acuminata* (chewing stick) stem extract on mild steel in 1.0M hydrochloric acid using the weight loss method. Results revealed that the extract effectively reduced the corrosion rate of mild steel, with inhibition efficiency increasing as the extract concentration increased.

At 500 ppm, the extract achieved a maximum inhibition efficiency of 41.30% after 24 hours, demonstrating its potential as a green and sustainable corrosion inhibitor. The observed inhibitory action is attributed to the adsorption of phytochemical constituents (such as flavonoids, alkaloids, and tannins) onto the steel surface, forming a protective barrier that retards metal dissolution.

The use of *Massularia acuminata* offers a cost-effective, environmentally friendly alternative to conventional synthetic inhibitors, especially in regions where the plant is abundant and locally accessible.

Recommendations

1. **Further Investigation with Other Techniques:** Complementary electrochemical methods such as potentiodynamic polarization (PDP) and electrochemical impedance spectroscopy (EIS) are recommended to confirm and expand upon the weight loss findings.
2. **Phytochemical Analysis:** A detailed phytochemical screening of the extract should be conducted to identify the specific active compounds responsible for corrosion inhibition.
3. **Surface Characterization:** Techniques such as Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) should be employed to study the morphology and chemical interactions on the steel surface after exposure.
4. **Temperature Effect Study:** Future studies should investigate the impact of temperature variation on inhibition efficiency to simulate industrial operating conditions.
5. **Formulation Development:** The extract can be explored further for industrial-scale formulation into corrosion-inhibiting coatings or additives for acidic cleaning processes.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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