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Inhibitory Effect of *Jatropha gossypiifolia* Leaf Extract on Carbon Steel in Acidic Solution: A Green Chemistry Approach Using Weight Loss Studies

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Abstract: Corrosion of carbon steel in acidic environments poses a significant challenge in industries where hydrochloric acid is used for cleaning, descaling, and oilfield operations. This study investigates the corrosion inhibition potential of *Jatropha gossypiifolia* leaf extract on carbon steel in 1.0 M HCl using the weight loss (gravimetric) method. Steel coupons were immersed in the acidic medium containing varying concentrations of the extract (100–400 ppm) over 24, 48, and 72 hours. The results revealed that corrosion rate decreased with increasing inhibitor concentration and exposure time. A maximum inhibition efficiency of 99.31% was recorded at 400 ppm after 24 hours, while a sustained efficiency of 56.44% was observed after 72 hours. Adsorption behavior was evaluated using the Langmuir isotherm, which showed a good linear fit (R^2 = 0.997), with an adsorption equilibrium constant of 0.01347 L/mg, suggesting moderate physical interaction between the inhibitor molecules and the metal surface. These findings support the effectiveness of *Jatropha gossypiifolia* as a green, biodegradable corrosion inhibitor. Its phytochemicals such as flavonoids, tannins, alkaloids, and terpenoids likely adsorb onto the metal surface, forming a partial protective film. These findings position *Jatropha gossypiifolia* as a promising green inhibitor and support further investigation into its adsorption mechanism and interaction with metal surfaces.

1. Introduction

Corrosion is a persistent and costly problem across numerous industrial sectors, particularly in systems where metals come in contact with acidic environments. It is defined as the deterioration of a metal due to electrochemical reactions between the metal surface and its surrounding environment. Industries such as petrochemical processing, mining, fertilizer production, and acid cleaning operations often utilize acidic solutions, including hydrochloric acid (HCl), which significantly accelerates metal degradation (Ettahiri *et al.,* 2024; Ech-chihbi *et al.,* 2023; Umoren *et al.,* 2019; Odewunmi *et al.,* 2015). Among structural metals, carbon steel is widely preferred due to its mechanical strength, weldability, and cost-effectiveness; however, it is especially prone to corrosion in acidic media (Ait Mansour *et al.,* 2025; Aichouch *et al.,* 2025; Raja and Sethuraman, 2008).

Organic inhibitors and plant extract inhibitors both reduce metal corrosion but differ in origin and properties. Organic inhibitors are synthetic compounds with well-defined structures that offer high and predictable efficiency. For example, the application of imidazopyridine derivatives as corrosion inhibitors for mild steel in acidic solution (Salim *et al.,* 2016; Ismaily Alaoui *et al.,* 2016; Ech-chihbi *et al.,* 2016). In contrast, plant extracts are natural, biodegradable, and eco-friendly, containing a mix of bioactive compounds. Though their composition is less controlled and their efficiency may vary, they are cost-effective and align with sustainable development goals compared to organic compounds (Verma *et al.,* 2018; Nahlé *et al.,* 2022). In response to these concerns, the field of green corrosion inhibition has emerged, promoting the use of natural products particularly plant extracts as eco-friendly alternatives. These materials are not only sustainable and biodegradable but also cost-effective and locally available (Ali *et al.,* 2021).

Plant extracts function as corrosion inhibitors primarily through the adsorption of their bioactive phytochemicals onto the metal surface, where they form a protective film that blocks active corrosion sites and hinders both anodic and cathodic electrochemical reactions. This adsorption is facilitated by the presence of electron-rich functional groups such as hydroxyl, carbonyl, methoxy, and amine groups found in natural compounds like alkaloids, tannins, flavonoids, and saponins. These groups can donate lone pair electrons or engage in π-electron interactions with the metal surface, enhancing the strength of the adsorption layer. Additionally, many of these molecules possess planar or conjugated structures, which improve surface coverage and promote uniform film formation. Studies have shown that such natural inhibitors are particularly effective in acidic media due to their ability to form stable complexes with metal ions, thereby slowing down the corrosion process. Furthermore, their biodegradability, renewability, and low toxicity make plant extracts an attractive alternative to synthetic inhibitors in the context of green chemistry and environmental sustainability (El-Etre, 2003; Ebenso *et al.,* 2010; Abidli *et al.,* 2020; Marsoul *et al.,* 2023). These compounds exhibit chelating abilities and can form a coordinated film with the metal surface, significantly reducing corrosion rates. Among under-explored plant species, *Jatropha gossypiifolia,* **Figure 1,** commonly known as bellyache bush offers substantial potential.

Figure 1: Images of fresh *Jatropha gossypiifolia* Leaves and Seedlings

It is a fast-growing shrub native to tropical and subtropical regions and has been used traditionally for wound healing, fever treatment, and anti-inflammatory purposes. Phytochemical investigations reveal that *J. gossypiifolia* is rich in flavonoids, phenolic acids, alkaloids, and terpenoids all of which have demonstrated antioxidant and metal-binding properties (Oyedapo *et al.,* 2008; Ezike *et al.,* 2014). Despite its known bioactivity, the corrosion inhibition potential of *Jatropha gossypiifolia* leaf extract on carbon steel in acidic environments remains poorly documented. This research, therefore, aims to evaluate the inhibitory performance of the leaf extract in 1 M hydrochloric acid using the weight loss (gravimetric) method. The study investigates the efficiency of the extract across different concentrations and immersion periods, and further explores its adsorption behavior on the metal surface. By adopting a green chemistry approach, this study contributes to the ongoing quest for sustainable corrosion control methods. It seeks to promote the utilization of indigenous plant resources in industrial corrosion mitigation.

2. Methodology

2.1. Carbon Steel Coupons

The carbon steel specimens used in this study had the following composition by weight (%): C (0.15), Mn (0.45), Si (0.10), P (0.04), S (0.05), and Fe (balance). The coupons were mechanically cut into dimensions of 2 cm × 2 cm × 0.1 cm, polished using emery papers of various grades (320 to 1200), washed with distilled water, degreased in ethanol, dried, and stored in a desiccator prior to use.

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

2.2. Corrosive Medium

A 1.0 M solution of hydrochloric acid (HCl) was prepared by dilution of analytical grade concentrated HCl with distilled water. This served as the corrosive medium for all gravimetric experiments.

2.3. Plant Material and Extract Preparation

Fresh leaves of *Jatropha gossypiifolia* were collected, washed thoroughly with distilled water, and shade-dried for 7 days. The dried leaves were then pulverized into fine powder using a mechanical grinder. Fifty grams (50 g) of the powder was soaked in 500 mL of ethanol for 48 hours with intermittent shaking. The mixture was filtered using Whatman No. 1 filter paper, and the filtrate was concentrated using a rotary evaporator at 45 °C to obtain a semi-solid crude extract. This extract was air-dried and reconstituted in 1 M HCl to prepare solutions of varying concentrations (100, 200, 300, and 400 ppm), **Figure 2**.

2.4. *Weight Loss (Gravimetric) Method*

Pre-weighed carbon steel coupons were immersed in 100 mL of the test solution (with and without inhibitor) contained in clean, labeled beakers. The beakers were kept in a water bath maintained at room temperature (27 ± 2 °C). The immersion times were set at 24, 48, and 72 hours. After each interval, the coupons were retrieved, washed gently with distilled water, scrubbed to remove corrosion products, rinsed in ethanol, dried, and reweighed.

Figure 2. Extracted *Jatropha gossyplifiolia* Leaf as Inhibitor

The **corrosion rate (CR)** in mg/cm²/hr was calculated using:

$$CR = \frac{\Delta W}{A * t}$$

Where:
ΔW = weight loss (mg)
A = surface area of coupon (cm²)
t = exposure time (hours)

The inhibition efficiency (IE%) was computed using:

$$\text{IE\%} = \frac{W_o - W_i}{W_o} * 100$$

Where:

W_0 = weight loss in uninhibited acid solution
W_i = weight loss in inhibited acid solution

2.5. Adsorption Isotherm Studies

To understand the mechanism of inhibition, adsorption behavior of the extract on carbon steel surface was assessed by fitting the experimental data to the Langmuir adsorption isotherm:

$$\frac{C}{\theta} = \frac{1}{K_{ads}} + C$$

Where:
C = Inhibitor concentration (ppm)
θ = surface coverage, calculated as $\theta = {IE\%}/{100}$
K_{ads} = equilibrium constant of adsorption
A plot of C/θ versus C was used to determine the applicability of the isotherm and the adsorption parameters.

3. Results

3.1. Weight Loss Data

The corrosion behavior of carbon steel in 1.0 M HCl, with and without *Jatropha gossypiifolia* extract, was evaluated by measuring the initial and final weights of the steel coupons after immersion for 24, 48, and 72 hours. The results are shown in **Table 1**. The blank solution (0 ppm) showed the greatest reduction in weight, indicating the highest corrosion. In contrast, as the concentration of the inhibitor increased, the weight loss of the steel decreased, demonstrating the protective effect of the extract.

Table 1: Initial and Final Weights of Carbon Steel Coupons in 1.0 M HCl with Varying Extract Concentrations

Concentration (ppm)	**Time**	**Initial Weight (g)**	**Final Weight (g)**
Blank (0 ppm)	24 hrs	4.300	4.265
	48 hrs	4.300	3.941
	72 hrs	4.300	3.430
100 ppm	24 hrs	4.300	4.269
	48 hrs	4.300	3.952
	72 hrs	4.300	3.796
200 ppm	24 hrs	4.300	4.274
	48 hrs	4.300	3.966
	72 hrs	4.300	3.840
300 ppm	24 hrs	4.300	4.280
	48 hrs	4.300	3.991
	72 hrs	4.300	3.870
400 ppm	24 hrs	4.300	4.294
	48 hrs	4.300	4.137
	72 hrs	4.300	3.921

3.2 Weight Loss, Corrosion Rate, and Inhibition Efficiency

Weight loss of carbon steel coupons decreased with increasing concentrations of *Jatropha gossypiifolia* extract. Corrosion rates were highest in the uninhibited acid solution and progressively decreased in inhibited solutions, confirming the inhibitor's effectiveness. Inhibition efficiency generally increased with concentration, with slight variations over time.

- This graph shows the Inhibition Efficiency (%) of *Jatropha gossypiifolia* extract against concentration at 24, 48, and 72 hours.

Table 2. Weight Loss, Corrosion Rate, and Inhibition Efficiency of Carbon Steel in 1.0 M HCl with Varying Concentrations of *Jatropha gossypiifolia* Extract

Concentration	**Time**	**Weight Loss (mg)**	**CR (mg/cm²/hr)**	**IE (%)**
Blank	24 hrs	35.0	0.085	–
Blank	48 hrs	359.0	0.435	–
Blank	72 hrs	870.0	0.703	–
100 ppm	24 hrs	31.0	0.075	96.44
100 ppm	48 hrs	348.0	0.422	60.00
100 ppm	72 hrs	504.0	0.407	42.07
200 ppm	24 hrs	26.0	0.063	97.01
200 ppm	48 hrs	334.0	0.405	61.61
200 ppm	72 hrs	460.0	0.371	47.13
300 ppm	24 hrs	20.0	0.048	97.70
300 ppm	48 hrs	309.0	0.374	64.48
300 ppm	72 hrs	430.0	0.347	50.57
400 ppm	24 hrs	6.0	0.015	99.31
400 ppm	48 hrs	163.0	0.197	81.26
400 ppm	72 hrs	379.0	0.306	56.44

Note: Surface area = 17.2 cm²

3.3 Adsorption Isotherm Studies

The adsorption behavior of *Jatropha gossypiifolia* extract on carbon steel in 1.0 M HCl was evaluated using the Langmuir adsorption isotherm. This model assumes monolayer adsorption on a homogeneous surface with no interaction between adsorbed molecules. The Langmuir equation is expressed as:

$C/\theta = 1/K_{ads} + C$

Where:
C = inhibitor concentration (ppm),
θ = surface coverage (calculated from IE%),
K_{ads} = equilibrium adsorption constant.

Based on the inhibition efficiencies at 72 hours, the following θ and C/θ values were obtained:

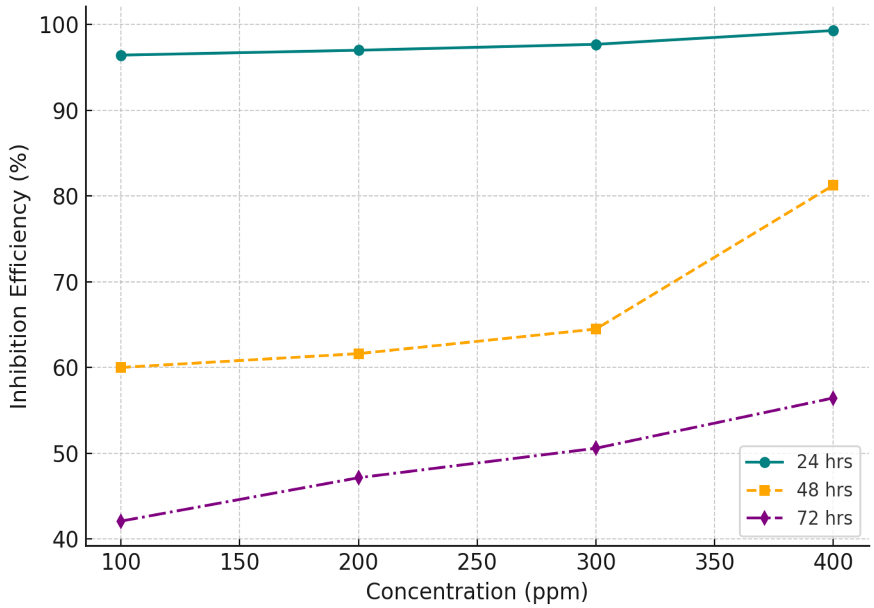


Figure 3. Inhibition Efficiency of Jatropha gossypiifolia Extract at Different Times

Table 3: Langmuir Adsorption Isotherm Parameters (72 hrs)

Concentration (ppm)	**IE (%)**	**θ**	**C/θ**
100	42.07	0.4207	237.69
200	47.13	0.4713	424.47
300	50.57	0.5057	593.33
400	56.44	0.5644	708.75

A plot of C/θ versus C produced a linear relationship with the regression equation:

$$C/\theta = 1.691C + 74.21 \quad (R^2 = 0.997)$$

From the intercept, the adsorption equilibrium constant was calculated:

$K_{ads} = 1 / 74.21 = 0.01347$ L/mg

The linearity of the Langmuir plot suggests that the adsorption of the extract followed monolayer adsorption on a homogenous metal surface. However, further studies using other isotherms such as Freundlich or Temkin are recommended to better understand the complex adsorption mechanism.

Table 3 presents the adsorption parameters derived from the inhibition efficiency data at 72 hours. The surface coverage (θ) was calculated by dividing the percentage inhibition efficiency by 100. The ratio of inhibitor concentration to surface coverage (C/θ) was then computed to assess the nature of adsorption. As the inhibitor concentration increased, both θ and C/θ values also increased, indicating enhanced surface coverage but also reflecting the increasing amount of extract required to achieve further surface saturation. The good fit to this model suggests that the inhibition efficiency increases with concentration until saturation is reached, beyond which no further improvement is observed. This indicates that a stable and compact barrier is formed, enhancing corrosion protection by minimizing localized attack and reducing metal dissolution (Hajjaji et al., 2019; Ettahiri et al., 2023).

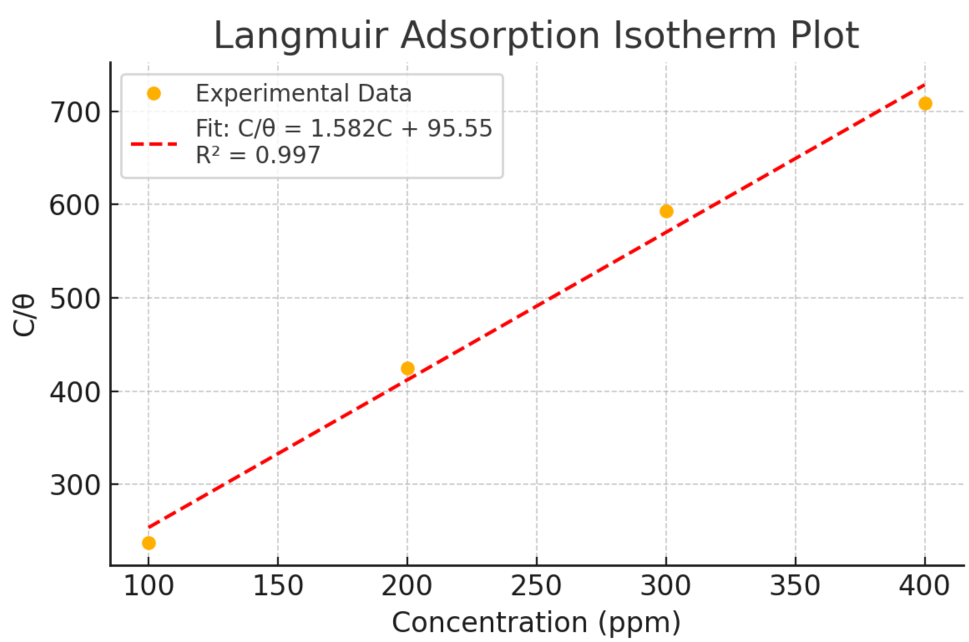


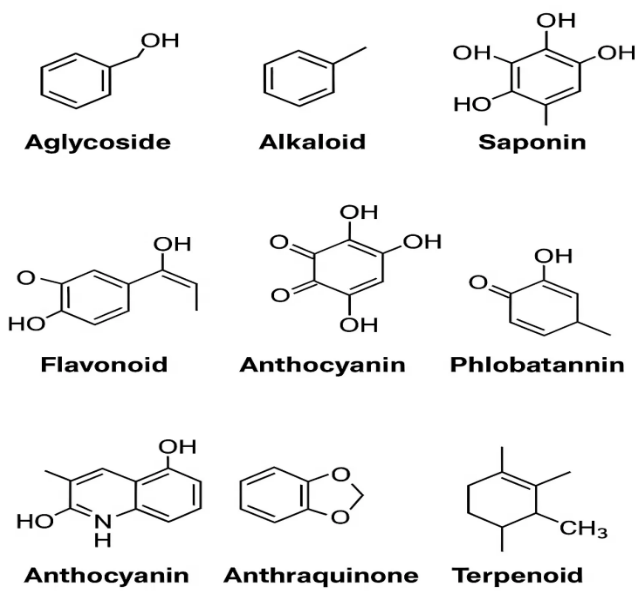
Figure 4. Langmuir Adsorption Isotherm Plot for Jatropha gossypiifolia Extract on Carbon Steel in 1.0M HCl

- The plot of C/θ versus C shows a linear relationship with the regression equation C/θ=1.582C+95.55C/\theta = 1.582C + 95.55C/θ=1.582C+95.55 and a correlation coefficient R2=0.997R^2 = 0.997R2=0.997. This strong linearity confirms that the adsorption of the extract molecules onto the carbon steel surface follows the Langmuir adsorption isotherm, indicating monolayer adsorption on a homogeneous surface.

4. Discussion

The weight loss analysis clearly demonstrated that the corrosion rate of carbon steel in 1.0 M hydrochloric acid decreased with increasing concentrations of *Jatropha gossypiifolia* leaf extract. This trend was consistent across all immersion times, confirming the inhibitor's effectiveness in acidic environments. The highest inhibition efficiency of 99.31% was observed at 400 ppm after 24 hours, while a sustained efficiency of 56.44% was recorded after 72 hours at the same concentration. These results indicate that the inhibition performance is both concentration- and time-dependent, a well-documented behavior of many plant-based green inhibitors.

The progressive decrease in weight loss and corrosion rate with increasing extract concentration suggests that active phytochemicals adsorbed onto the metal surface, forming a protective film that hindered the access of aggressive chloride (Cl^-) and hydrogen (H^+) ions. This hypothesis is further supported by the slower decrease in pH values in the inhibited systems, indicating a buffering effect due to surface interactions between the extract components and the steel surface. Adsorption studies using the Langmuir isotherm model (**Figure 4**) provided a good linear fit with $R^2 = 0.997$, confirming that the surface coverage correlated predictably with concentration under the Langmuir assumptions.



The calculated adsorption equilibrium constant (K_{ads}) was 0.01347 L/mg**.** This relatively low value suggests a moderate interaction between the inhibitor molecules and the carbon steel surface, potentially involving weak physical forces such as hydrogen bonding or van der Waals interactions.

This observation aligns with the known phytochemical composition of *Jatropha gossypiifolia*, which includes glycosides, alkaloids, flavonoids, tannins, saponins, terpenoids, and anthraquinones (Utshudi *et al.,* 2022). These compounds possess functional groups such as hydroxyl (–OH), carbonyl (C=O), methoxy ($–OCH_3$), and amine ($–NH_2$), which can donate electrons or interact with the steel surface via π-electron interactions, promoting surface adsorption (Okonji*,* 2025). While the Langmuir model showed strong statistical agreement, further studies using other isotherms (e.g., Freundlich, Temkin) may provide a more comprehensive understanding of the adsorption mechanism.

Therefore, the inhibition mechanism is likely a multi-site, multilayered adsorption process, with partial surface coverage and film formation playing a critical role in reducing metal dissolution. Future studies should consider evaluating additional isotherm models (e.g., Freundlich, Temkin) and conducting surface characterization techniques such as FTIR, SEM, or XPS to gain deeper insights into the interaction between the extract molecules and the steel substrate. The inhibitory process is generally interpreted by the intermolecular synergistic effect due to the various components rich in aromatic, ketones, double bonds and heteroatoms as nitrogen, oxygen… (Okonji *et al.,* 2025; Vashi, 2025; Lrhoul *et al.,* 2023; Ezeh & Chinedu*,* 2023).

Conclusion

This study has demonstrated that *Jatropha gossypiifolia* leaf extract effectively inhibits the corrosion of carbon steel in 1.0 M hydrochloric acid. Inhibition efficiency increased with extract concentration across all immersion times. The highest inhibition efficiency of 99.31% was recorded at 400 ppm after 24 hours, with a sustained performance of 56.44% after 72 hours, confirming the extract's capacity to offer significant corrosion protection over time.

The inhibition is attributed to the adsorption of phytochemicals such as flavonoids, tannins, phenols, alkaloids, and terpenoids onto the metal surface, forming a partial protective barrier that retards the electrochemical reaction responsible for metal degradation. Langmuir adsorption modeling provided a good linear fit ($R^2 = 0.997$).

These findings suggest that while the extract functions effectively as a corrosion inhibitor, the mechanism may involve multisite, multilayer physisorption rather than strong chemical bonding. As a green, biodegradable, and locally abundant plant resource, *Jatropha gossypiifolia* holds promise as an eco-friendly alternative to toxic synthetic inhibitors. Future work should include surface characterization techniques (e.g., FTIR, SEM, XPS) and fitting to additional adsorption isotherms (e.g., Freundlich, Temkin) to further elucidate the inhibition mechanism.

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References

Abidli I., Souissi N., Novoa X.R. (2020) Corrosion inhibition of steel by prickly pear: Extraction, characterization and electrochemical studies, *Revue Roumaine De Chimie*, 65(4), 353–360

Aichouch, I., El Magri, A. & Hammouti, B. Influence of laser power and scan speed on porosity, microhardness, and corrosion resistance in HCl medium of additively manufactured H13 tool steel. *Prog Addit Manuf* (2025). https://doi.org/10.1007/s40964-025-01068-7

Ait Mansour A., El house M., Arrousse N., Hadfi A., Salghi R. (2025) Sustainable Corrosion Inhibition of N80 Carbon Steel in 15% HCl Using Ocimum basilicum Extract: Experimental and Theoretical Perspectives, *Chemistry Select,* 10 (24), e01726, https://doi.org/10.1002/slct.202501726

Ali, N. H., Hassan, A. A., & Ibrahim, M. A. (2021). Green corrosion inhibitors: Progress, challenges, and future perspectives. *Journal of Molecular Liquids, 342*, 117518. https://doi.org/10.1016/j.molliq.2021.117518

Ebenso, E. E., Arslan, T., Kandemirli, F., Kaya, S., & Banerjee, P. (2010). Quantum chemical studies of some non-toxic corrosion inhibitors: Molecular structure considerations. *International Journal of Quantum Chemistry, 110*(13), 2614–2631. https://doi.org/10.1002/qua.22534

Ech-chihbi, E., R. Salim, H. Oudda, A. Elaatiaoui, Z. Rais, A. Oussaid, F. El Hajjaji, B. Hammouti, H. Elmsellem, and M. Taleb. (2016), Effect of some imidazopyridine compounds on carbon steel corrosion in hydrochloric acid solution. *Der Pharm Chem* 8(13), 214-230.

Ech-chihbi E., Adardour M., Ettahiri W., Salim R., Ouakki, M., Galai M., A. Baouid, Taleb M. (2023), Surface interactions and improved corrosion resistance of mild steel by addition of new triazolyl-benzimidazolone derivatives in acidic environment, *Journal of Molecular Liquids,* 387, 122652, ISSN 0167-7322, https://doi.org/10.1016/j.molliq.2023.122652

El-Etre, A. Y. (2003). Inhibition of acid corrosion of carbon steel using aqueous extract of *Opuntia dillenii*. *Journal of Applied Electrochemistry, 33*(12), 1175–1180. https://doi.org/10.1023/B:JACH.0000003939.89864.a6

Ettahiri, Walid, Rajae Salim, Mohamed Adardour, Elhachmia Ech-Chihbi, Ismaeel Yunusa, Mohammed M. Alanazi, Sanae Lahmidi et al. (2023), Synthesis, characterization, antibacterial, antifungal and anticorrosion activities of 1, 2, 4-triazolo [1, 5-a] quinazolinone. *Molecules,* 28(14), 5340.

Ettahiri W., Adardour M., Ech-chihbi E., Azam M., Salim R., Dalbouha S., Min K., Rais Z., Baouid A., Taleb M. (2024), 1,2,3-triazolyl-linked benzimidazolone derivatives as new eco-friendly corrosion inhibitors for mild steel in 1 M HCl solution: Experimental and computational studies, *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 681, 132727, ISSN 0927-7757, https://doi.org/10.1016/j.colsurfa.2023.132727

Ezeh E. M., Chinedu A. P. (2023)Assessment of the Corrosion Inhibitory Potentials of Chromolaena Odorata Leaf Extract on Mild Steel in Hydrogen Chloride Acid Environment, *Mor. J. Chem.* 11 N°1, 188-204 https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i3.30521

Ezike, A. C., Akah, P. A., Okoli, C. O., & Ezeuchenne, N. A. (2014). Anti-inflammatory and analgesic activities of *Jatropha gossypiifolia* extract in experimental animals. *Journal of Medicinal Plants Research, 8*(37), 1070–1075. https://doi.org/10.5897/JMPR2014.5432

Hajjaji, F. E., Belghiti, M.E., Drissi, M., Fahim M., *et al*. (2019), Electrochemical, quantum calculations and monte carlo simulation studies of N1, N2-Bis (1-phenylethylidene) ethane-1, 2-diamine as a corrosion inhibitor for carbon steel in a 1.0 M hydrochloric acid solution. *Portugaliae Electrochimica Acta* 37(1), 23-42.

Ismaily Alaoui K, Ouazzani F, Kandri Rodi Y, Azaroual AM, Rais Z, ... (2016), Effect of some Benzimidazolone compounds on C38 steel corrosion in hydrochloric acid solution, *J. Mater. Environ. Sci.,* 7 (1), 244-258

Lrhoul H., Sekkal H., Hammouti B. (2023) Natural plants as corrosion inhibitors: thermodynamic's restrictions, *Moroccan Journal of Chemistry* 11 (3), 689-698

Marsoul, A., A. Boukir, M. Ijjaali, M. Taleb, N. Arrousse, R. Salim, and A. Dafali. (2023), Phytochemical characterization, antioxidant proprieties and electrochemical investigations of methanolic extract of Rubia tL roots for LC-steel corrosion protection in 1 M HCl medium. *Journal of Bio-and Tribo-Corrosion* 9(2), 32.

Nahlé, A., R. Salim, F. EL Hajjaji, E. Ech-Chihbi, A. Titi, M. Messali, S. Kaya, B. El Ibrahimi, M. Taleb. (2022), Experimental and theoretical approach for novel imidazolium ionic liquids as Smart Corrosion inhibitors for mild steel in 1.0 M hydrochloric acid. *Arabian Journal of Chemistry* 15(8), 103967.

Odewunmi, N. A., Umoren, S. A., & Gasem, Z. M. (2015). Watermelon rind as a potential green corrosion inhibitor for mild steel in hydrochloric acid solution. *Journal of Industrial and Engineering Chemistry, 21*, 239–247. https://doi.org/10.1016/j.jiec.2014.03.037

Okonji K.S. (2025) Weight Loss Study on Massularia acuminata (Chewing Stick) Extract as a Green Corrosion Inhibitor of Mild Steel in Acidic Environment, J. Mater. Environ. Sci., 16(7), 1361-1372

Oyedapo, O. O., Sab, F. C., & Olagunju, J. A. (2008). Bioactivity of *Jatropha gossypiifolia* leaf extract. *Phytotherapy Research, 22*(1), 63–66. https://doi.org/10.1002/ptr.2277

Raja, P. B., & Sethuraman, M. G. (2008). Natural products as corrosion inhibitors for metals in corrosive media—A review. *Materials Letters, 62*(1), 113–116. https://doi.org/10.1016/j.matlet.2007.04.079

Salim, R., Ech-Chihbi, E., Oudda, H., Aoufir, Y. E. L., El-Hajjaji, F., Elaatiaoui, A., Taleb, M. (2016). The inhibition effect of imidazopyridine derivatives on C38 steel in hydrochloric acid solution. *Der Pharma Chem,* 8(3), 200.

Umoren, S. A., Solomon, M. M., & Israel, A. U. (2019). Green corrosion inhibitors for steel in acidic medium: A review. *Egyptian Journal of Petroleum, 28*(1), 1–18. https://doi.org/10.1016/j.ejpe.2019.02.001

Utshudi, O. M., Ogbuehi, H. C., & Ugwu, E. A. (2022). Phytochemical screening and antibacterial activity of *Jatropha gossypiifolia* leaf extract against selected clinical pathogens. *International Journal of Plant Research, 10*(2), 1–9. https://journalijpr.com/index.php/IJPR/article/view/173

Vashi R. T. (2025) Banana (Musa paradisiaca) as a Green Corrosion Inhibitor for Protection of Metals and Alloys-A Review, *J. Mater. Environ. Sci.,* 16(3), 523-537

Verma, C., Ebenso, E. E., Quraishi, M. A., & Obot, I. B. (2018). Ionic liquids as green and sustainable corrosion inhibitors for metals and alloys: An overview. *Journal of Molecular Liquids, 271*, 261–277. https://doi.org/10.1016/j.molliq.2018.08.087

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