SHORT RESEARCH COMMUNICATION

Inhibition and adsorption potentials of mild steel corrosion using methanol extract of *Gongronema latifoliuim*

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Abstract

Gongronema latifolium was used as a low-cost green inhibitor for mild steel by applying the weight loss method at 303–323 K. There was a decrease in percentage inhibition with temperature increase and a rise in inhibition efficiency with an increase in the concentration of inhibitor. The obtained results showed that *Gongronema latifolium* extract of methanol had percentage inhibition efficiencies in the range of 59.06–81.69%. Corrosion inhibition of mild steel showed a good fit to the Langmuir model compared to the Freundlich and El-Awardy adsorption models. Thermodynamics parameters, such as E_a, Q_{ads} and ΔG_{ads} were evaluated and showed that the mechanism of corrosion inhibition of mild steel by methanol extract of *Gongronema latifolium* was physisorption. The results of this work indicated efficient potentials of the methanol extract of *Gongronema latifolium* as a low-cost corrosion inhibitor in acidic media for mild steel, which could be applied to reduce corrosion of metals in industries.

Keywords Corrosion inhibition · *Gongronema latifolium* extract · Adsorption

Introduction

Numerous failures and eventual losses of equipment in the chemical industry have been traced to corrosion processes. However, corrosion inhibitors utilization has been discovered to be a very suitable and efficient option (Quraishi and Singh 2010). Inhibitors used for corrosion are substances able to retard the rate of corrosion when added, by being adsorbed on the surface of the metal through the mechanism of physical or chemical adsorption (Douadi et al. 2014). Naturally occurring substances, especially plant extracts as inhibitors for corrosion of materials, have received attention worldwide as a replacement for synthetic ones, which have several detrimental effects on the environment and human beings (Ebenso et al. 2008). Green corrosion inhibitors are less toxic, easily accessible, less expensive and biodegradable (Eddy et al. 2010). Plant extracts are organic and contain phytochemical compounds (Kristianto et al. 2019). Organic inhibitors are those containing hetero-atoms in their structures, which allows easy adsorption onto the surface of the metal. Sulphur, phosphorus, nitrogen and oxygen are hetero-atoms present in their structures which act as adsorption centres (Ebenso et al. 2010). Different plant extracts have been widely reported as effective corrosion inhibitors in various corrosive environments (Umoren et al. 2013; Okafor et al. 2008; Deepa and Selvaraj, 2010; Deng and Li 2012; Eduok et al. 2012). *Gongronema latifolium* belongs to the family *Asclepidiaceae*. It is called utaziin in the south-eastern part of Nigeria. *Gongronema latifolium* is a highly valued vegetable in the south-eastern part of Nigeria because of its nutritional and medicinal properties. The study investigated the inhibition effect of methanol extract of *Gongronema latifolium leaf* for corrosion of mild steel in hydrochloric acid solution by gravimetric technique.

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Materials and methods

Material preparation

Physicochemical characterization of mild steel sheets showed the following chemical compositions by weight (%): Carbon (0.2), Silicon (0.1), Sulphur (0.01), Phosphorous (0.01), Manganese (0.1) and the balance iron. It was obtained commercially. Mild steel coupons have a 0.12 cm in thickness and were manually cut in dimension into 4×3 cm. A hole was drilled for suspension in the acid at the edge of each coupon. This was followed by polishing the coupons, then degreased by adding absolute ethanol, then acetone aided drying before storage in desiccators for use in the experiment. A solution of 0.5 M hydrochloric acid was prepared from analytical grade hydrochloric acid was used as the corrodent for the experiment.

Preparation of *Gongronema latifolium* methanol leaf extract

The leaves were dried and blended into powdered form. These were soxhlet extracted using methanol. The solutions were evaporated at 65 °C to remove methanol. The stock solution was diluted with 0.5 M HCl solution to obtain inhibitor solutions of 0.1–0.5%w/v concentrations. This leaf extract was subjected to phytochemical analysis.

Gravimetric method

The work was done using different temperatures of 303, 313 and 323 K using 250-ml beakers. Weighed mild steel coupons ($4 \times 3 \times 0.12$ cm) with threads were dipped into a 250 ml beaker containing 0.5 M HCl in a water bath. Mild steel coupons were retrieved at 24 h intervals for 5 days. They were scrubbed with a brush in ethanol, dried in acetone and reweighed. The experimental work was repeated with different concentrations of inhibitor in 0.5 M HCl. Experiment were performed twice to ensure accuracy, and the average values for the 5 days were used. From the change in the weight loss of coupons, the rate of corrosion was evaluated using the equation (Eddy et al. 2010; Odewole et al. 2021):

$$C = \frac{k \times \Delta W}{A \times t \times D} \tag{1}$$

where ΔW is the loss in weight in milligram, A shows exposed surface area of the coupons, k, the rate constant, D is the density of mild steel, t is the time of exposure of metal in hours and C represent the rate of corrosion (mm/yr).

The percentage inhibition was extrapolated by applying the following using the:

$$\text{I.E\%} = \frac{W - W_i}{W} \times 100 \tag{2}$$

where W_i and W represent the measured weight loss of the steel in inhibited and uninhibited solutions, respectively.

The following equation was utilized to calculate the extent of surface coverage:

$$\theta = \frac{W_i - W}{W_i} \tag{3}$$

Results and discussion

Phytochemical analysis

It is observed from Table 1 that methanol extract of *Gongronema latifoilum* contains phytochemical constituents reported as good corrosion inhibitors (Eddy et al. 2010). The corrosion inhibition of mild steel by methanol extract of *Gongronema latifolium* was as a result of complex chemical compositions of some phytochemical constituents that contain hetero-atoms that form chemical bonds between the iron in the mild steel and the extract. Normally, suitable effective

Table 1 Phytochemicals of *Gongronema latifolium*

Parameters	Presence
Alkaloids	+
Flavanoid	++
Reducing Sugars	−
Tannins	++
Phlobatannins	+
Proteins	+
Amino acid	+
Resins	++
Saponins	++
Glycosides	−
Cardiac glycosides	++
Carbohydrates	++
Terpenoid	++
Triterpenes	++
Steroids	++
Quinones	+++
Anthraquinones	−
Phenols	+
Anthracene	−

$+$ = Trace amount, $++$ = Moderate amount, $+++$ = Appreciable amount, $-$ = Abensence

Fig. 1 Weight loss variation for *Gongronema latifolium* at different temperatures in 0.5 M HCl
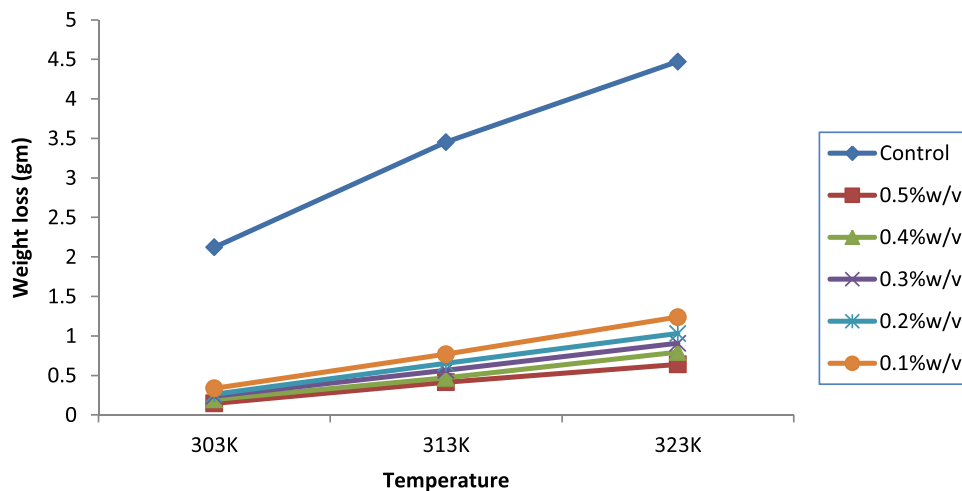
Fig. 2 Corrosion rates of *Gongronema latifolium* obtained by gravimetric method at different temperatures
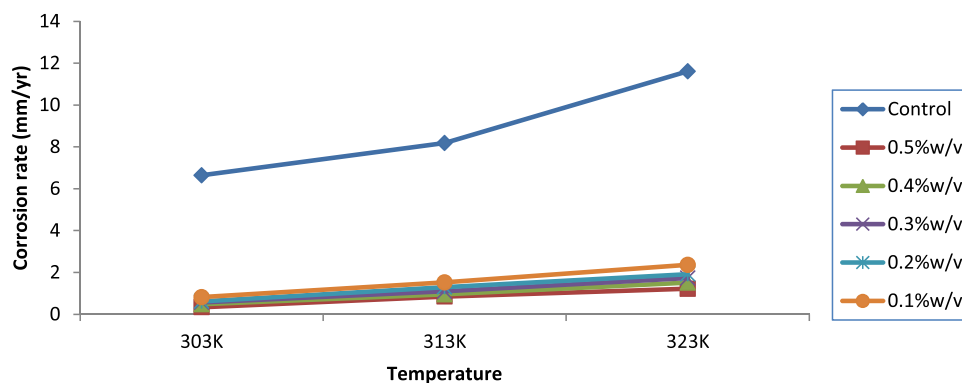
organic compounds used for corrosion inhibition usually contain hetero-atoms like phosphorous, sulphur, oxygen and nitrogen (Shukla and Quraishi 2009; Sapra et al. 2008). This is due to the ability of the hetero-atoms lone pair of electrons to form a protective film on metal surfaces thereby decreasing the rate of corrosion (Barouni et al. 2014; Li et al. 2009). The results showed the presence of these phytochemicals containing hetero-atoms which are responsible for the inhibition efficiency. This suggests good potentials of the extract of *Gongronema latifoilum* as a corrosion inhibitor.

Weight loss evaluation

Figure 1 represents the weight loss against temperature for mild steel at temperatures 30, 40 and 50 °C. An increase in extract concentration reduced the weight loss while an increase in temperature increased the mild steel weight loss. Corrosion rate plot against inhibitor concentration for mild steel corrosion in 0.5 M HCl at various temperatures is shown in Fig. 2. An increase in the concentration of extract reduced the corrosion rate while the increase in temperature increased the corrosion rate. Besides, an increase in temperature increased the susceptibility of the

Table 2 Inhibition efficiency (I %) in different concentration of *Gongronema latifolium* leaf methanol extract

Inhibitor concentration of GL (%w/v)	Inhibition efficiency (%)		
	303 K	313 K	323 K
0.1	63.14	59.06	56.75
0.2	69.25	64.57	62.87
0.3	72.49	70.13	68.17
0.4	78.35	76.22	72.51
0.5	81.69	78.74	77.47

metal to corrosion (James et al. 2007). Table 2 showed inhibition efficiency variation against different extract concentration of mild steel in 0.5 M HCl at the various temperatures studied. An increase in extract concentration increased the inhibition efficiency while temperature increase reduced the efficiency of inhibition. Decreased inhibition efficiency at high temperatures was due to the increase in kinetic energy of the extracts, which makes adsorption between the extract and mild steel insufficient at the binding sites (Umoren et al. 2006).

Thermodynamics studies

The temperature effect on the corrosion rate of mild steel in a solution of HCl was studied using the following equation (Odiongenyi et al. 2015)

$$\log \frac{\text{CR}_2}{\text{CR}_1} = \frac{E_a}{2.303R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \qquad (4)$$

CR_1 and CR_2 represents the corrosion rates at T_1 and T_2, respectively, Activation energy was represented with E_a and Molar gas constant was represented with R which is $\left(8.314 \text{ JK}^{-1} \text{ mol}^{-1}\right)$

The heat of adsorption was determined using the equation (Ebenso et al. 2008).

$$Q_{ads} = 2.303R\left[\log\left(\frac{\theta_2}{1-\theta_2}\right) - \log\left(\frac{\theta_1}{1-\theta_1}\right)\right]\frac{T_1 \times T_2}{T_2 - T_1} \qquad (5)$$

Table 3 shows the results of E_a and ΔQ_{ads} at various inhibitor concentrations. Activation energy results showed that the inhibited system values were greater than the uninhibited

Table 3 Thermodynamics adsorption parameters of *Gongronema latifolium* methanol extract

Concentration of inhibition (%w/v)	E_a (kJ/mol)	Q_{ads} (KJ/mol)
Control	17.34	–
0.1	51.32	– 13.26
0.2	61.57	– 14.29
0.3	54.67	– 11.62
0.4	56.77	– 8.92
0.5	76.19	– 15.31

system. E_a values lower than 80 kJ/mol is consistent with physisorption, while E_a values greater than 80 kJ/mol followed chemisorption (Ebenso et al. 2010). The obtained results showed that the adsorption followed the physical adsorption mechanism. Negative values of ΔQ_{ads} showed that the reaction was exothermic (Rao and Khan 2017; Ribas et al. 2020).

Adsorption considerations

The extent of surface coverage evaluations was utilized for the determination of Freundlich, Langmuir, and El-Awardy isotherms. Langmuir adsorption isotherm is expressed using the relationship (Bilgic and Caliskan 2001).

$$C/\theta = C + 1/K \qquad (6)$$

Taking the log of both sides of the equation yields Eq. 7

$$\text{Log } C/\theta = \log C - \log K \qquad (7)$$

where the concentration of the inhibitor is represented as C, the degree of surface coverage is θ is and the equilibrium constant of adsorption is represented as K. The graph of log C/θ against log C in Fig. 3 gave linear plots and a good correlation coefficient indicated strong support to Langmuir isotherm. Langmuir isotherm parameters are shown in Table 4. The slopes obtained are close to 1 which showed that the extract adsorption on the metal was monolayer adsorption and that no interaction existed between extract and mild steel (Ashassi-Sorkhabi et al. 2004; Ebenso et al. 2008; Dawodu et al. 2020; Kamga 2019).

Freundlich adsorption isotherm of *Gongronema latifolium* extracts on mild steel surface was given by Eqs. 8 (Adejo et al. 2013).

Fig. 3 Adsorption of Langmuir isotherm plot of *Gongronema latifolium* on the surface of mild steel at different temperatures
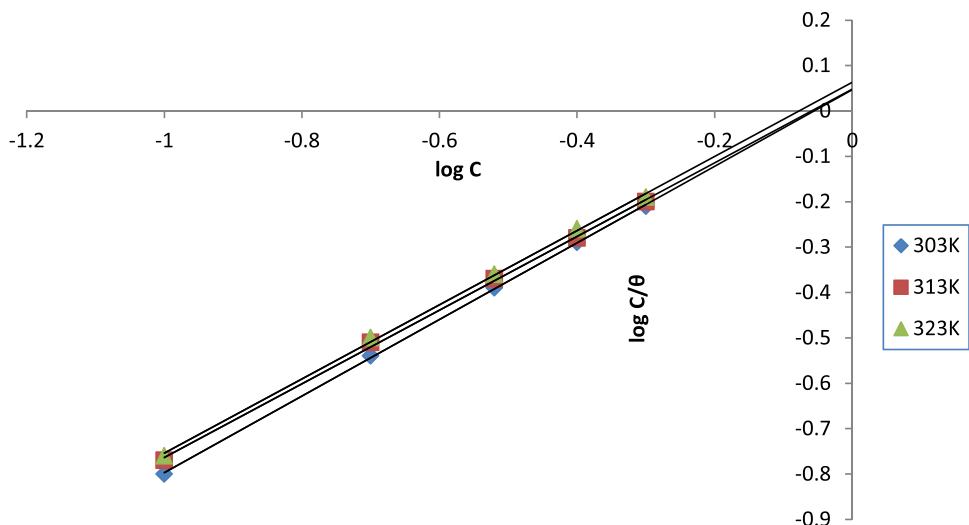
Table 4 *Gongronema latifolium* adsorption parameters on the mild steel surface

Isotherm	Temp (°C)	K_{ads}	ΔG_{ads} (kJ/mol)	R^2
Langmuir	30	0.90	−9.85	0.9998
	40	0.90	−10.18	0.9990
	50	0.86	−10.38	0.9990
Freundlich	30	89.13	−21.43	0.9783
	40	89.64	−22.16	0.9603
	50	87.00	−22.78	0.9840
El-Awardy	30	5.84	−14.57	0.9182
	40	5.28	−14.78	0.9108
	50	4.60	−14.89	0.9583

$$\frac{x}{m} = kc^{1/n} \tag{8}$$

Taking again the logarithm of both sides of the equation yields Eq. 9:

$$\log \frac{x}{m} = \log K + \frac{1}{n} \log C \tag{9}$$

$\frac{x}{m}$ represents the inhibitor efficiency, n and k are constant. $\frac{1}{n}$ represents the slope and $\log K$ represents the intercept. Freundlich adsorption isotherm parameters were established by plotting log inhibition efficiency (I.E %) versus log C in Fig. 4 which gives a straight line graph produced that followed Freundlich adsorption (Adejo et al. 2012). The parameters of Freundlich adsorption isotherm are presented in Table 4. R^2 values are close to 1, which followed Freundlich adsorption.

El-Awardy isotherm, which can be written as (Shukla and Ebenso 2011; Adejo et al. 2013).

$$\log \left(\frac{\theta}{1 - \theta} \right) = \log k + y \log C \tag{10}$$

where C is the inhibitor concentration, θ represents the surface coverage degree, the equilibrium constant is denoted as K and y is the number of molecules in a given site. El-Awardy adsorption parameters were derived by plotting log $(\theta/1 - \theta)$ against log C in Fig. 5 which produced straight

Fig. 4 Adsorption of Freundlich isotherm plot of *Gongronema latifolium* on the surface of mild steel at different temperatures
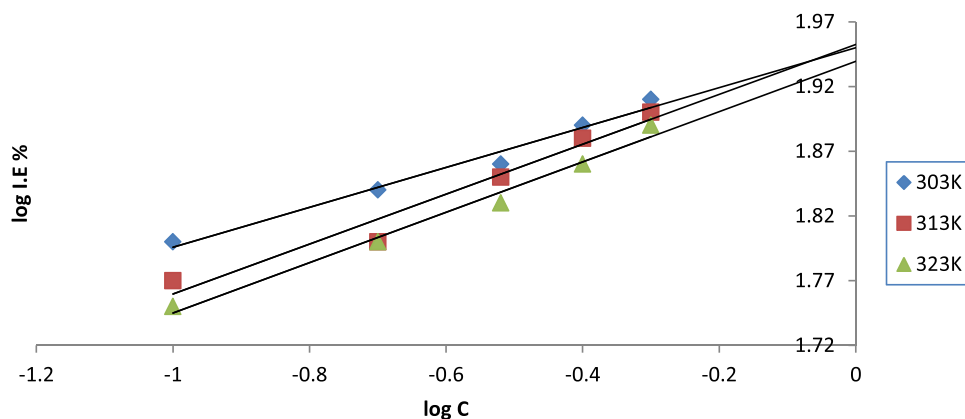
Fig. 5 Adsorption of El-Awardy isotherm of the extract of *Gongronema latifolium* on mild steel surface at different temperatures
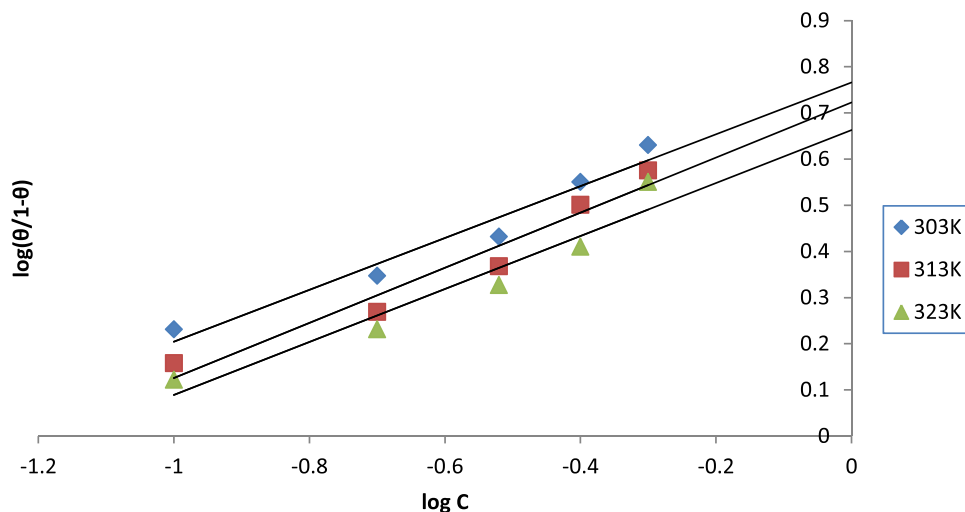
lines with a good correlation coefficient which showed that the experimental data fits the isotherm (Shukla and Ebenso 2011; Adejo et al. 2012). Values of $1/y$ which are above 1 showed the extract indicates that the inhibitor takes more than one active site on the surface of the metal, which implies that more than one water molecule was replaced in the course of the inhibition process (Ebenso et al. 2010).

K_{ads} represents the strength of adsorption between adsorbate and adsorbent. Calculated results of K_{ads} obtained from the plots decreased with temperature rise. It was attributed that at higher temperatures, the adsorbing molecules that interact with the metal surface were weak, which justified the mechanism of physisorption (Odiongenyi et al. 2015).

$$= -2.303RT \ \log(55.5 \ K) \tag{11}$$

Gas constant was represented with R, the temperature was represented by T, equilibrium constant was represented by K, and 55.5 represents the molar heat of water adsorption. K values from the intercept of Langmuir, Freundlich and El-Awardy models were used to evaluate ΔG_{ads} based on Eq. 11 and the result shown in Table 4. The ΔG_{ads} values for the corrosion inhibition were negative which showed a feasible and spontaneous inhibition process. Also, values of ΔG_{ads} lower than 40 kJ/mol depicts chemisorptions, however, our values obtained were lower which suggested the mechanism of adsorption followed physisorption.

Conclusion

Gongronema latifolium methanol extract was utilized as a green corrosion inhibitor for mild steel in aqueous media. The *Gongronema latifolium* extract was found to be composed of several phytochemical components desirable for efficient corrosion inhibition. The corrosion inhibition efficiency of the plant extract was increased as the inhibitor concentration increased and decreased with temperature increase. The corrosion inhibition efficiency of 56.75–81.69% was obtained for the plant extract for the mild steel, which indicated efficient potentials of the methanolic plant extract. The adsorption of *Gongronema latifolium* extract obeyed the Langmuir adsorption model with $R^2 > 0.99$, though good fits were also observed for the Freundlich and El-Awardy adsorption isotherms. The adsorption thermodynamics of the inhibition process gave activation energies in the range 17.34–76.19 kJ/mol indicating a physical adsorption mechanism of corrosion. The results of this study showed the potential of *Gongronema latifolium* extract as a low-cost green inhibitor of mild steel which could be utilized in industries to prevent corrosion.

Compliance with ethical standards

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