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# Phytochemical Composition and Corrosion Inhibitory Efficiency of *Tinospora cordifolia* and *Senna alata* Plant Extracts on Mild Steel in Acidic Media

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## Abstract

*Tinospora cordifolia* and *Senna alata* are well-known medicinal plants recognized for their extensive antibacterial, antifungal, and therapeutic applications. In addition to their well-established medicinal values they show great promise as eco-friendly corrosion inhibitors. In this study, plant extracts from *Tinospora cordifolia* and *Senna alata* were used as sustainable inhibitors to prevent the corrosion of mild steel in acidic environments. Plant extracts were prepared using the Soxhlet extraction technique with water, hexane, and methanol as solvents. Qualitative phytochemical analysis revealed the presence of alkaloids, glycosides, coumarins, and terpenoids, which are known for their anticorrosive properties. The efficacy of the plant extracts as corrosion inhibitors was assessed using the weight loss method in 1 M HCl solution. An anticorrosion study indicated that the methanol extract of *T. cordifolia* attained the highest inhibition efficiency of 93.09%. In comparison, the aqueous extract of *S. alata* exhibited 86.81% efficiency at 1000 ppm concentration. The adsorption studies indicated that the inhibition process followed the Langmuir adsorption isotherm model. This study underscores the potential of adopting natural plant extracts as non-toxic and environmentally friendly corrosion inhibitors for practical industrial application.

**Keywords:** Phytochemicals, anticorrosion, *Tinospora cordifolia*, *Senna alata*, Langmuir adsorption

## Introduction

Metal corrosion is the natural deterioration of metal surfaces, caused by reactions with environmental elements (Bhardwaj et al., 2021; Popoola et al., 2014; Umoren et al., 2019). This process can lead to serious damage to metal components on a significant scale within the industrial machinery and construction sectors, thereby reducing their performance and lifespan (Hoai et al., 2019). Reactive metals naturally tend to revert to their most stable and lowest-energy states through corrosion (Budhathoki et al., 2024), making metals and alloys vulnerable to damage that results in financial losses from repairs, replacements, product degradation, safety hazards, and environmental pollution. As the principal structural material, mild steel is commonly used in several industrial sectors, such as heat exchangers, oil and gas pipelines, cooling towers, and mining machinery, owing to its favorable cost and mechanical performance (Kahyarian & Nesic, 2020). However, the challenge of preventing corrosion of mild steel in aggressive acidic environments remains significant (Maraveas, 2020). A variety of scientific research efforts have been dedicated to improving the corrosion resistance of metals, with corrosion inhibitors emerging as a superior solution compared to alloying elements (Banik et al., 2023), coatings (Kong et al., 2019; Madhan Kumar et al., 2015), heat treatments (Dutta et al., 2015), and plastic deformation (Edalati et al., 2022), because of their cost-effectiveness, minimal manufacturing disruption, and improved control over material loss (Natarajan & Zahir Said Al Shibli, 2021; Raja et al., 2016). Numerous established corrosion inhibitors, such as those based on chromate and synthetic organic compound pose significant toxicity, mutagenicity, and carcinogenic risk to animals and humans.

*T. cordifolia* and *S. alata* (L), two widely used non-controversial herbs in Ayurvedic medicine, contain biologically significant phytochemicals such as lactones, alkaloids, glycosides, steroids, sesquiterpenoids, and diterpenoids, which can also function as effective corrosion inhibitors (Bhardwaj et al., 2021; Haldhar et al., 2023; P. Sharma et al., 2019). These compounds can adhere to metal surfaces, creating a protective coating that acts as a barrier between the metal and the corrosive agents, particularly in acidic environments. The protective layer effectively slows down the rate of corrosion, increasing the durability of metal equipment, such as mild steel and aluminum. An environmentally benign and biodegradable substitute for conventional synthetic inhibitors, which frequently cause health and environmental hazards, is the use of plant-based extracts as corrosion inhibitors. The increasing need for sustainable solutions in industrial environments has prompted the investigation of natural inhibitors, which offer a promising eco-friendly method for corrosion prevention.

Fig 1: *Senna alata* plant

Fig 2: *Tinospora cordifolia* plant

*T. cordifolia*, known as Guduchi in Sanskrit, is a genetically diverse, glabrous, herbaceous vine with heart-shaped leaves, elongated, twisting branches, thin twining stems, and pale yellow flowers that are recognized for their importance in traditional medicine (Saha & Ghosh, 2012). It belongs to the Menispermaceae family and is distributed across India, Sri Lanka, Nepal, Bangladesh, and China, thriving at altitudes of up to 300 m (Sharma et al., 2021). This plant grows on other trees, and its stems, leaves, and roots are valued in Ayurvedic medicine for their immunomodulatory, anti-inflammatory, and antioxidant properties. *S. alata*(L)**,** commonly referred to as Candle Bush, is an ornamental and ethnomedicinal shrub or small tree that can reach heights of 3 - 4 m (Oladeji et al., 2020). It is widely distributed across tropical and humid regions and is recognized for its rapid proliferation and thriving even under challenging climatic conditions (Pradhan et al., 2023). The plant belongs to the *Caesalpinioideae* subfamily within the *Fabaceae* family and has large pinnate leaves. *S. alata* is native to Asia and Africa, known by various local names. Different sections of the plant, such as flowers, leaves, stems, bark, seeds, and roots, are valued for their diverse biological activities, ranging from antifungal to anti-inflammatory properties. Thus, it is a key component of traditional medicine (Alshehri et al., 2022). This study investigated the phytochemical composition of these two plants and evaluated their potential anticorrosion performance to assess their effectiveness in protecting steel equipment from corrosion.

## Materials and Methods

### Sampling and identification of the plant specimens

Plant specimens were procured from the Biratnagar area, and their identification was conducted at the Department of Botany, Mahendra Morang Adarsh Multiple Campus Biratnagar. All reagents utilized in this study were of analytical grade (AR), and double-distilled water was used for solution preparation, as well as for the cleaning and rinsing of glassware. The solvents used for extraction, methanol, and hexane, were obtained from Qualigens and procured from local chemical suppliers in Biratnagar.

### Drying

The stems of the plants were cleaned using tap water and then distilled water to remove dirt and impurities and cut into small pieces using scissors and knives. They were left to dry in shade on the floor above the chart paper for approximately 25 days. The dried stems were crushed and ground into fine powder using an electronic grinder. Afterward, the powdered sample was dried in a laboratory oven at 37°C for two days to eliminate moisture prior to the extraction process (Lazarjani et al., 2021).

### Extraction

Plant extracts were obtained using the Soxhlet extraction method with hexane, water, and methanol as solvents (Fagbemi et al., 2021). Dried plant powder (30 g) was packed in three thimbles prepared using Whatman No. 1 filter paper (Bitwell et al., 2023). All thimbles were placed in a Soxhlet extractor, and extraction was performed using 350 ml of hexane, methanol, and water. The solutions were heated at approximately 35°C,40°C, and 80°C using an electric heater for about 16, 20, and 48 h respectively (Zhang et al., 2018). A small volume of the extract was separated for phytochemical screening, and the remainder was left for drying in the incubator. The dried sample was used to assess the anticorrosion activity of the plant sample.

## Phytochemical Screening

Qualitative phytochemical profiling was conducted for methanol, hexane, and water extracts of plant the samples according to the standard method (Adil et al., 2024; Ahou et al., 2014; Basak et al., 2018; Phuyal et al., 2019). Each test was performed in triplicate to confirm the phytochemical composition of the plant extracts.

## Anticorrosion activity

Gravimetric analysis (weight loss) was adopted to assess the effectiveness of plant extract in preventing corrosion of mild steel (MS) in the HCl solution. A stock solution with a concentration of 1000 ppm was prepared by dissolving the plant extract in 1 M HCl, and this solution was further diluted to 800, 600, 400, and 200 ppm. The MS specimens (2 x 2 cm) were cut from a metal sheet and smoothed to a shiny finish using emery paper with different grits. They were subsequently rinsed with distilled water and acetone, air dried, and stored in a desiccator (Fouda et al., 2024). Their dimensions and weights were determined before they were immersed in a crucible containing 25 ml of test solution at room temperature. Weight loss was calculated by subtracting the original weight MS coupons from their weight after 24 h of immersion. The test was conducted in triplicate, and the average weight loss was applied to compute the rate of corrosion (C.R.), inhibition efficiency ($\eta$), and surface coverage$(\theta)$ using the equations below (Chung et al., 2020). The anticorrosion parameters were calculated using the following formula:

$$\text{Rate of corrosion (C.R.) in}\frac{\text{mm}}{\text{year}} = \frac{\Delta w \times 87600}{\text{Density}(d) \times \text{Area}(A) \times \text{Time}(t)} \qquad (1)$$

Where "Δw" represents weight loss measured in grams after the immersion time (t) in hours, 'd' and ‘A’ represent the density (gm/cm$^3$) and area (cm$^2$) of MS respectively.

$$\text{Efficiency } (\eta) = \frac{W_1 - W_2}{W_1} \times 100\% \qquad (2)$$

$$\text{Surface coverage}(\theta) = 1 - \frac{W_2}{W_1} \qquad (3)$$

Where, $W_1$ and $W_2$ represent the weight loss values of MS with or without the inhibitor, respectively.

## Results and discussion

### Percentage Yield:

The percentage yield indicates the percentage of extract derived from a given weight of plant powder sample. Comparing the amount of extract obtained to the amount of powdered plant sample taken, the percentage yield of *T. cordifolia* was 26.6%, 20.0%, and 17.0%, while *S. alata* yielded 25.4%, 20.0%, and 16.8% in water, methanol, and hexane, respectively, as shown in **Table 1**. These results suggest that water is a promising solvent for the extraction of secondary metabolites from plant samples.

**Table 1**: Percentage yield of both *T. cordifolia* and *S. alata* plants by Soxhlet process

| | **Weight of extract (g)** | | **% yield** | |
|---|---|---|---|---|
| **Quantity in solvent** | *T. cordifolia* | *S. alata* | *T. cordifolia* | *S. alata* |
| 30 grams in 350 ml water | 8.0 g | 7.62 g | 26.6 % | 25.4 % |
| 30 grams in 350 ml methanol | 6.0 g | 6.0 g | 20.0 % | 20.0 % |
| 30 gram in 350 ml hexane | 5.1 g | 5.04 g | 17.0 % | 16.8 % |

## Phytochemical Screening:

All 15 phytochemical tests were applied to detect the presence of phytochemical constituents in three different extracts of *T. cordifolia* and *S. alata*. **Table 2** shows the phytochemical analysis for both plant extracts.

**Table2:** Qualitative Phytochemical screening of *T. cordifolia* and *S. alata*

| **S.N.** | **Phytochemical Test** | ***Tinospora cordifolia*** | | | ***Senna alata*** | | |
|---|---|---|---|---|---|---|---|
| | | Aqueous | Methanol | Hexane | Aqueous | Methanol | Hexane |
| **1.** | Test for alkaloids | | | | | | |
| | a) Wagner's test | + | + | + | + | + | + |
| | b) Mayer's test | + | + | + | + | + | + |
| **2.** | Test for coumarins | + | + | + | - | + | - |
| **3.** | Test for saponin | + | - | - | + | - | - |
| **4.** | Test for tannin | - | - | - | - | - | - |
| **5.** | Test for flavonoids | - | - | - | - | + | + |
| **6.** | Test for cardiac glycoside | + | + | + | + | - | + |
| **7.** | Test for reducing sugar | | | | + | + | + |
| | a) Fehling's test | + | + | + | + | + | + |
| | b) Molisch's test | + | + | + | - | + | - |
| **8.** | Test for Glucoside | + | - | + | - | - | + |
| **9.** | Test for glycoside | + | + | + | - | + | - |
| **10.** | Test for anthraquinone | - | + | - | + | + | - |
| **11.** | Test for emodins | - | - | - | - | - | - |
| **12.** | Test for phlobatannins | - | - | - | + | + | + |
| **13.** | Test for terpenoids | + | + | + | + | - | - |
| **14.** | Test for protein | + | + | + | - | + | + |
| **15.** | Test for steroid | + | + | + | - | + | - |

(+) sign denotes the presence of a constituent in the corresponding screening test, while the (-) sign indicates its absence.

Phytochemical profiling of the plant extracts revealed the presence of several phytochemical constituents, including alkaloids, coumarins, cardiac glycosides, reducing sugars, glycosides, terpenoids, and steroids, in *T. cordifolia*. Glucosides were detected in the methanol and hexane extracts, whereas saponins were exclusively found in the methanol extract. In the case of *S. alata*, alkaloids, reducing sugars, and phlobatannins were present in all the three extracts. Flavonoids and proteins were found in the hexane and methanol extracts, whereas glycosides and steroids were present only in the methanol extract. Saponins were detected only in the aqueous extract of *S. alata*. The presence of various components has been shown to increase the corrosion resistance of mild steel in acidic media (Thomas K et al., 2021).

## Anticorrosion study

The weight loss analysis of the MS specimens was carried out to increase the concentration of the *T. cordifolia* extract (TCE). The corrosion parameters of both *T. cordifolia* extracts are listed in **Table 3**. The corrosion rate of the MS coupons decreased with increasing inhibitor concentration, resulting in higher inhibition efficiency (IE) of the TCE. As the concentration of the extract increased, the fraction of the surface covered by adsorbed molecules also increased. A graphical representation of the rate of corrosion and inhibition effectiveness with respect to the concentration is shown in **Fig. 3** and **4**. At maximum concentration, methanol extracts of *T. cordifolia* showed better inhibition efficiency (93.09 %) than the aqueous extracts (90.79 %). This highest attended IE is in accordance with the IE of 94.73 % in 1 M HCl at 5% TCE concentration, reported by Thomas K et al. (Thomas K et al., 2021).

**Table 3:** Corrosion parameters of methanol and aqueous extract of *T. cordifolia* immersed for 24 h

| Test sample | Concentration (ppm) | Corrosion rate (mm/yr) | Surface coverage (θ) | Inhibition efficiency ( ) (%) |
|---|---|---|---|---|
| **Methanol extract** | 1000 | 0.33 | 0.93 | 93.09 |
| | 800 | 0.44 | 0.90 | 90.79 |
| | 600 | 0.66 | 0.86 | 86.18 |
| | 400 | 1.11 | 0.76 | 76.97 |
| | 200 | 1.33 | 0.72 | 72.37 |
| **Control** | 0 | 4.836 | - | - |
| **Aqueous** | 1000 | 0.44 | 0.90 | 90.79 |

| | | | | |
|---|---|---|---|---|
| **extract** | 800 | 0.55 | 0.88 | 88.48 |
| | 600 | 0.67 | 0.86 | 86.18 |
| | 400 | 0.78 | 0.83 | 83.88 |
| | 200 | 1.11 | 0.76 | 76.97 |
| **Control** | 0 | 4.836 | - | - |

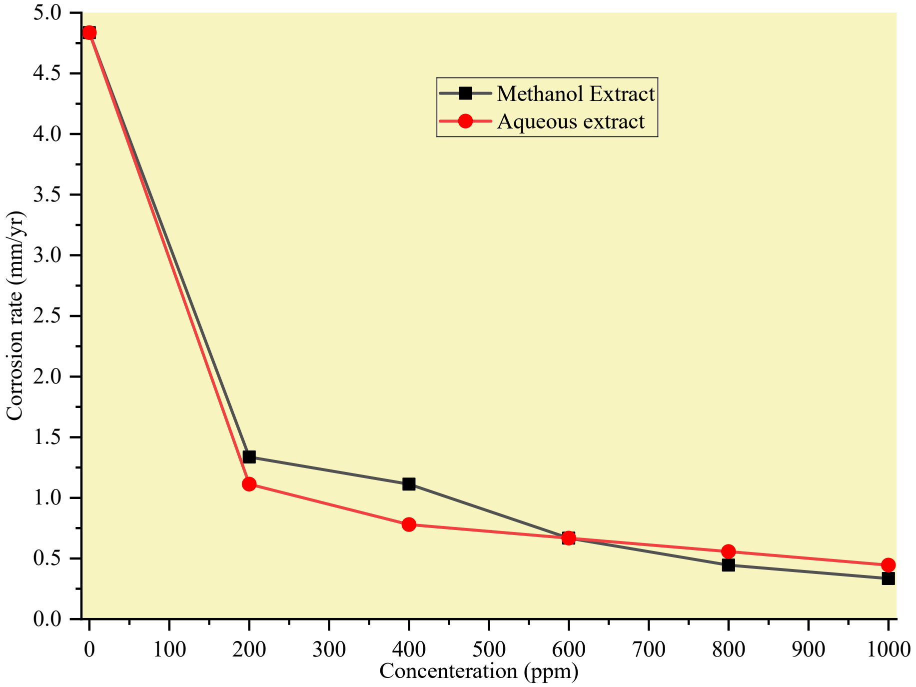

**Fig 3:** Rate of corrosion of MS in different concentrations of *T. cordifolia* extracts immersed for 24 h.

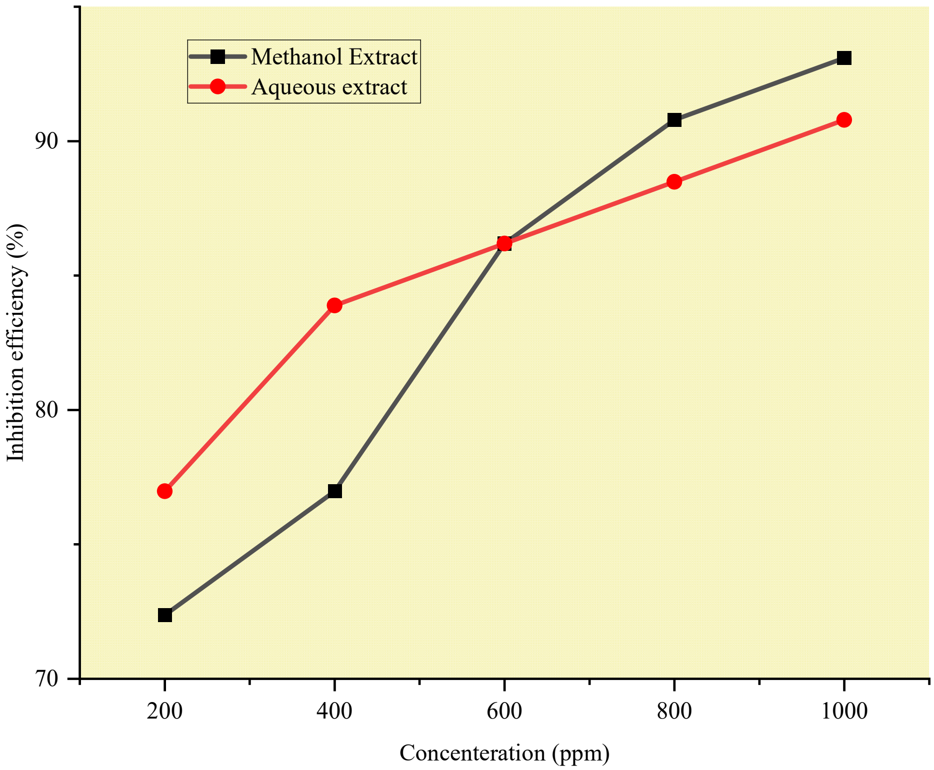

**Fig 4:** Inhibition efficiency of *T. cordifolia* extracts at different concentrations immersed for 24 h.

The corrosion rates of MS evaluated with and without the presence of *S. alata* extract (SAE) and the inhibition efficiencies at different concentrations of SAE are presented in **Table 4**. Similar results were observed with the SAE, showing that the rate of corrosion of MS decreased, while the inhibition efficiency increased as the concentration of SAE increased. The aqueous *S. alata* extract achieved the highest IE of 85.81 % compared to the methanol extract at maximum concentration. The graphical representation of corrosion rate and IE with varying concentrations of SAE is shown in **Fig. 5** and **Fig. 6**. These results indicate that both plant extracts reduced corrosion due to acidic exposure in mild steel compared to the control solution. The anticorrosion activity varied significantly among the different extracts owing to differences in their phytochemical compositions. The enhanced performance of the methanol extract may be attributed to its ability to dissolve specific bioactive compounds, which adhere more effectively to the steel surface. Similarly, the effectiveness of the *S. alata* extracts varied; the aqueous extract was the most effective, likely because it contains many polar phytochemicals that bond well to the steel surface. These findings are consistent with the Langmuir adsorption isotherm, which suggests that the manner in which these compounds interact with the surface affects their adsorption efficiency.

**Table 4:** Corrosion parameters of methanol and aqueous extract of *S. alata* immersed for 24 h

| Test sample | Concentration (ppm) | Corrosion rate (mm/yr) | Surface coverage (θ) | Inhibition efficiency ( )(%) |
|---|---|---|---|---|
| **Methanol extract** | 1000 | 0.957 | 0.80 | 80.20 |
| | 800 | 1.068 | 0.77 | 77.89 |
| | 600 | 1.447 | 0.69 | 70.07 |
| | 400 | 2.783 | 0.41 | 42.44 |
| | 200 | 3.340 | 0.3 | 30.93 |
| **Control** | 0 | 4.836 | - | - |
| **Aqueous extract** | 1000 | 0.638 | 0.864 | 86.81 |
| | 800 | 1.364 | 0.720 | 71.80 |
| | 600 | 2.189 | 0.472 | 54.74 |
| | 400 | 2.761 | 0.410 | 42.91 |
| | 200 | 3.030 | 0.356 | 37.35 |
| **Control** | 0 | 4.836 | - | - |

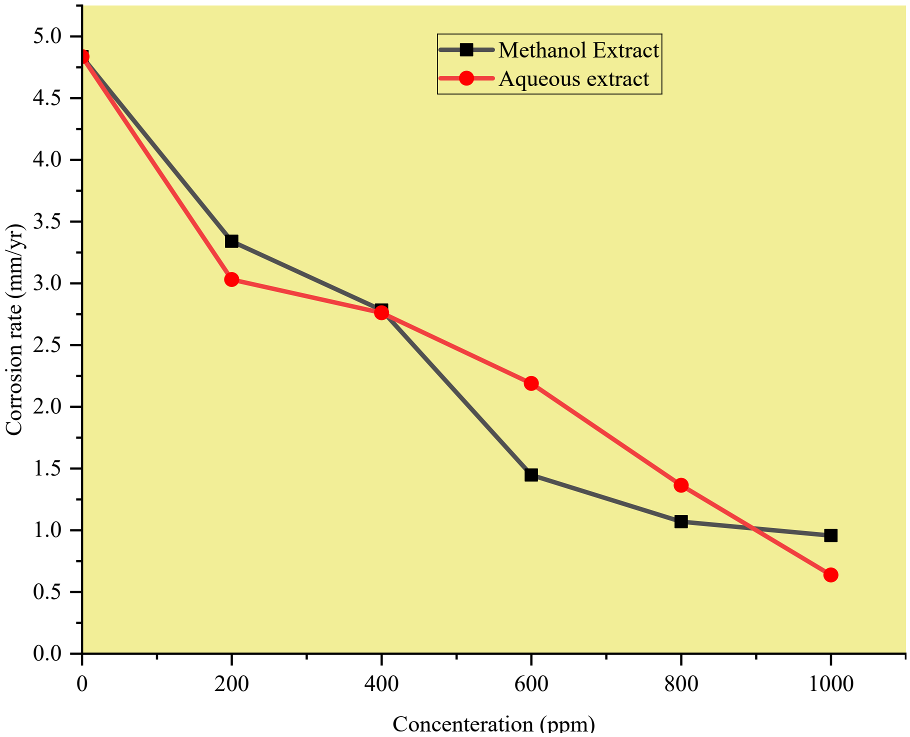

**Fig 5:** Rate of corrosion of MS in different concentrations of *S. alata* extracts immersed for 24 h.

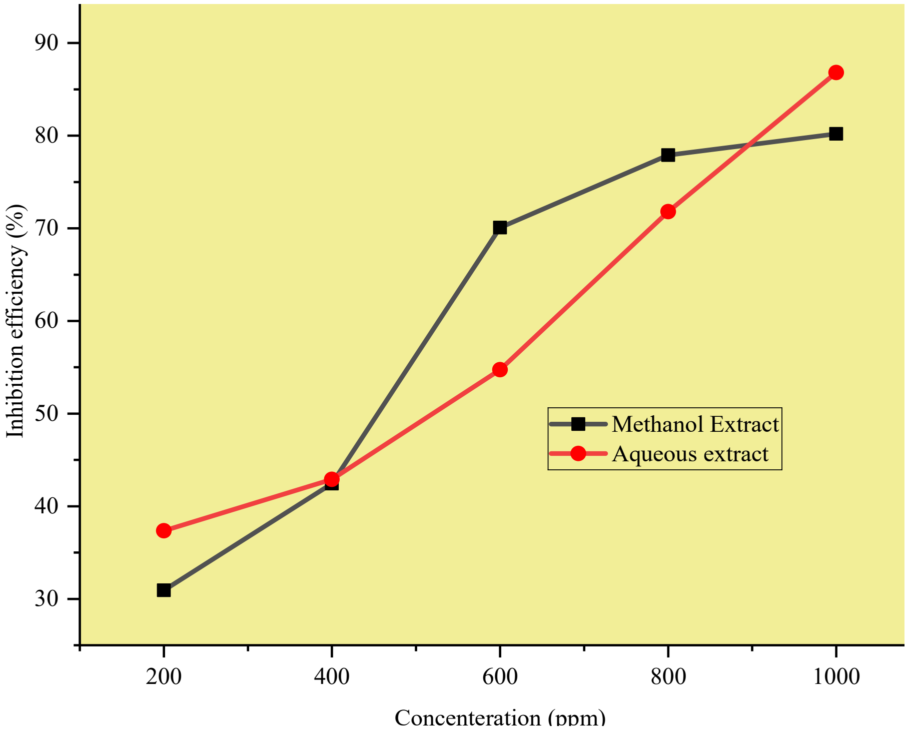

**Fig 6:** Inhibition efficiency of *S. alata* extracts at different concentrations immersed for 24 h.

### Adsorption isotherm study

The influence of the inhibitor on the rate of corrosion is associated with the adsorption of its molecules on the metal substrate. The mechanism of adsorption involves blocking the release of hydrogen ions ($H^+$) and the dissolution of metal ions by the plant extract. Additionally, plant extract contain polar groups such as organic nitrogen (N), sulphur (S), and hydroxyl (OH) groups, which can bond with the metal surface (Iloamaeke et al., 2015). This bonding helps to prevent further corrosion. A graph plotted between $\frac{C}{\theta}$ and the different concentration of plant extract (C) was best fitted to the Langmuir adsorption isotherm to illustrate the behavior of inhibitor adherence on MS. The Langmuir isotherm is represented by equation (Tran et al., 2021).

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

Where C is the inhibitor concentration in g/L and $K_{ads}$is an adsorption equilibrium constant.

The obtained plots in **Fig. 7** and **Fig. 8** are linear, and the intercept of the plot permits the calculation of the $K_{ads}$. The values of $K_{ads}$ obtained from the intercept of the linear plot were applied to evaluate the free energy of adsorption ($\Delta G^0$) (Bidi et al., 2020; Umoren et al., 2016).

$$\Delta G^0 = -RT\ln(1000K_{ads})$$

Where R represents the universal gas constant, T denotes absolute temperature respectively, and 1000 is the concentration of water molecules in g/L.

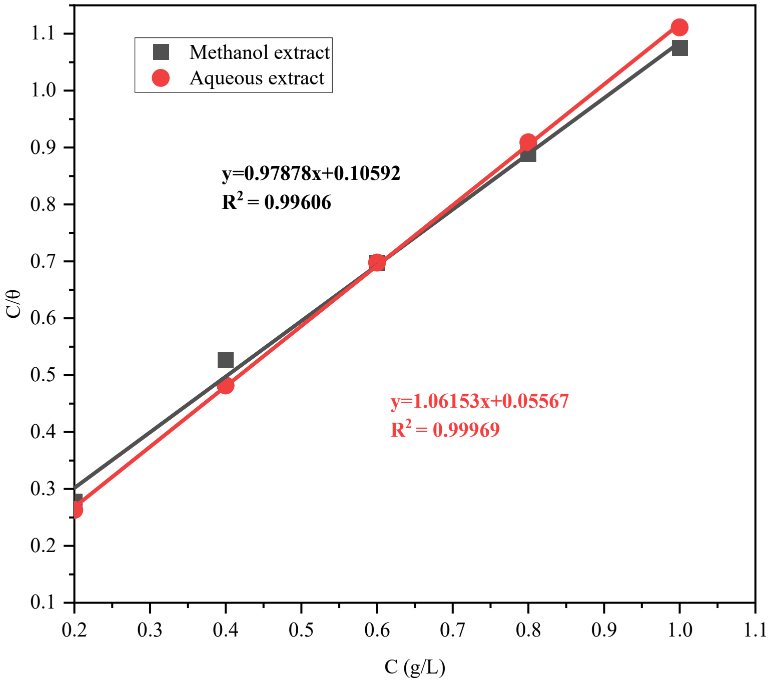

**Fig 7:** Langmuir adsorption isotherm plot with different concentrations of methanol and aqueous extract of *T. Cordifolia*

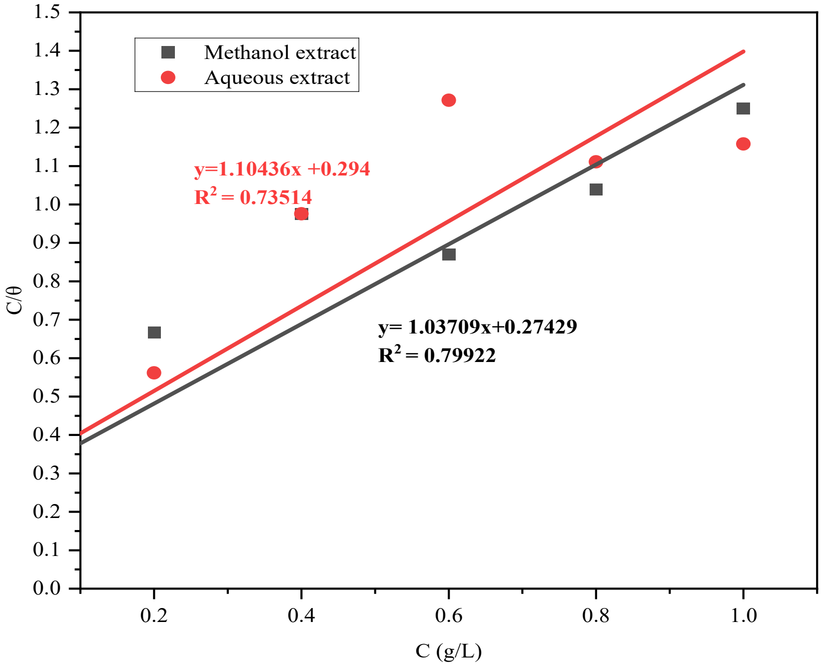

**Fig 8:** Langmuir adsorption isotherm plot with different concentrations of Methanol and aqueous extract of *S. alata*

The ΔG° values were found to be -17.167 kJ/mol and -16.96 kJ/mol for methanol and aqueous extracts of *T. cordifolia* respectively. Similarly, the ΔG° for methanol and aqueous extracts of *S. alata* was calculated to be -16.85kJ/mol and -17.024 kJ/mol respectively. All negative free energy values suggest that adsorption on the steel surfaces is both spontaneous and sustained. Here, the values of ΔG° indicate the adsorption of methanol and aqueous extracts of both plant inhibitors on MS in 1M HCl through a physisorption process (Darweesh et al., 2022).

## Conclusion

In this study, the phytochemical constituents and anticorrosion activity of *T. cordifolia* and *S. alata* plant extracts were investigated using methanol, hexane, and aqueous solvents. Phytochemical analysis of the plant extracts indicated the presence of alkaloids, cardiac glycosides, steroids, reducing sugars, and several other bioactive compounds, with variation depending on the solvent used. The ability of the plant extracts to inhibit corrosion was tested on MS specimens in 1 M HCl solution using the gravimetric method. These findings demonstrated that the plant extracts, especially *T. cordifolia*, showed significant anticorrosion activity. Among the tested extracts, the methanolic extract of *T. cordifolia* exhibited the highest IE of 93.09%, whereas the aqueous extract showed an IE of 90.79 % at 1000 ppm. Similarly, *S. alata* extracts showed promising results, with the highest IE (86.81%) achieved by the aqueous extract at 1000 ppm. The Langmuir adsorption isotherm confirmed that the adsorption of the plant extracts onto the mild steel surface followed typical physical adsorption behaviour. Overall, this study highlighted the potential of these plant extracts as environmentally friendly and efficient corrosion inhibitors for MS under acidic conditions. The variation in IE among extracts and concentrations underscores the importance of further research to optimize the use of these natural inhibitors in industrial applications.

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