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Original Research Article

Mechanistic Insights and RSM-Based Optimization of Aluminium Corrosion Inhibition Using Banana Leaf Extract

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ABSTRACT

The corrosion inhibition performance of banana (*Musa* spp.) leaf extract on aluminium in acidic medium was evaluated using Response Surface Methodology (RSM) considering immersion time, temperature, and inhibitor concentration. The regression model exhibited strong predictive accuracy, with predicted and experimental inhibition efficiencies closely aligned along the 45° line. Residual normality was confirmed, with most residuals following the reference line and only minor deviations at approximately –3.0 and +3.8. The externally studentized residuals analysis showed that only one observation (predicted efficiency ≈ 75%) exceeded the critical limit of ±3.71733, while the remaining runs were within acceptable limits. Cook's distance values ranged from 0.02 – 0.74, all below the influence threshold of 0.8845, with the highest values recorded for Run 2 (0.74), Run 15 (0.56), and Run 7 (0.51). Leverage values varied between 0.05 and 0.32, remaining below the critical value of 0.4706 and above the average leverage of 0.2353. DFFITS diagnostics identified Run 2 (+2.3) and Run 16 (–1.8) as relatively influential compared with the threshold of ±1.45521. Similarly, DFBETAS analysis for the intercept showed influential values for Run 2 (+1.05) and Run 17 (–0.95) relative to the limit of ±0.7276. The Box–Cox transformation produced an optimal **λ ≈** 1.0 (95% CI), indicating stable variance and no need for response transformation. Perturbation analysis indicated a sensitivity order of immersion time > temperature > inhibitor concentration, with immersion time and temperature exerting negative effects while concentration showed a mild positive influence. Overall, the robust statistical diagnostics and predictive performance confirm the effectiveness of banana leaf extract as a sustainable green inhibitor for aluminium corrosion in acidic environments.

INTRODUCTION

Corrosion is a persistent electrochemical degradation process that compromises the structural integrity and performance of metals exposed to aggressive environments (Adeleke *et al.*, 2024). It remains a critical engineering challenge with far-reaching safety, environmental, and economic consequences across sectors such as chemical processing, transportation, construction, and manufacturing (Mehdi *et al*., 2024). Although aluminium is widely utilized due to its favorable strength-to-weight ratio and the presence of a protective passive oxide film, it remains highly susceptible to dissolution in acidic and chloride-rich media (Fatima *et al*., 2024). Such degradation results in material loss, mechanical failure, reduced thermal conductivity, production downtime, and costly maintenance or replacement operations. Consequently, the development of efficient corrosion mitigation strategies is of substantial industrial importance (Naveen *et al*., 2025).

Corrosion inhibitors represent one of the most practical and cost-effective protection approaches. Conventional inorganic inhibitors, including chromates, nitrites, and phosphates, as well as synthetic organic compounds containing heteroatoms and π-electron systems, exhibit high inhibition efficiency through adsorption and surface film formation (Siti *et al*., 2024). However, their toxicity, environmental persistence, and regulatory restrictions have intensified the search for sustainable alternatives (Oluwaseun *et al*., 2024). Green corrosion inhibitors (GCIs) have emerged as sustainable alternatives to conventional toxic inhibitors, offering an environmentally friendly approach to corrosion control. Among these, plant extracts represent a prominent category of GCIs derived from renewable biomass. They are biodegradable, cost-effective, and environmentally compatible, making them suitable for large-scale applications (Carlos *et al*., 2024). Their effectiveness is largely attributed to the presence of phytochemicals such as flavonoids, alkaloids, tannins, saponins, and phenolic compounds, which contain heteroatoms and π-electron systems that facilitate strong adsorption onto metal surfaces (Imane *et al*., 2024). This adsorption leads to the formation of a protective barrier that inhibits both anodic and cathodic reactions, thereby reducing corrosion in aggressive media.

Banana leaf extracts represent an abundant yet underutilized agricultural waste with significant inhibitory potential. Its high content of polyphenols and flavonoids facilitates strong adsorption onto aluminium surfaces, promoting protective film formation in acidic media (Mohammed *et al*., 2025). To systematically evaluate and optimize inhibition performance, this study employs Response Surface Methodology using the Box–Behnken Design. This statistical framework enables efficient modeling of variable interactions (e.g., concentration, temperature, immersion time) while minimizing experimental runs. The proposed approach integrates green chemistry principles with process optimization, advancing a scalable, eco-friendly strategy for sustainable aluminium corrosion control.

MATERIALS AND METHODS

All reagents utilized in this investigation were of analytical grade and applied without further purification. The chemicals included concentrated sulfuric acid (H_2SO_4, 98% purity), ethanol, acetone, and distilled water. Experimental apparatus comprised standard laboratory glassware (beakers, volumetric flasks, and measuring cylinders), spatulas, glass stirring rods, retort stands, a precision analytical balance, and a thermostatically regulated hot plate.

Collection and Pre-treatment of Plant Material

Fresh banana leaves (Musa spp.) were collected from agricultural areas in Anyigba, Kogi State, Nigeria. The leaves were thoroughly rinsed with distilled water to eliminate adhered soil particles and surface contaminants. To preserve thermolabile and photosensitive phytoconstituents, the samples were shade-dried under ambient conditions for five days. The dried material was subsequently milled into fine powder using a laboratory grinder and stored in airtight containers to prevent moisture uptake prior to extraction.

Preparation of Banana Leaf Extract

A 40 g portion of the powdered banana leaves was subjected to Soxhlet extraction using 180 mL of ethanol as the extraction solvent for 4 h. The resulting extract was concentrated to remove residual solvent and filtered to obtain a homogeneous filtrate. This concentrated extract served as the stock solution for preparing different inhibitor concentrations in the acidic corrosive medium.

Phytochemical Characterization

Qualitative phytochemical screening of the ethanolic extract was conducted using established analytical protocols to identify bioactive constituents relevant to corrosion inhibition. The analysis confirmed the presence of secondary metabolites such as alkaloids, flavonoids, tannins, and saponins compounds known to contain heteroatoms and π-electron systems capable of adsorbing onto metal surfaces and forming protective films.

Preparation of Aluminium Coupons

Commercial aluminium sheets were sectioned into coupons measuring 2 cm × 2 cm × 0.2 cm and perforated centrally (0.2 cm diameter) to facilitate suspension during immersion tests. The specimens were mechanically polished with successive grades of emery paper to remove surface oxides, degreased with acetone, rinsed with distilled water, and air-dried. Prepared coupons were stored in a desiccator prior to experimentation. The initial mass of each specimen was recorded using a precision balance before exposure to the test solution.

Preparation of Corrosive Medium

A 0.1 M H_2SO_4 solution was prepared by carefully diluting 5.43 mL of concentrated sulfuric acid (98% purity, density 1.84 g mL^{-1}, ≈18.4 M) into approximately 500 mL of distilled water under continuous stirring. After cooling to room temperature, the solution was quantitatively transferred into a 1 L volumetric flask and diluted to the calibration mark with distilled water. The prepared solution was homogenized thoroughly prior to use.

Experimental Design and Statistical Analysis

Optimization of the corrosion inhibition process was performed using Response Surface Methodology (RSM) based on the Box–Behnken Design (BBD) implemented in Design-Expert® software (Version 13). A total of 17 experimental runs were generated to evaluate the interactive effects of three independent variables; temperature, immersion time, and inhibitor concentration, each examined at three coded levels (−1, 0, +1). Statistical significance and model adequacy were assessed using analysis of variance (ANOVA). Three-dimensional response surface and contour plots were constructed to elucidate parameter interactions and determine optimal conditions for minimizing corrosion rate and maximizing inhibition efficiency.

Table 1: Experimental Range of the Independent Variables, With Factor Levels for The Inhibition of Banana Leaf Extract on Aluminium in 0.1M H_2SO_4 Solution

Independent Variable	Symbols	Range and Levels		
		-1	0	+1
Time of Exposure (h)	X_1	24	96	168
Temperature of the solution (°C)	X_2	20	40	60
Inhibitor concentration in the extract (v/v)	X_3	1	4	7

Gravimetric Analysis and Response Surface Optimization

Corrosion behavior was evaluated using the conventional weight loss (gravimetric) technique under static total-immersion conditions. Experiments were conducted in 250 mL glass beakers containing 0.1 M H_2SO_4 solution in the absence and presence of banana leaf extract derived from Musa spp. as the corrosion inhibitor. The experimental runs were structured according to the Box–Behnken design matrix, incorporating predetermined combinations of inhibitor concentration, immersion time, and temperature.

The operational variables were systematically varied as follows: immersion time (24 – 168 h), inhibitor concentration (1 – 7% v/v), and temperature (20 - 60 °C). Thermal regulation during exposure was achieved using a thermostatically controlled water bath to ensure uniform heating and reproducibility of results.

At the end of each immersion period, the aluminium coupons were withdrawn, rinsed with distilled water, and gently abraded with fine emery paper to remove loosely adhered corrosion products. The specimens were subsequently washed, degreased with acetone, air-dried, and accurately reweighed. Weight loss (ΔW) was determined as the difference between the initial and final masses of each coupon.

The gravimetric data were employed to compute corrosion rate and inhibition efficiency (IE%) using standard equations. Statistical evaluation and process optimization were performed using Response Surface Methodology (RSM) implemented in Design-Expert (Version 13). Analysis of variance (ANOVA) was applied to assess model adequacy, while three-dimensional response surface plots were generated to elucidate the individual and interactive effects of temperature, concentration, and immersion time. The developed regression models were further utilized to predict optimal inhibition conditions and validate experimental responses.

Weight loss was calculated by finding the difference between the weight of each coupon before and after immersion;

$$\Delta W = W_b - W_a \quad (1)$$

Where W_b is the weight before immersion, Wa is the weight after immersion.

Inhibition efficiency was calculated as

$$IE\% = \frac{Wo - W1}{Wo} \times 100 \quad (2)$$

Where W_1 and W_o are the weight loss values in the presence and absence of the inhibitor, respectively, IE% is the inhibition efficiency.

RESULTS AND DISCUSSION

Phytochemical Analysis

Qualitative analysis of banana leaf extract revealed the presence of flavonoids (+++), tannins (++), saponins (++), total phenols (+), and alkaloids (+), confirming a rich profile of bioactive compounds. The predominance of flavonoids and tannins suggests strong adsorption onto aluminium surfaces, facilitating the formation of a protective film that suppresses both anodic and cathodic reactions. Saponins and phenolic compounds contribute to surface coverage and stabilization of the adsorbed layer, while alkaloids may provide additional inhibitory interactions. Collectively, these phytochemicals enable the extract to act as an effective green corrosion inhibitor, with synergistic interactions governing inhibition efficiency, film persistence, and adsorption-controlled protection of aluminium in acidic media.

Table 2: Phytochemical Profiling of the Ethanol Extract of Banana Leaf

Parameter	Observation	Inference
Tannins	Blue black colouration Observed	Present {++}
Total Phenol	Blue black colouration Observed	Present {+}
Flavonoid	Yellow coloration Observed	Present {+++}
Alkaloid	Reddish Brown Colouration observed	Present {+}
Saponins	Stable Prothing was observed	Present {++}

Fit Summary Statistics

The regression model developed for predicting aluminium corrosion inhibition demonstrated a high coefficient of determination (R^2 = 0.8039), indicating that 80.39% of the variability in inhibition efficiency (IE) is explained by immersion time, temperature, and banana leaf extract concentration. The low standard deviation (SD = 5.04) and coefficient of variation (C.V. = 7.44%) reflect minimal deviation between experimental and predicted values, highlighting strong reproducibility and experimental reliability.

Furthermore, an adequate precision value of 14.17, significantly above the minimum threshold of 4, confirms excellent signal-to-noise discrimination and sufficient model sensitivity across the design space. The mean inhibition efficiency of 67.84% underscores the substantial protective effect of banana leaf extract in acidic media, with higher IE values corresponding to optimized conditions of lower temperature and higher extract concentration. Collectively, these statistical metrics not only confirm the robustness and predictive accuracy of the model but also validate the mechanistic role of phytochemical adsorption, surface film formation, and concentration-dependent surface coverage in achieving effective and sustainable green corrosion inhibition of aluminium.

Table 3: Fit Summary Statistics for the Inhibition Efficiency by Banana Leaf Extract

Parameter	Value
R-Squared	0.8039
Std. Dev.	5.04
Mean	67.84
C.V (%)	7.44
Adeq. Precision	14.1692

Box–Behnken Response for the Inhibition Efficiency by Banana Leaf Extract

The inhibition efficiency (IE) values generated from the Box–Behnken design demonstrate clear parametric influences of immersion time, temperature, and inhibitor concentration on aluminium corrosion behavior in acidic medium. The data reveal strong interactive effects governing adsorption stability and protective film persistence.

At shorter exposure periods (24 h), relatively high efficiencies were recorded, including 74.31% (24 h, 20 °C, 4 v/v%) and 70.78% (24 h, 40 °C, 7 v/v%). This indicates rapid adsorption of phytochemical constituents from banana leaf extract onto the aluminium surface, leading to effective initial surface coverage and barrier formation (El-Haddad and Fouda, 2025). At intermediate exposure (96 h), IE values ranged from 58.87% to 76.82%. The highest efficiency at this duration, 76.82% (96 h, 20 °C, 7 v/v%), confirms the synergistic effect of low temperature and high inhibitor concentration in stabilizing the adsorbed film. On the other hand, efficiency decreased to 56.65% at 96 h, 60 °C, and 7 v/v%, reflecting thermally induced desorption and accelerated corrosion kinetics at elevated temperatures (Adamu *et al*., 2025) .

Prolonged immersion (168 h) resulted in further decline in inhibition performance, with lower values such as 45.44% (168 h, 40 °C, 7 v/v%) and 49.82% (168 h, 40 °C, 1 v/v%). This reduction may be attributed to gradual degradation of the protective layer, depletion of active phytochemicals, and increased instability of the adsorbed film over time (Motawea, 2025). Temperature exerted a pronounced influence across all runs, with lower temperature (20 °C) consistently favored higher IE values (e.g., 74.31% at 24 h and 76.82% at 96 h), supporting an exothermic adsorption mechanism. In contrast, elevated temperature (60 °C) reduced efficiency (e.g., 47.76% at 96 h, 1 v/v%), which was consistent with enhanced desorption and increased metal dissolution rates (Udom, 2025).

Results also revealed that inhibitor concentration positively influenced performance. For example, at 96 h and 20 °C, increasing concentration from 1 v/v% to 7 v/v% improved IE from 60.84% to 76.82%, suggesting progressive surface site occupation approaching adsorption equilibrium behavior (Chu *et al*., 2025).

Overall, optimal inhibition was achieved under conditions of lower temperature, shorter exposure time, and higher inhibitor concentration. These findings confirm that banana leaf extract functions through adsorption-controlled mechanisms, with performance governed by thermodynamic stability and concentration-dependent surface coverage.

Table 4: Design Matrix and Response for the Inhibition Efficiency by Banana Leaf Extract

Run	Time (h)	Temp (°C)	Conc. (v/v)	Inhibition Efficiency (%)
1	24	40	7	70.78
2	96	20	7	76.82
3	96	60	7	56.65
4	24	40	1	67.65
5	96	40	4	58.87
6	168	60	4	51.19
7	96	40	4	58.87
8	168	20	4	52.74
9	96	40	4	58.87
10	96	40	4	58.87
11	168	40	1	49.82
12	96	20	1	60.84
13	24	60	4	62.49
14	96	40	4	58.87
15	96	60	1	47.76
16	168	40	7	45.44
17	24	20	4	74.31

Diagnostics

Normal Probability Plot

The normal probability plot (Figure 1) shows that most residuals closely align with the theoretical straight line, indicating that the assumption of normality is satisfied. This suggests that variations in inhibition efficiency resulting from changes in extract concentration, immersion time, and temperature are largely attributable to random experimental error rather than systematic bias. Consequently, the validity of the subsequent ANOVA and regression-based optimization is supported, enhancing the reliability of the developed predictive model for banana leaf inhibitor performance. Although two residual points approximately –3.0 and +3.8 deviate from the reference line at the distribution tails, these departures are minor and likely reflect process variability under extreme experimental conditions rather than model inadequacy (Zhang *et al*., 2025). Overall, the residual distribution confirms acceptable normality, validating the application of regression-based predictive tools for process optimization. This outcome demonstrates the robustness of the model in forecasting inhibition efficiency across the experimental domain and further highlights the potential of banana leaf extract as a sustainable, plant-based inhibitor for mitigating aluminium corrosion in acidic environments.

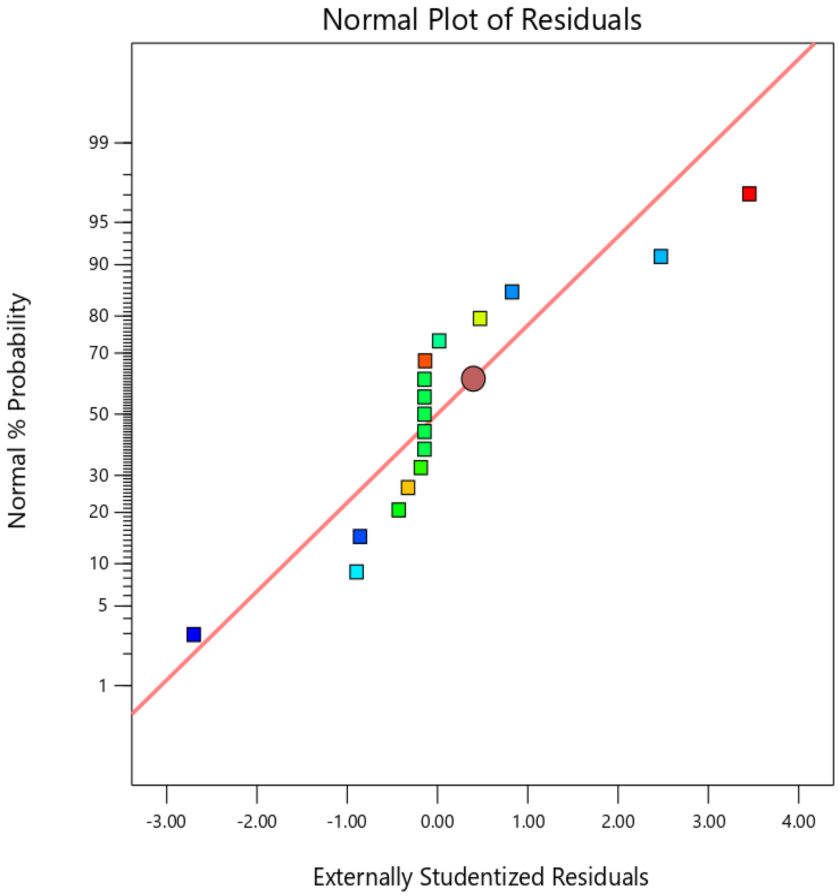

Figure 1: Normal Probability Plot on the Inhibition efficiency by Banana Leaf Extract

Pertubation Plot

The perturbation plot (Figure 2) illustrates the relative influence of immersion time (A), temperature (B), and inhibitor concentration (C) on inhibition efficiency around the central experimental point. The steepness of each curve reflects the sensitivity of the response to variations in each factor.

Immersion time (A) exhibits the steepest negative slope, indicating the strongest adverse effect on inhibition efficiency, likely due to gradual loss of protective adsorption and increased exposure of the aluminium surface to aggressive ions. Temperature (B) also shows a negative trend, suggesting that elevated temperatures may weaken adsorption and promote desorption of phytochemical constituents, thereby reducing inhibition performance. In contrast, inhibitor concentration (C) displays a mild positive slope, indicating that increased concentration slightly enhances inhibition efficiency by increasing the availability of active molecules for surface adsorption (Singh and Verma, 2025).

Overall, the perturbation analysis reveals a clear sensitivity order of A (time) > B (temperature) > C (concentration), highlighting immersion time and temperature as the dominant factors influencing corrosion inhibition efficiency.

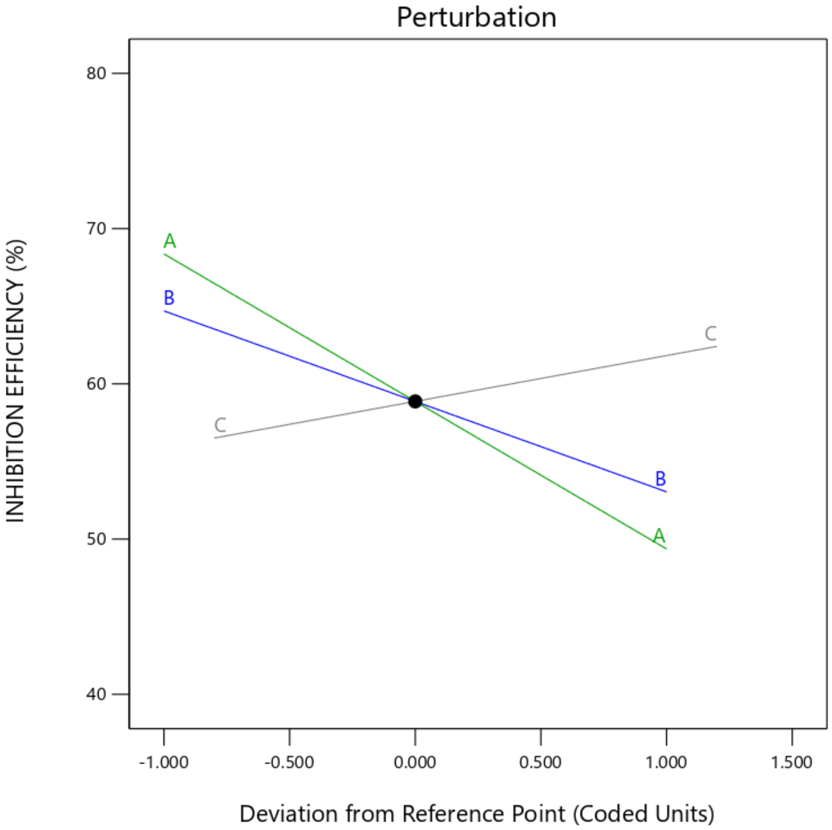

Figure 2: Perturbation Plot on the Inhibition Efficiency by Banana Leaf Extract

Predicted vs. Actual Values

The predicted versus actual plot (Figure 3) demonstrates strong agreement between the model-predicted inhibition efficiency values and the experimentally obtained results. Most data points cluster closely around the 45° reference line, indicating high predictive accuracy and minimal systematic bias. This trend confirms that the regression model effectively captures the relationships among banana leaf extract concentration, immersion time, temperature, and the resulting corrosion inhibition efficiency of aluminium in an acidic medium.

Minor deviations from the reference line are observed at both the lower and higher efficiency ranges. At lower efficiencies, slight under-prediction may result from kinetic limitations associated with reduced inhibitor concentration, where incomplete adsorption of phytochemical constituents leads to partial surface coverage (Ibrahim *et al.*, 2024). Also, modest over-prediction at higher efficiencies may arise from partial desorption or instability of adsorbed inhibitor molecules at elevated temperatures, which can reduce surface passivation despite high inhibitor dosage.

Overall, the distribution of points confirms that the model exhibits strong predictive capability and mechanistic consistency. The reliability of the predictions likely reflects the adsorption behaviour of banana leaf phytochemicals—including tannins, flavonoids, and polyphenolic compounds which interact with aluminium oxide/hydroxide surfaces to suppress metal dissolution in acidic environments (Shathani *et al.*, 2025). The small deviations observed remain within acceptable limits for corrosion inhibition modelling studies, thereby affirming the robustness of the experimental design and the applied statistical modelling approach.

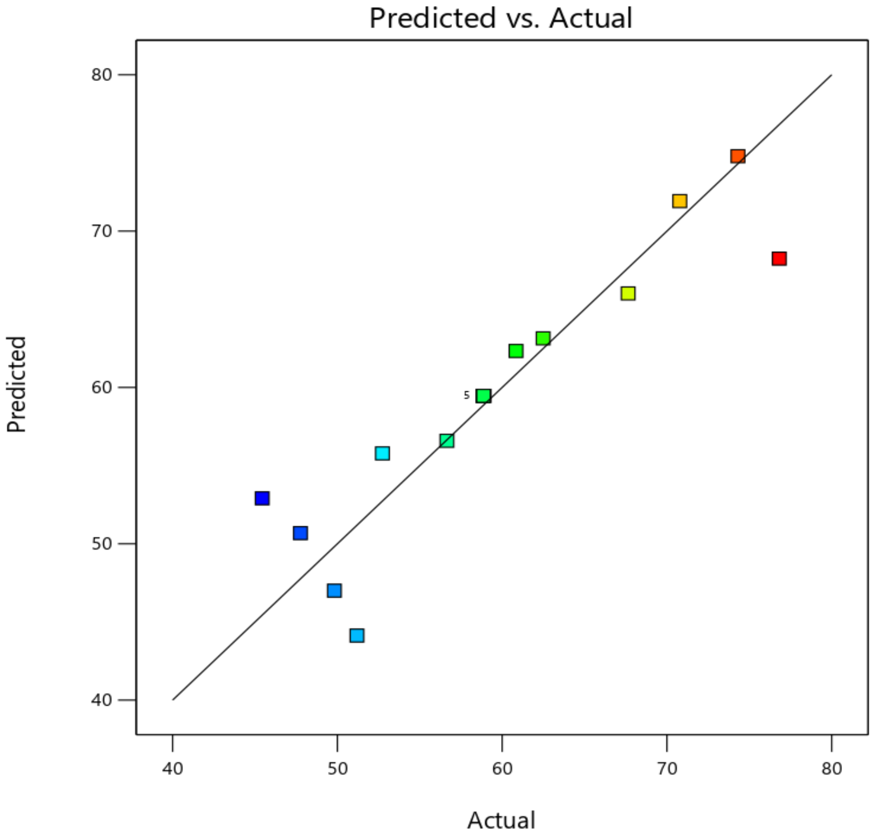

Figure 3: Predicted vs Actual Values Plot on the Inhibition efficiency by Banana Leaf Extract

Residuals vs. Predicted Values

The externally studentized residuals versus predicted plot (Figure 4) was used to evaluate the adequacy of the Response Surface Methodology (RSM) model for predicting the corrosion inhibition efficiency of banana (*Musa* spp.) leaf extract on aluminium in acidic medium. The horizontal limits at ±3.71733 represent the critical studentized residual thresholds at the 95% confidence level.

The plot shows that only one experimental run, corresponding to a predicted inhibition efficiency of approximately 75%, slightly exceeds the upper critical limit, indicating a minor under-prediction by the model. This deviation may be attributed to variations in the phytochemical composition of the banana leaf extract, particularly in flavonoids and polyphenols that influence adsorption behaviour on aluminium surfaces (Yousif *et al*., 2025). No points fall below the lower limit, suggesting the absence of extreme underestimations.

Apart from this single observation, the residuals are randomly distributed around zero with no discernible trend, confirming homoscedasticity and indicating that the RSM model adequately captures the interaction effects of inhibitor concentration, temperature, and immersion time. Overall, the diagnostic results confirm the statistical adequacy and robustness of the developed predictive model.

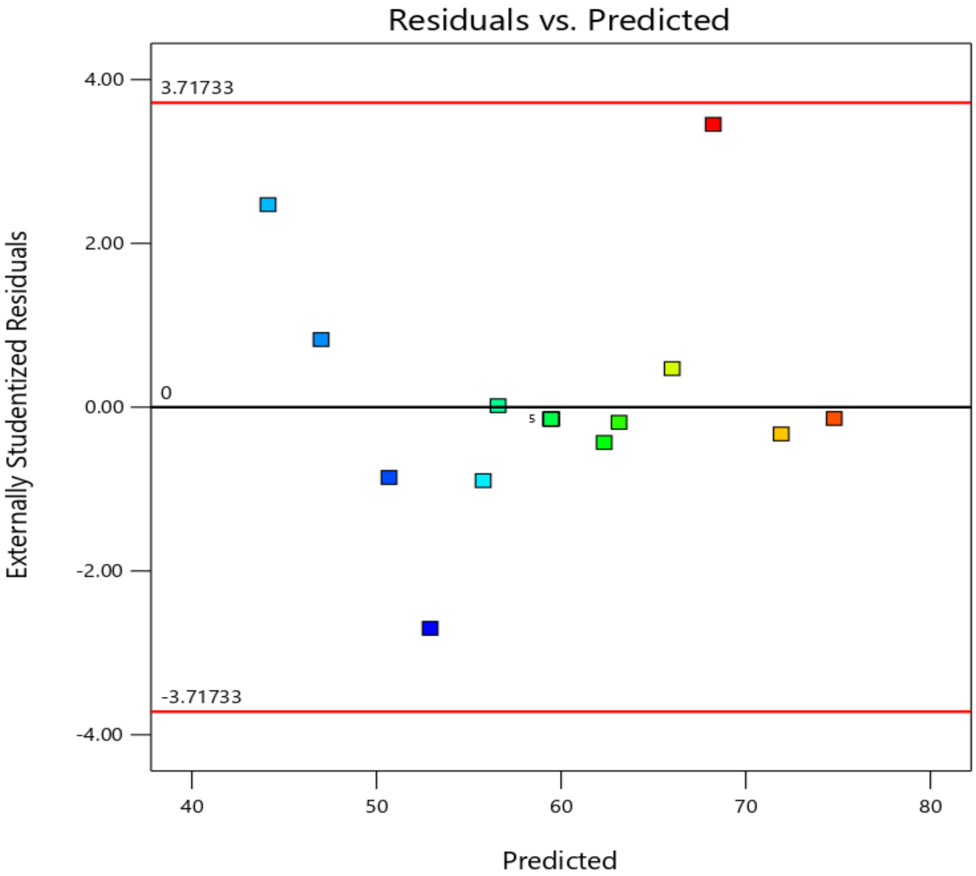

Figure 4: Residual vs Predicted Values Plot on the Inhibition efficiency by Banana Leaf Extract

Residuals vs Run Number

The residuals versus run plot (Figure 5) shows the distribution of externally studentized residuals across the experimental runs. Most residuals fall within the ±3.71733 control limits, indicating the absence of severe outliers and confirming the stability of the developed model. This trend suggests that variations in inhibition efficiency are largely explained by the model variables; banana leaf extract concentration, temperature, and immersion time rather than random experimental error.

Two runs show residuals approaching the control limits: a high positive residual in Run 2 and a low negative residual in Run 16. These slight deviations may reflect minor experimental variability Zineb *et al*., 2024). For instance, the higher residual in Run 2 may result from enhanced phytochemical adsorption under favourable micro-environmental conditions (Adewale *et al*., 2024), while the lower residual in Run 16 may be associated with partial desorption of active compounds such as tannins and flavonoids at elevated temperatures or longer immersion times. Overall, the residual pattern confirms the adequacy and reliability of the developed predictive model.

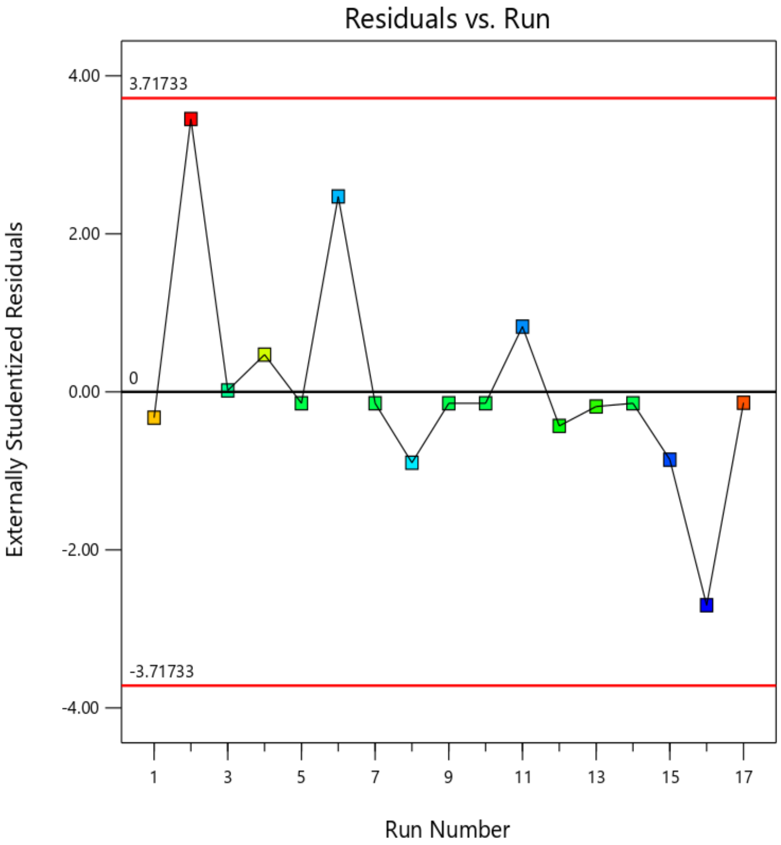

Figure 5: Residual vs Run Number Plot on the Inhibition efficiency by Banana Leaf Extract

Leverage vs Run Number

The leverage versus run plot (Figure 6) evaluates the influence of individual experimental runs on the regression model used to predict aluminium corrosion inhibition efficiency. The horizontal reference line at 0.2353 represents the average leverage value, while the upper limit at 0.4706 indicates the threshold above which observations may exert excessive influence on the fitted model.

From the plot, several runs (notably Runs 1 – 4, 6, 8, 11 – 13, 15 – 17) exhibit leverage values around 0.30, slightly above the average leverage but well below the critical threshold. These runs likely correspond to experimental conditions located near the edges of the design space where variations in inhibitor concentration, temperature, and immersion time exert stronger effects on the predicted inhibition efficiency (Peter, 2025). However, because none of the observations exceed the upper limit of 0.4706, no run can be considered excessively influential.

In contrast, Runs 5, 7, 9, 10, and 14 display relatively low leverage values (≈0.05–0.07), indicating that these observations lie closer to the center of the experimental design and contribute less influence to parameter estimation.

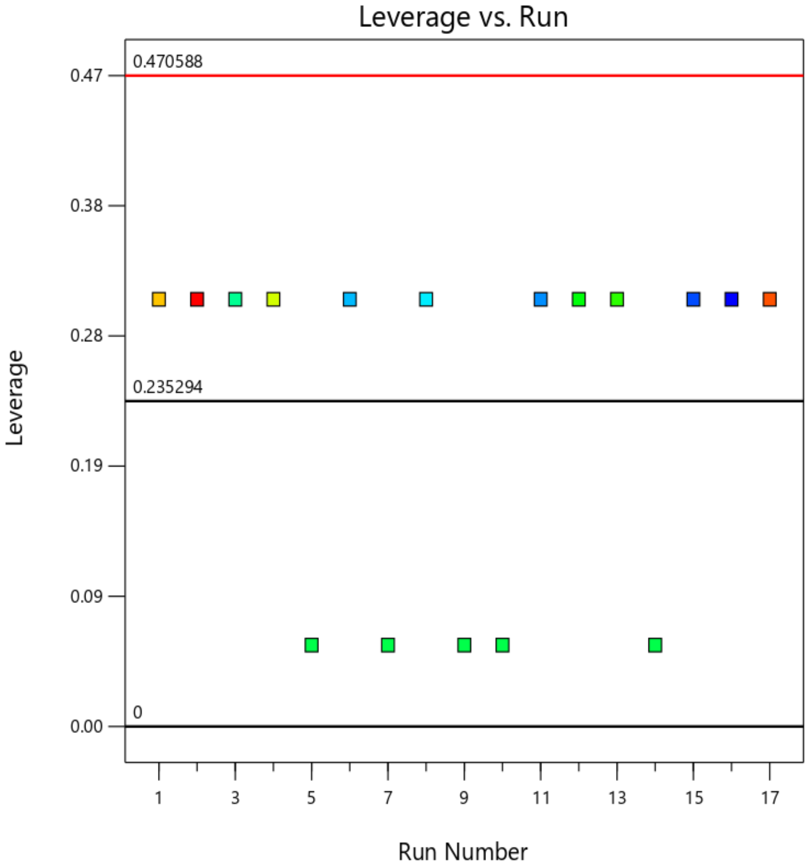

Figure 6: Leverage vs Run Number Plot on the Inhibition efficiency by Banana Leaf Extract

Cook's Distance

The Cook's distance plot (Figure 7) shows that all experimental runs fall below the influence threshold of 0.8845, indicating the absence of disproportionately influential observations and confirming the statistical stability of the regression model. Runs 2 (0.74), 7 (0.51), and 15 (0.56) exhibit relatively higher Cook's distance values, likely corresponding to experimental conditions near the extremes of the design matrix where variations in inhibitor concentration, immersion time, and temperature exert stronger effects on corrosion inhibition efficiency (Okuma *et al*., 2024). Although these runs remain within acceptable limits, they may represent conditions of increased mechanistic sensitivity (Saleem *et al*., 2025).

At higher extract concentrations and temperatures, adsorption–desorption dynamics of phytochemical constituents such as polyphenols, tannins, and flavonoids may shift toward partial desorption, leading to slight deviations from predicted responses. Also, lower inhibitor concentrations or shorter immersion times may result in incomplete surface coverage of aluminium, permitting localized corrosion processes. Overall, the Cook's distance profile confirms the robustness of the developed model while highlighting experimental conditions where adsorption behaviour may vary slightly.

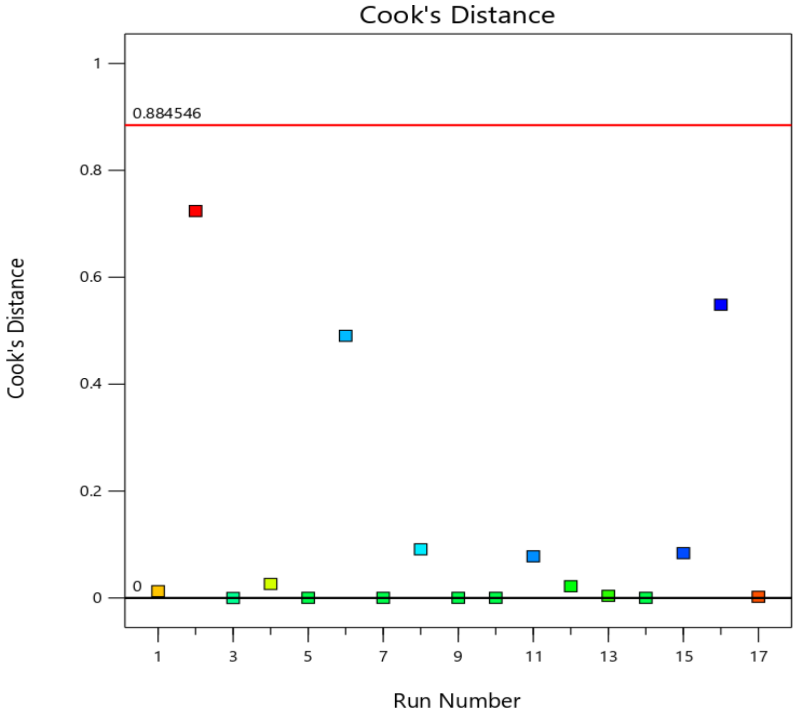

Figure 7: Cook's Distance Plot on the Inhibition efficiency by Banana Leaf Extract

Box-Cox Plot

The Box–Cox plot (Figure 8) produced an optimal transformation parameter (λ) of approximately 1.0, which lies within the 95% confidence interval, indicating that no transformation of the response variable is required. This result confirms that the inhibition efficiency data satisfy the assumptions of normality and homoscedasticity and maintain a linear relationship with the predictor variables under the applied experimental design (Zhiqiang *et al*., 2025). The λ value close to unity further suggests that the variance in inhibition efficiency remains stable across the investigated factor levels; banana leaf extract concentration, immersion time, and temperature indicating the absence of significant heteroscedasticity. This behaviour is consistent with adsorption-controlled corrosion inhibition by plant extracts, where equilibrium adsorption of phytochemical constituents stabilizes the residual distribution (Milad, 2024). Mechanistically, the statistical adequacy reflected in the Box–Cox analysis may be attributed to the uniform adsorption of polar phytochemicals such as flavonoids, polyphenols, and tannins on the aluminium oxide surface in acidic media.

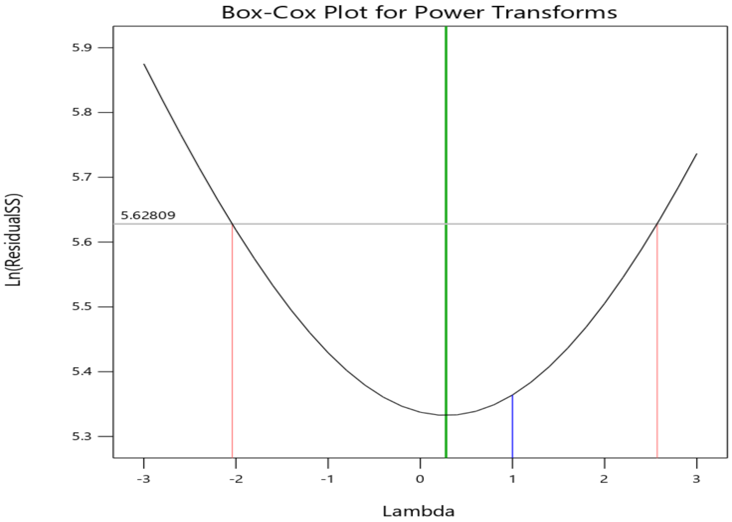

Figure 8: Box Cox's Plot on the Inhibition efficiency by Banana Leaf Extract

DFBETAS Plot for Intercept vs. Run Number

The DFBETAS plot for the intercept (Figure 9) was used to evaluate the influence of individual experimental runs on the estimation of the model intercept. The threshold limits of ±0.7276 were determined using the criterion 2/√n for n=17 experimental runs. Observations exceeding this limit are considered potentially influential on the intercept estimate. Run 2 shows a DFBETAS value of approximately +1.05, exceeding the upper threshold, indicating that its removal would significantly decrease the intercept estimate and that it exerts a strong positive influence on the baseline response. In contrast, Run 17 records a value of approximately –0.95, falling below the lower threshold, suggesting a strong negative influence on the intercept.

All other runs fall within the ±0.7276 limits, indicating minimal influence on the intercept parameter (Hassan *et al.*, 2025). While the presence of influential points does not necessarily imply experimental error, such runs often occur at extreme factor levels in designed experiments and may represent valid process conditions. Overall, the results indicate that the model intercept is generally stable, although Runs 2 and 17 warrant further consideration to ensure the robustness of the fitted model.

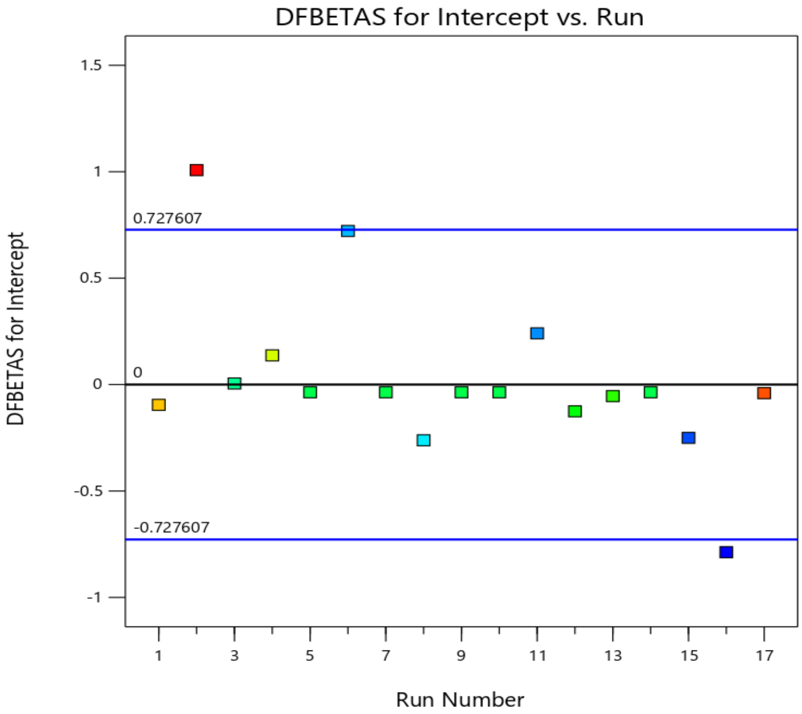

Figure 9: DFBETAS vs Run Plot on the Inhibition efficiency by Banana Leaf Extract

DFFITS Plot for Intercept vs. Run Number

The DFFITS versus run plot (Figure 10) evaluates the influence of individual experimental observations on the fitted regression model predicting aluminium corrosion inhibition efficiency. The horizontal blue lines at ±1.45521 represent the critical DFFITS threshold; observations exceeding these limits are considered influential because they substantially affect the model's predicted values. From the plot, Run 2 exhibits a DFFITS value of approximately +2.3, exceeding the upper threshold and indicating a strong positive influence on the fitted response. This suggests that the predicted inhibition efficiency for this run is highly sensitive to the inclusion of this observation (Nasir and Atif, 2024). Similarly, Run 16 shows a DFFITS value of approximately –1.8, falling below the lower threshold, indicating a notable negative influence on the regression predictions.

The remaining experimental runs fall within the ±1.45521 limits and cluster around zero, indicating minimal influence on the model predictions. These observations therefore contribute normally to the estimation of the regression parameters without distorting the fitted surface.

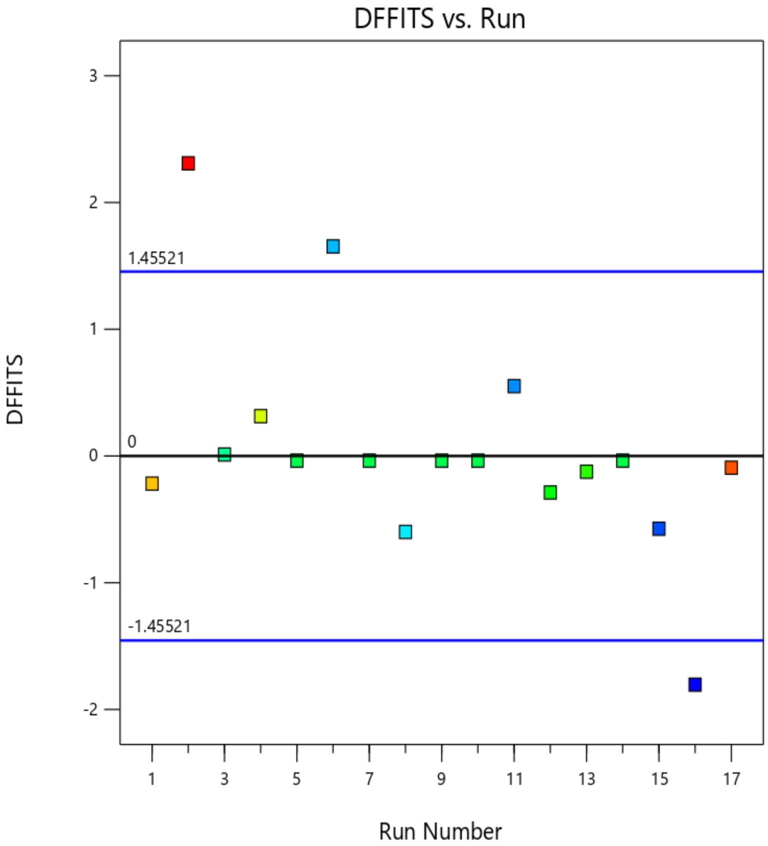

Figure 10: DFFITS vs Run Plot on the Inhibition efficiency by Banana Leaf Extract

CONCLUSION

This study assessed the corrosion inhibition performance of banana (*Musa* spp.) leaf extract on aluminium in acidic medium using Response Surface Methodology (RSM). The developed model showed strong agreement between predicted and experimental inhibition efficiencies, while diagnostic analyses confirmed the validity of key statistical assumptions and the absence of influential outliers.

Perturbation analysis revealed that immersion time had the strongest negative effect on inhibition efficiency, followed by temperature, whereas inhibitor concentration exerted a moderate positive influence. The inhibition mechanism is attributed to the adsorption of phytochemical constituents such as flavonoids, tannins, and saponins on the aluminium surface, forming a protective barrier against corrosion.

Overall, the results demonstrate that banana leaf extract is an effective and environmentally benign inhibitor, highlighting its potential as a sustainable alternative to conventional corrosion inhibitors in acidic environments.

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