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Investigation of the inhibitive Properties of *Irvingia gabonensis*Extractan for the Corrosion of Aluminum Alloy (aa4007) in 1 m HCl

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Abstract: *The corrosion efficiency of Irvingiagabonensis leaf extract for aluminium in 1MHCl media was investigated by gravimetric methods. The phytochemical analysis of the plant extract indicated the presence of saponin, alkaloid, flavonoid, and tannin which were considered effective against the corrosion of metals due to the commended chemical structures of the identified phytochemicals. Observations of results from weight loss experiments showed a progressive enhancement of the inhibitory efficiency with extract concentration and decreasing temperature. The maximum observed inhibition efficiency of the plant extract was 98% under HCl concentration of 1.0 M and a reaction temperature of 318 K.*

Keywords: Aluminium, electrochemical degradation, retardation, plant extract, *Irvingiagabonensis* leaf

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1.0 Introduction

The use of aluminium (Al) and its alloys in industries have significant advantages due to some unique properties of the metal. However, corrosion of the metal is a challenge that has been identified as common among several industries employing the metal (Olasunkanmi *et al*., 2017). Some factors have such as the coverage of the metal with thin film oxide to create passivity, employment of cathodic/anodic protection protocols, coating, etc (Chidiebere *et al*., 2017). Results from several kinds of literature have indicated that aluminium corrosion becomes more significant in an aggressive medium environment and can better be retarded by the use of corrosion inhibitors (Isaiah and Iroha, 2023). In several reported cases, several corrosion inhibitors have been certified to be highly efficient for the protection of aluminium against corrosion but current challenges are continually aligned to the environmental toxicity of most corrosion inhibitors such as inorganic compounds, etc (Alamry *et al*., 2023). The consequence is the need to carefully select corrosion inhibitors that can fulfil the following requirements,

(i) Ease of accessibility (Eddy *et al*., 2022)
(ii) Cost-effectiveness (Eddy and Ita, 2011)
(iii) Non-toxicity or environmental friendliness (Eddy *et al*., 2009).
(iv) Future sustainability (Sowmyashree *et al*., 2023)
(v) Enhanced efficiency

In view of the above considerations, corrosion experts have coined the word, green corrosion inhibitor, to describe those compounds that can meet the listed requirements (Eddy and Ebenso, 2008)

The major class of compounds that have met the criteria for green corrosion inhibition are dominantly, extracts of plants and animals or other natural sources (Eddy *et al*., 2023). However, some of them suffer from low efficiency and present difficulty in understanding the mechanism of inhibition since they are often factors with inhibition efficiency that arises from a synergistic combination of several components of the extract (Eddy *et al*., 2009). An approach to progress in the targeted success of identifying or synthesizing green corrosion inhibitors with excellent efficiency, therefore, requires continuous searches and documentation. Therefore, the present study aims to investigate the corrosion inhibition efficiency of *Irvingiagabonensis* leaf extract.

*Irvingiagabonensis*an African wild/bush mango is a perennial plant, habitat in the humid forest zone of West/central Africa (Atangana *et al*., 2011). Based on some previous studies conducted in this plant, enrichment with some organic compounds have been compound including those that have high molecular weight, hetero atoms, aromatic rings and other compounds that have been established to be active or effective against corrosion attack such as, tannins, saponins, alkaloids, anthraquinones and phenols which are capable of physicochemical adsorption on metal surfaces (Babatunde *et al.*, 2012).

The use of this plant leaf or other components of the same plant as a corrosion inhibitor is not strange. For example Onyekwere (2022) reported an inhibition efficiency of 67% when the plant extract was employed in the inhibition of the corrosion of mild steel in 1 M HCl. However, studies reported by Babatunde *et al*. (2012) and Onah *et al*. (2019) indicated that efficiency up to 90% and above can be achieved for the inhibition of mild steel corrosion by the same plant extract depending on the reaction condition and the grade of the mild steel, which is mainly determined by its carbon content. Studies conducted by Ubani *et al*. (2021) indicated low inhibition efficiency of *Irvingiagabonensis* leaf extract for aluminium (67%) but an enhancement was observed when iodide ion was used to create synergism with the inhibitor. Despite the usefulness of the leaf extract of *Irvingiagabonensis* as a corrosion inhibitor, literature is still scanty on its application for the inhibition of the corrosion of aluminium.

2.0 Materials and Methods

2.1 Materials preparation and phytochemical analysis

Ethanol extract from the plant leaves was obtained as an evaporate after the dried and ground sample was soaked for twenty-four hours.

The organic extract underwent phytochemical analysis using the typical procedure described in (Harbourne,). To identify the presence of secondary plant components such as alkaloids, tannins, flavonoids, saponins, phenols, and reducing sugar in the sample, basic phytochemical screening was done utilizing easy chemical tests.

On a sheet of aluminium alloy (AA4007) with the following compositions: Mn (1.2%), Si (1.4%), Ni (0.3%), Cr (0.1%), Fe (0.7%), and Al (96.3%), corrosion experiments were conducted. Aluminum was manually cut, had a hole drilled in one end for free suspension, and had a number punched into it before the corrosion process. After that, each coupon's surface was smoothed out using 220, 800, and 1200 emery sheets. The coupons underwent additional acetone degreasing, were rinsed with distilled water to remove debris, and were then dried in warm air. The coupons were rinsed three times: once with nitric acid to stop the reaction, once with distilled water to get rid of the inhibitor solution, and once more with ethanol and acetone to dry them. The mass loss was calculated using an electronic analytical balance with a sensitivity of 0.001g to compare the weight of the specimens before and after immersion. To ensure the validity of the findings, the tests were repeated, and the mean value of the mass loss is provided. The corrosion rate was calculated from mass loss measurements and represented in mg cm-2 hr-1 for the samples (Khadom *et al*., 2015). From the weight loss experiments, the following parameters were calculated, weight loss (equation 1), corrosion rate (equation 2 and inhibition efficiency (equation 3),,

$$\Delta w = w_2 - w_1 \quad (1)$$

$$CR\ (mpy) = \frac{\Delta w}{\rho A t} \quad (2)$$

$$\%IE = \frac{CR_b - CR_{inh}}{CR_b} \times \frac{100}{1} \quad (3)$$

In the above equations, w_1 and w_2 define the weight of the metal coupon in the acid solution without and with an inhibitor respectively. CR_b and CR_{inh} are the corrosion rate of the metal for the blank and inhibited systems respectively while t is the period of immersion, A, and ρ is the density of the metal and

The degree of surface coverage was also evaluated using the corrosion rates in the inhibited and uninhibited system according to equation 4 (i.e. the inhibition efficiency divided by 100).

$$\theta = \frac{CR_b - CR_{inh}}{CR_b} \times \frac{100}{1} \quad (4)$$

2.2 Electrochemical analysis

The potentiodynamic polarization (PDP) and EIS investigations were conducted using beta software installed on an electrochemical workstation having a three-electrode cell including a calomel, platinum, and aluminium as reference, counter, and working electrodes respectively. The current generated as the potential of the metal changes from -0.250 to +0.250 were recorded and applied to plot potentiodynamic polarization plot while the inhibition efficiency was calculated using the equation,

$$\%IE_{PDP} = \frac{i^{\circ}_{corr} - i'_{corr}}{i^{\circ}_{corr}} \times \frac{100}{1} \quad (5)$$

The electrochemical impedance measurements were performed with an open circuit potential of 10 mV under an operating frequency range of 100 kHz to 0.1 Hz.

The EIS measurements were carried out under potentiostatic circumstances with an open-circuit potential (OCP) of 10 mV and a frequency limit of 100 kHz–0.1 Hz. The Tafel polarization responses were examined to establish inhibition efficiency by considering the changes that occur to the polarization resistance in the absence (R_p) and presence ($R_{p(inh)}$) of the inhibitor using the following equation,

$$\%IE_{EIS} = \frac{R_{p(inh)} - R_p}{R_{p(inh)}} \times \frac{100}{1} \quad (6)$$

3.0 Results and Discussion

3.1 Phytochemical analysis

In Table 1, the phytochemical content of the plant extract is indicated and the results show alkaloids as the most significant phytochemicals while reducing sugar is the least in terms of concentration. Also found in the phytochemicals are saponin, tannins, flavonoids and phenol. Some previous studies have shown that the identified compounds have some corrosion-inhibitory roles (Eddy *et al*., 2022b)

Table 1 Qualitative phytochemical screening of the ethanol extract of *Irvingia gabonensis*

Phytochemicals	Activity
Saponin	++
Alkaloids	+++
Tannins	++
Flavonoid	++
Phenol	+
Reducing sugar	

-Absent, +Mild, ++moderate, +++ Abundance

3.2 Gravimetric analysis

Weight loss results showed that the corrosion of the metal increases with the period of contact of te metal with the solution of HCl. However, various concentrations of the extract showed a remarkable change in the corrosion rates when introduce to the corrosion medium such that the corrosion rate decreases as the extract concentration increases as shown in Fig. 1a. Therefore leaf extract of *Irvingia gabonensis* is an inhibitor for the corrosion of aluminium in a solution of HCl (Eddy *et al*., 2010). On the other hand, the inhibition efficiency increases with an increase in the concentration of the plant extract as shown in Fig. 1b. Therefore, the leaf extract of *rvingia gabonensis* is an adsorption inhibitor for aluminium in HCl medium because the surface coverage of the inhibitor increases with increase in concentration (Eddy and Ita, 2011). At extract concentrations of 0.2 and 1 g/L, the inhibition efficiencies were 78 and 91%.

It has been established that the inhibition of metal corrosion operates through an initial mechanism of adsorption, which can be physical or chemical (Lashgari and Malek 2010). Adsorption isotherm can provide information on the type of adsorption, mechanism and characteristics of the adsorption. Trial tests for the fitness of different adsorption isotherms was carried out to ascertain the best-fitted adsorption model and the outcome reveals that the Langmuir, Temkin and Freundlich isotherms best fitted the adsorption of the inhibitor on the surface of aluminium as shown in Fig. 2a-c.

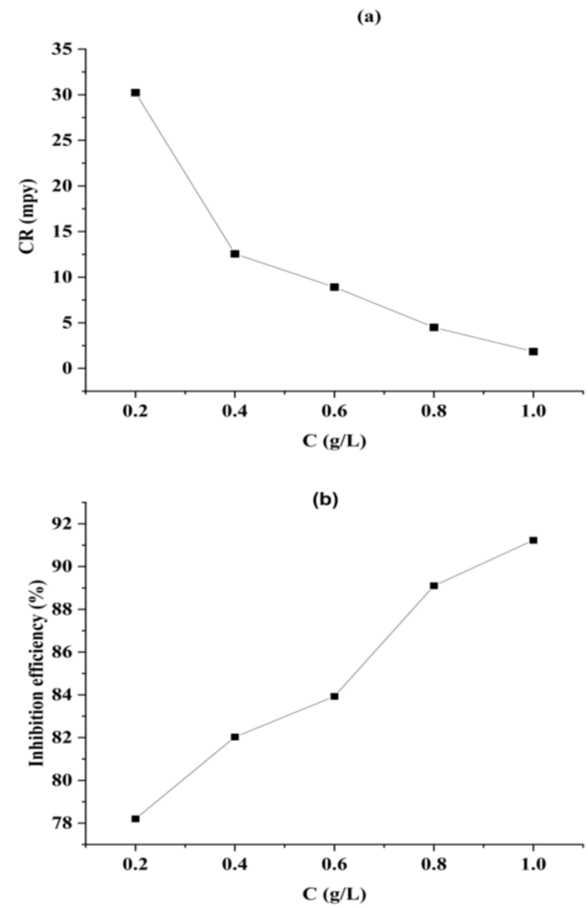

Fig. 1: Variation of (a) corrosion rate of aluminium with concentration (b) inhibition efficiency of various concentrations of *Irvingia gabonesis* leaf extract with concentration at 303 K

Evaluated R^2 values and the intercept are indicated in each plot. The Langmuir adsorption gave R^2 values of 0.9914, while those calculated for the Fruendlich and Temkin plots were 0.9974 and 0.9721 respectivel.

The Langmuir equation can be represented in terms of the linear variation of the ratio of the concentration to degree of surface coverage to the concentration of the inhibitor, which fits the model described by equation 7 (Mokhtar *et al.*, 2019; Nnanna and Iroha 2020).

$$\frac{C}{\theta} = k_{ads} - C \quad (7)$$

The Langmuir adsorption equilibrium constant (k_{ads}) can be applied to evaluate the free energy associated with the adsorption process, based on the Gibb-Helmholtz equation (equation 8) (Kanoma *et al.*, 2014)

$$\Delta G_{ads} = -RTlnk_{ads} \quad (8)$$

The Fruendlich and Temkin isotherm are consistent with the expression shown by equations 9 and 10 (Ogunleye, *et al.*, 2020)

$$\ln(\theta) = lnk_{ads} + nln(C) \quad (9)$$

$$\theta = \frac{-lnk_{ads}}{2a} - \frac{\ln(C)}{2a} - \quad (10)$$

Adsorption parameters associated with the three fitted isotherms are shown in Table 2. The slope of the Langmuir isotherm was greater than unity which indicates that there is an interaction between the adsorbed species (Odiongenyi *et al.*, 2008). Consequently, other isotherms were considered to establish the nature of the interaction. The interaction parameter deduced from the Temkin plot (i.e. 1 = 2.97) indicated that between the adsorbed species, there is an attraction (Eddy *et al.*, 20i8). However, the fitness of the Fruendlich isotherm to the adsorption of the plant extract on the surface of aluminium (Al) suggests substitution or replacement of adsorbed water molecules by the inhibitor (Ih) as a possible mechanism

$$Al_{(nH_2O-ads)} + In \rightarrow Al_{(ads-Inh)} + H_2O \quad (11)$$

From equation 11, it can be deduced from the Freundlich isotherm that since n = 1, then one molecule of the inhibitor replaced each molecule of water and thus led to adsorption as the replacement process continues (Zhang *et al.*, 2022).

The standard free energy of the adsorption concerning *Irvingia gabonesis* leaf extract and the aluminium surface was evaluated using the Gibb Helmholtz equation (Ukpe, 2019a; Ukpe *et al.*, 2014)

$$\Delta G^0_{ads} = -RTln(55.5k_{ads}) \quad (12)$$

In equation 12, R represents the gas constant, T, the temperature, k_{ads},the adsorption constant and 55.5 the molar heat capacity of water. Evaluated values of ΔG^0_{ads} shown in Table 2 presents a range of -10.19 to -17.30 kJ/mol which confirms the dominance of the physical adsorption mechanism because the free energy change is in the range of 0 to -20 kJ/mol (Ukpe, 2019b).

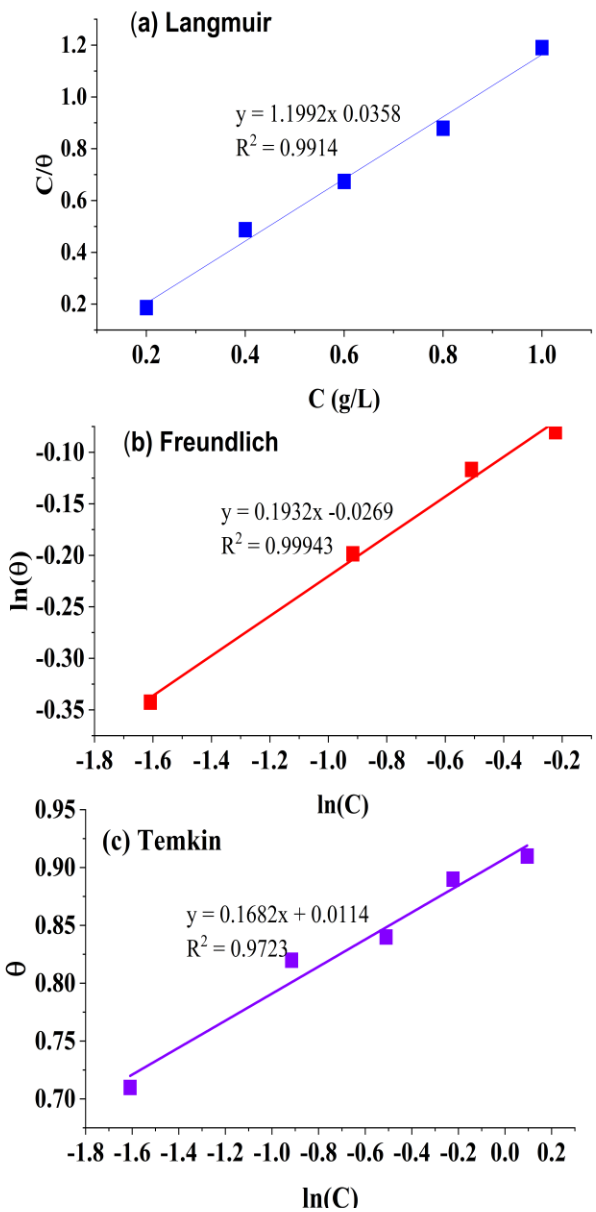

Fig 5 Langmuir isotherm for adsorption of *irvingiagabonesis* on aluminum surface

Table 2: Fitted isotherms parameters for the adsorption of ethanol extract of *Irvingia gabonesis* leaf

Isotherm	Parameetr	Values
Langmuir		
	Slope	1.1992
	Intercept	0.0358
	R^2	0.9714
	k_{ads}	0.0358
	ΔG_{ads}	-17.30
	Slope	0.1932
Freundlich		
	Intercept	0.0269
	R^2	0.9943
	k_{ads}	1.0273
	n	1.00
	ΔG_{ads}	-10.19
	Slope	0.1682
Temkin		
	Intercept	0.0114
	R^2	0.9723
	k_{ads}	1.0701
	a	2.97
	ΔG_{ads}	-10.29

3.3 Potentiodynamic polarization study

A plot of corrosion of logarithm of corrosion current versus corrosion potential describing the potentiodynamic polarization results for the inhibition of aluminium alloy corrosion by 100 and 1000 mg/L of the investigated inhibitor is shown in Fig. 3. The plot reveals equilibrium corrosion potential and other data that are presented in Table 3. The anodic arm of the plot seems to show higher displacement than the cathodic arm, which suggests that the inhibitor is an anodic inhibitor.

The corrosion current showed wider variability between the inhibited and the uninhibited systems. In the blank, the corrosion current was observed to be 219 μA/cm^2 but decreased to 81 and 41 μA/cm^2 upon the introduction of 100 and 1000 mg/L of the *Irvingia gabonensis* leaf extract. This reveals the retardation in the corrosion process as a consequence of the inhibitive property of the extract, which showed an increase with an increase in concentration. The observation also correlates with results obtained from weight loss measurement and the inhibition efficiencies of 63 and 81% deduced for the two concentrations are also comparable to values recorded for similar concentrations through weight loss experiment. The displacement in the potential current with respect to the blank and at extract concentrations of 100 and 1000 mg/L are 110 and 113 mV which confirms that the inhibitor is anodic since they are less than the threshold value of 85 mV (Eddy *et al*., 2022).

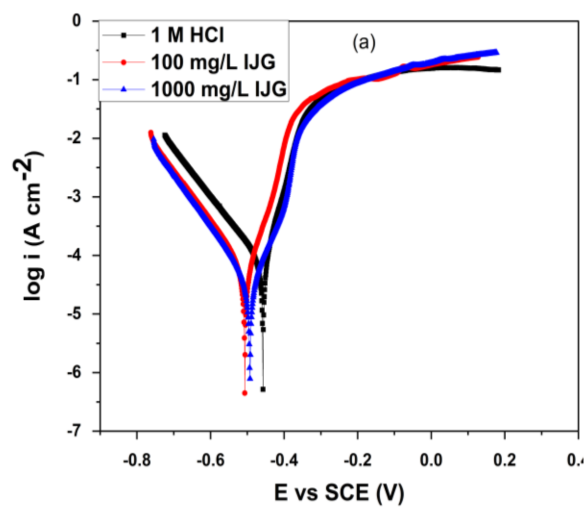

Fig. 3: Potentiodynamic polarization plots for the inhibition of the corrosion of aluminium by leaf extract of *irvingia gabonesis*

3.4 Electrochemical impedance spectroscopy

Fig. 4 shows the Nyquist plots representing the inhibition of the corrosion of aluminium by two different concentrations of *Irvingia gabonensis* leaf extract. From the plots, the diameter for the semicircle showed the lowest value for the blank but a progressive increase is observed as the concentration of the extract increases. This also lead to an increase in inhibition efficiency with concentration from

60 to 80%, revealing a very close comparison with efficiencies calculated for similar concentrations (i.e. 100 and 1000 mg/L) of the extracts for the potentiodynamic polarization method. The evaluated charge transfer resistance showed the least value for the blank than those obtained for the inhibited system. A trend showing an increase in charge transfer resistance with inhibition efficiency, is also upheld for the study. Such an increase in charge transfer resistance with the inhibitor's concentration is consistent with the increase in the barrier created by the adsorption of the inhibitor on the metal surface. The combined effect of relaxation at the low-frequency loop and the increasing charge transfer resistance as the concentration of the inhibitor increases led to a decrease in corrosion rate and a subsequent increase in inhibition efficiency.

Table 3: Electrochemical Parameters for Aluminum Steel in 1 M HCl in the Absence and Presence of *Irvingia gabonensis* leaf extract

System	E_{corr} (mV vs SCE)	I_{corr} (μA/cm²)	$I\eta_{PDP}$(%)	R_{ct} (Ωcm²)	N	R_{LI} (Ωcm²)	I.E (%)
1 M HCl	**- 445.2**	**218.6**		**199.7**	**0.88**		
100 mg/L	- 554.8	80.7	63.1	512.4	0.89	273.6	61.0
1000 mg/L	-568.6	41.3	81.1	976.5	0.89	86.5	79.5

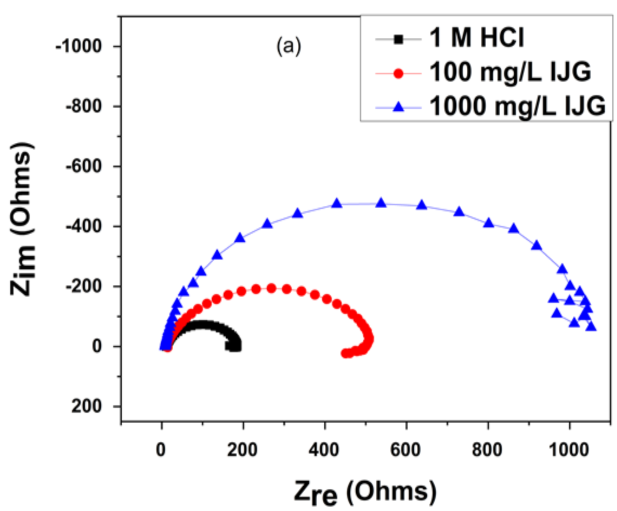

Fig. 8: Nyquist plots for the inhibition of the corrosion of aluminium in 1 M HCl by 100 and 1000 mg/L concentrations of *Irvin giagabonensis* leaf extracts.

The observed changes are also consistent with a decrease in the local dielectric constant and the increase in the thickness of the double layer, which have an overall effect of decreasing the double layer capacitance and subsequent decrease in corrosion rate. This trend is best on the relationship between the charge transfer resistance (R_{ct}), the imaginary impedance at the maximum frequency (f_{max}) and the double layer capacitance as shown by equation 13 (Raviprabha & Bhat, 2023),

$$C_{dl} = \frac{1}{f_{max} R_{ct}} \quad (13)$$

Equation 13 reveals that since the values of f_{max} and R_{ct} increases as the diameter of the capacitive loop increases, the C_{dl} is seen to decrease with an increase in inhibition efficiency.

4.0 Conclusion

Based on the results and findings of the study, the following conclusions were made.

Leaf extract of *Irvingiagabonesis* is a potent corrosion inhibitor for aluminium alloy in 1 M HCl with optimum corrosion inhibition to be 97.6%. The extract inhibited the aluminium corrosion by a physical adsorption mechanism and showed behaviour that describes the attractiveness of the molecules during adsorption. The efficiency of the inhibitor shows a major dependent on concentration, charge transfer resistance, double layer capacitance and the imaginary frequency of the capacitive loops.

5.0 References

Alamry, K.A., Khan, A., Aslam, J., Hussein, M. A. & Aslam, R. (2023). Corrosion inhibition of mild steel in hydrochloric acid solution by the expired Ampicillin drug. *Sci Rep*., 13, 6724, https://doi.org/10.1038/s41598-023-33519-y

Babatunde, A. I., Ogundele, O. & Abiola, O. K. (2012). The inhibitive effect of *Irvinga gabonesis* extract on the corrosion of aluminium in 1 M HCl solution. *Advances in Applied Science Research*, 3, 6, pp. 3944-3949.

Chidiebere, M. A., Simeon, N., Njoku, D., Iroha, N. B., Oguzie, E. E. & Li Y. (2017). Experimental study on the inhibitive effect of phytic acid as a corrosion inhibitor for Q235 mild steel in 1 M HCl environment, *World News of Natural Sciences*, 15, pp. 1-19.

Eddy, N. O. &Ebenso, E. E. (2008). Adsorption and inhibitive properties of ethanol extract of *Musa sapientum* peels as a green corrosion inhibitor for mild steel in H_2SO_4. *African Journal of Pure and Applied Chemistry* 2, 6, pp. 1-9.

Eddy, N. O. &Ita, B. I. (2011). Theoretical and experimental studies on the inhibition potentials of aromatic oxaldehydes for the corrosion of mild steel in 0.1 M HCl. *Journal of Molecular Modeling* 17: 633-647. DOI:10.1007/s00894-010-0749.

Eddy, N. O., Awe, F. E. & Ogoko, E. C. (2018). Experimental and quantum chemical studies on ethanol extract of *Phyllanthus amarus (EEPA)* as a green corrosion inhibitor for aluminium in IM HCl. *J. Mater. Environ. Sci*., 9, 11, pp. 3075-3086.

Eddy, N. O., Ibok, U. J., Garg, R., Garg, R. Falak, A. I., Amin, M., Mustafa, F., Egilmez, M. and. Galal, A. M. (2022b). A brief review on fruit and vegetable extracts as corrosion inhibitors in acidic environments of steel in an acidic environment. *Molecules*, 27, 2991. https://doi.org/10.3390/molecules27092991.

Eddy, N. O., Odiongenyi, A. O., Ebenso, E. E., Garg, R and Garg, R. (2023). Plant Wastes as alternative sources of sustainable and green corrosion inhibitors in different environments. *Corrosion Engineering Science and Technology*, https://doi.org/10.1080/1478422X.2023.2204260

Eddy, N. O., Odoemelam, S. A. &Odiongenyi, A. O. (2009). Ethanol extract of Musa species peels as a green corrosion inhibitor for mild steel: Kinetics, adsorption and thermodynamic considerations. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, 8, 4, pp. 243-255.

Eddy, N. O., Odoemelam, S. A., Ogoko, E. C., Ukpe, R. A., Garg, R. &Anand, B. (2022a). Experimental and quantum chemical studies of synergistic enhancement of the corrosion inhibition efficiency of ethanol extract of *Carica papaya* peel for aluminium in solution of HCl. *Results in Chemistry*, 100290,https://doi.org/10.1016/j.rechem. 2022.100290.

Eddy, N. O., Odoemelam, S. A., Ogoko, E. C., Ukpe, R. A., Garg, R. & Anand, B. (2022). Experimental and quantum chemical studies of synergistic enhancement of the corrosion inhibition efficiency of ethanol extract of *Carica papaya* peel for aluminium in solution of HCl. *Results in Chemistry*, 100290, https://doi.org/10.1016/j.rechem.2022.100290.

Eddy, N.O., Odoemelam, S.A. & Odiongenyi, A.O. (2009). Joint effect of halides and ethanol extract of *Lasianthera africana* on inhibition of corrosion of mild steel in H_2SO_4 . *J Appl Electrochem*, 39, pp. 849–857 https://doi.org/10.1007/s10800-008-9731-z.

Harbourne, J. B. (1998). *Phytochemical methods: A guide to modern technique of plant analysis*. 2nd edition London: Chapman and Hall Ltd.Pp. 282.

Iroha, N. B. & Hamilton-Amachree, A. (2018). Adsorption and anticorrosion performance of Ocimum Canum extract on mild steel in sulphuric acid pickling environment. *American Journal of Materials Science*, 8, 2, pp.39-44.

Isaiah, L. C. & Iroha, N. B. (2023). Evaluation of mild steel corrosion protection in 1MHCl solution by *Vildagliptin*: Experimental and theoretical studies. *World Scientific News* 177, pp. 51-67.

Khadom, A. A., Hassan, A. F. & Abod, B. M. (2015). Evaluation of environmentally friendly inhibitor for galvanic corrosion of steel-copper couple in petroleum wastewater. *Process Safety. Environ. Protection*, 98, pp. 93-101.

Odiongenyi, A. O., Enengedi, I. S., Ibok, I. & Ukpong, E. J. (2015). Inhibition of the corrosion of zinc in 0.1 M HCl by ethanol extract of honey. *International Journal of Chemical, Materials and Environmental Research*, 2, pp. 16-25.

Okuma, S. O. & Onyekwere, K. C. (2022). Inhibitive effect of *IrvingiaGabonensis* leaf extract on the corrosion of mild steel in 1.0m hydrochloric acid. *Journal of Applied Sciences and Environmental Management*, 26, 1, DOI: 10.4314/jasem.v26i1.4.

Olasunkanmi, I. O., Obot, I. B., Kabanda, M. M & Ebenso, E. E. (2017). Some quinoxalin-6-yl derivatives as corrosion inhibitors for mild steel in hydrochloric acid: experimental and theoretical studies. *J Phys Chem C*, 119, pp. 16004–19.

Onah, C. C., Mbah, C. N. &Nnakwo, K. C. (2019). Inhibitive Characteristics of IrvingiaGabonensis Extract on Mild Steel Corrosion in Hydrochloric Acid. *American Journal of Chemistry and Materials Science*, 6, 2, pp. 15-20.

Raviprabha, K. & Bhat, R. S. (2023). Corrosion inhibition of mild steel in 0.5 M HCL by substituted 1,3,4-oxadiazole. *Egyptian Journal of Petroleum*, 32,2, pp. 1-10. https://doi.org/10.1016/j.ejpe.2023. 03.002.

Sowmyashree, A. S., Somya, A., Rao, S., Kumar, C. B. P., Al-Romaizan, A. N., Hussein, M. A., Khan, A., Marwani, H. M. & Asiri, A. M. (2023). Potential sustainable electrochemical corrosion inhibition study of Citrus limetta on mild steel surface in aggressive acidic media. *Journal of Materials Research and Technology*, 24, pp. 984-994,https://doi.org/10.1016/j.jmrt.2023.0 2.039.

Ubani, C. O. L., Nwadire, F. C., Igwe, O. U., Bilar, A. &Agunanne, A. (2021). Halide ions and methanolic extract of *Irvingiagabonesis*as an enhanced corrosion inhibitory agent on aluminium in HCl. *Journal of Chemical Society of Nigeria*, 46, 1, https://doi.org/10.46602/jcsn.v46i1.585.

Ukpe, R. (2019b). Joint effect of ethanol extract of orange peel and halides on the inhibition of the corrosion of aluminum in 0.1 M HCl: An approach to resource recovery. *Communication in Physical Science*, 4, 2, pp. 118-132.

Ukpe, R. A. (2019a). Joint effect of halides and ethanol extract of sorghum on the inhibition of the corrosion of aluminum in HCl. *Communication in Physical* Science, 4, 2, pp. 141-150.

Ukpe, R. A., Odoemelam, S. A., Odiongenyi, A. O. & Eddy, N. O. (2014). Inhibition of the corrosion of aluminium in 0.1 M HCl by ethanol extract of mango peel waste.

Journal of Bioprocessing and Chemical Engineering, 2, 2, pp. 2348-3768.

Zhang, X., Zhang, Y., Su, Y, Wang, X. & Lv, R. (2022). Synthesis and corrosion inhibition performance of mannish bases on mild steel in lactic acid media. *ACS Omega*, 7, 36, pp. 32208-32224. doi: 10.1021/acsomega.2c03545.

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AEE cariied out the experimental session together with LAN, OB while AEE, VEI and ECN jointly wrote the manuscript.