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A Comparative Investigation of *Terminalia* genus Extracts as a Green Corrosion Inhibitor for Mild Steel in 1N HCl acid Media

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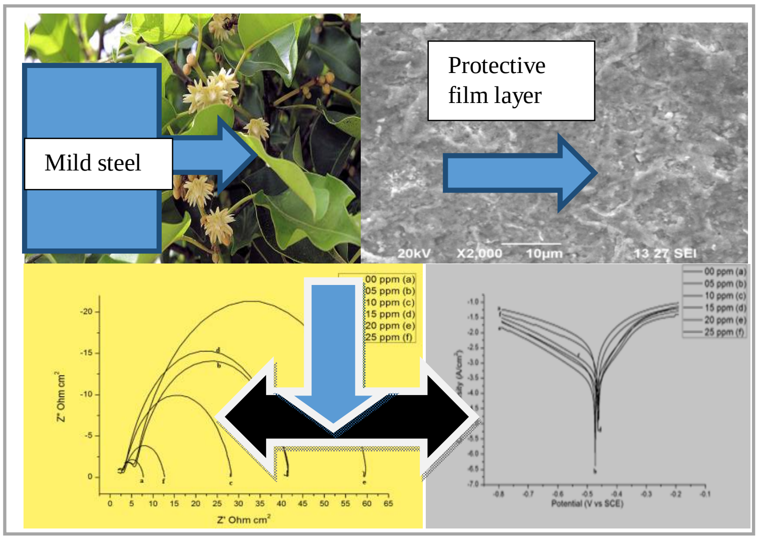
ABSTRACT

Using the weight-loss method, potentiodynamic polarization, and electrochemical impedance spectroscopy techniques, the inhibitory impact of various components of the plant Terminalia genus (TG) extract (leaves, fruits, stems, seeds) on mild steel corrosion in 1 N HCl medium was examined. The plant extract acts as a mixed-type inhibitor, according to polarization experiments. The inhibitory efficiency of Terminalia genus extracts increases in a concentration-dependent way, according to the weight-loss method, which was also corroborated by the findings of electrochemical methods. In comparison, Terminalia genus leaf extracts had the highest inhibitory efficacy, with 98.50 percent at 20 ppm concentration. The remarkable performance of the plant extract's inhibitive activity was validated by the SEM morphology of the adsorbed protective coating on the mild steel surface. Surface coverage levels were graphed to see if they were acceptable for adsorption. Temperature experiments found that when the temperature rises, the inhibitory efficacy decreases, implying a physisorption process.

Graphical Abstract



Keywords: Mild steel, Corrosion test, EIS, SEM.

INTRODUCTION

The degradation of metal caused by chemical assault or reactivity with the environment is known as corrosion. It's a never-ending problem that's tough to entirely eradicate. Complete eradication would be impractical and impossible. Prevention would be more practical and doable. Following the disruption of the protective barrier, corrosion occurs quickly and is accompanied by a series of reactions that alter the composition and properties of both the metal surface and the surrounding environment, such as the formation of oxides, metal cation diffusion into the matrix, local pH change, and electrochemical potential. Mild steel corrodes rapidly in acidic environments and during the pickling process. Pickling, descaling, and chemical cleaning of mild steel are all done using hydrochloric acid. In general, organic compounds with O, N, and S atoms are utilized as inhibitors to prevent the mild steel from corroding in hydrochloric acid [**1**]. Several researchers have been drawn to environmentally friendly inhibitors. Metal corrosion management is important for technical, economic, environmental, and aesthetic reasons. Inhibitors are one of the easiest ways to prevent metals and alloys from corrosion, especially in acidic environments. A corrosion inhibitor is a material that, when applied in tiny amounts to an environment, effectively slows the pace at which a metal exposed to it corrodes. To assess their corrosion inhibition capability, a large variety of organic compounds has been examined and is continuously being studied. However, most of these compounds are not only costly but also pose health and environmental risks, necessitating the search for alternatives. Plant extracts are thought to be an extraordinarily rich source of corrosion inhibitors that are also ecologically friendly. Many natural compounds have been employed as corrosion inhibitors for various metals in a variety of situations [**2-15**]. Plants have also been identified as a source of naturally occurring molecules known as "green" compounds, some of which have a highly complicated molecular structure and a wide range of physical, chemical, and biological characteristics. Several of these chemicals are already being used in traditional applications including medicines and biofuels. Furthermore, natural and medicinal plants are increasingly being employed as corrosion inhibitors since they are an environmentally friendly, widely available, and renewable source of a wide range of chemicals. The extract of several common plant based chemicals and their by-products have been tested as a metal inhibitor in many environments due to their biodegradability, eco-friendliness, cheap cost, and easy availability. The *Terminalia* genus (TG) is a ubiquitous plant with therapeutic properties. Many medicinal plant extracts have recently been shown to be good corrosion inhibitors (*Allium sativum* and *Madhuca longifolia*). Mimusaps Elangi plants have medicinal properties due to phytochemical compounds that have a specific physiological impact on the human body [**16**]. In this study, similar medicinal plants (TG) but diverse components like leaves, seeds, barks, and fruits have been selected to explore the inhibitory impact on the corrosion of mild steel in a 1N HCl environment.

MATERIALS AND METHODS

Preparation of mild steel specimen: Mild steel strips were mechanically cut into strips of size 4 cm x 2 cm x 0.1cm containing the composition of C- 0.030 %, Mn- 0.169 %, Si- 0.015 %, P- 0.031 %, S - 0.029 %, Cr- 0.029 %, Ni- 0.030 %, Mb- 0.016 %, Cu- 0.017 % and the remainder Fe and provided with a hole of uniform diameter to facilitate suspension of the strips in the test solution for weight loss method. Mild steel strips with the same composition but a $1cm^2$ exposed area were employed for electrochemical experiments. Mild steel strips were polished with 400, 600, 800, 1000 and 1200 grit emery paper, then degreased with acetone, rinsed with deionized water, and dried for 5 minutes in a desiccator. Four digital electronic analytical balances were used to accurately weigh the metal (Shimadzu ay220 model).

Preparation of the plant extract: The leaves, barks, fruits, and seeds of the *Terminalia* genus of medicinal plants were chopped into small pieces, dried at room temperature, and pulverized into powder. 50 g of powder from each was refluxed in 500 mL of distilled water overnight. The refluxed solution was then meticulously filtered, and the filtrate volume was increased to 250 mL using double distilled water as the stock solution, with the stock solution's concentration stated in terms of ppm [17].

Weight loss method: Glass hooks and rods were used to immerse mild steel specimens in 200 mL of 1N HCl solution without and with varied doses of inhibitors for predefined time duration (24 h) at room temperature. A four-digit electronic analytical balance was used to determine the weights of the specimens before and after immersion (shimadzu ay 220 model). The corrosion rate was computed using the following relationship based on the weight loss observations.

$$\text{CR (mmpy)} = \frac{\mathbf{K} \text{ x Weight Loss}}{\text{D x A x t (in hours)}} \qquad \text{... (1)}$$

Where K = 8.76 x 10^4 (constant), D is density in gm/cm^3 (7.86), W is weight loss in grams and A is area in cm^2.

The inhibition efficiency (%) was calculated using equation (2)

$$\text{IE \%} = \frac{W_0 - W_i}{W_0} \text{x100} \qquad \text{...(2)}$$

Where, W_0 and W_i are the weight loss in the absence and presence of the inhibitor respectively.

Potentiodynamic polarization methods: The materials were measured for potentiodynamic polarization using a CHI660E electrochemical analyzer. Measurements of polarization were taken to determine the corrosion current and potential from the Tafel slope. Experiments were conducted in a three-electrode cell assembly with a mild steel specimen of 1cm^2 area exposed and the remainder coated with red lacquer as working electrode, a rectangle Pt foil as the counter electrode, and a saturated calomel electrode as a standard reference electrode. Each experiment was given a 15-min time period to reach the steady-state open-circuit voltage. The polarization was swept at a rate of 1 mV per second from a cathodic potential of -800 mV (vs SCE) to an anodic potential of -200 mV (vs SCE). Tafel slopes, corrosion potential, and corrosion current were computed using the polarization curves. The inhibitor efficiency was calculated using the formula:

$$\text{IE \%} = \frac{I_{Corr} - I_{*Corr}}{I_{Corr}} \text{x 100} \qquad \text{...(3)}$$

Where I_{corr} and I_{*corr} are corrosion currents in the absence and presence of inhibitors.

Electrochemical impedance method: The CHI660E electrochemical analyzer was also used to assess the samples' electrochemical AC-Impedance. Experiments were conducted in a three-electrode cell assembly similar to that utilized in potentiodynamic polarization investigations. On the steady-state open circuit potential, a sine wave with a 10mV amplitude was superimposed. At frequencies ranging from 100 KHz to 10 MHz, the real component (Z') and imaginary part (Z") were measured. A graph of Z' vs. Z" was created. The charge transfer resistance (R_{ct}) was determined from the plot, and the double-layer capacitance (C_{dl}) was derived using the formula:

$$C_{dl} = \frac{1}{2\pi} f_{max} R_{ct} \qquad \text{...(4)}$$

Where R_{ct} is charge transfer resistance, and C_{dl} is double-layer capacitance. The experiments were carried out in the absence and presence of different concentrations of inhibitors.

$$\text{IE\%} = \frac{R_{ct} - R_{ct}^0}{R_{ct}} \text{x 100} \qquad \text{... (5)}$$

Where R_{ct} and R^0_{ct} are the charge transfer resistance values in the inhibited and uninhibited solution respectively.

Scanning electron microscopy: The mild steel specimen was removed after one day of immersion in the blank and inhibitor solutions, cleaned with double distilled water, dried, and examined under a scanning electron microscope for surface morphology. A computer-controlled scanning electron microscope (JEOL) was used to analyze the surface morphology of mild steel.

RESULTS AND DISCUSSION

Weight loss method: The weight loss experiments were carried out in 1N HCl acid with and without various concentrations of plant extract ranging from 5 to 20 ppm. The corrosion rate and inhibitory efficiency have been estimated using the weight loss data, and the results are shown in table 1. The weight loss of mild steel reduced, the corrosion rate dropped, and the inhibition efficiency rose when the plant extract was added to 1N HCl acid, as shown in the table 1. For a one-day immersion period, the optimum concentration for *Terminalia* genus leaves was found to be 20 ppm with a maximum inhibition efficiency of 98.50 percent, barks at ppm with a maximum inhibition efficiency of 97.34 percent, fruits at 20 ppm with a maximum inhibition efficiency of 92.18 percent, and seeds at 20 ppm with a maximum inhibition efficiency of 98.32 percent. This finding suggested that the plant extract may be used to prevent mild steel corrosion in 1N HCl. *Terminalia* genus leaves > seeds > barks > fruits were shown to have the highest inhibitory efficacy in 1 N HCl among extracts from the same plant but various portions of the plant.

Table 1. Percentage of inhibition efficiency (IE %) and corrosion rate (CR) at different concentrations of inhibitor in 1N HCl medium

Parts of *Terminalia* genus plant	Conc.of the extract (ppm)	Weight loss (g)	Corrosion rate (mmpy)	Inhibition efficiency (%)
	Blank	0.1107	64.258	-
Terminalia genus leaves	5	0.0102	0.986	80.58
	10	0.0087	0.875	86.80
	15	0.0067	0.754	89.04
	20	0.0020	0.638	98.50
Terminalia genus barks	5	0.0066	4.817	80.70
	10	0.0047	2.318	88.18
	15	0.0035	2.031	93.72
	20	0.0022	0.116	97.34
Terminalia genus fruits	5	0.0083	4.817	65.20
	10	0.0040	2.321	72.84
	15	0.0025	1.290	86.37
	20	0.0012	0.934	97.17
Terminalia genus seeds	5	0.0120	6.965	81.01
	10	0.0110	3.385	90.24
	15	0.0089	1.992	94.56
	20	0.0003	0.170	98.32

Potentiodynamic polarization studies: The potentiodynamic polarization curves of mild steel in 1N HCl acid medium without and with different concentrations of TG extracts are shown in figure 1. Table 2 lists electrochemical data such as corrosion potential (E_{corr}), current density (I_{corr}), cathodic Tafel slope (b_c), anodic Tafel slope (b_a), and % inhibition efficiency based on polarisation tests. The corrosion current density (I_{corr}) decreases as the concentration of inhibitors increases, as seen in the table. The inclusion of the plant extract resulted in a significant drop in corrosion current density (I_{corr}) and a change in the corrosion potential to less negative values, according to the polarization experiments. Furthermore, the anodic and cathodic Tafel slope values are somewhat different, indicating that this behavior represents the plant extract's potential to prevent mild steel corrosion in 1N HCl solution by adsorbing its molecule on both anodic and cathodic sites. The greatest inhibitory efficiency of 98.23 percent was recorded for Terminalia genus seeds extract at 15 ppm, 95.74 percent for leaves at 15 ppm, 95.57 percent for bark at 20 ppm, and 91.10 percent for fruits at 15 ppm when the plant extract concentration was raised from 5 to 20 ppm. The anodic and cathodic curves in the presence of TG extracts revealed lower current density than those obtained in the solution without TG extracts, as shown in Fig.1. This suggests that TG extracts help to prevent rusting. In the acid media, the corrosion current density values for the green inhibitor reduced significantly. The change in corrosion potential (E_{corr}) values for TG plant extract, on the other hand, is not significant. If the corrosion potential shift in the presence of the inhibitor was greater than 85 mV compared to the absence of the inhibitor, the inhibitor was classed as cathodic or anodic [18-20]. The charges of E_{corr} for the examined plants extract are less than 85 mV, indicating that TG extracts operate as a mixed type inhibitor for mild steel corrosion in 1N HCl medium [21-31].

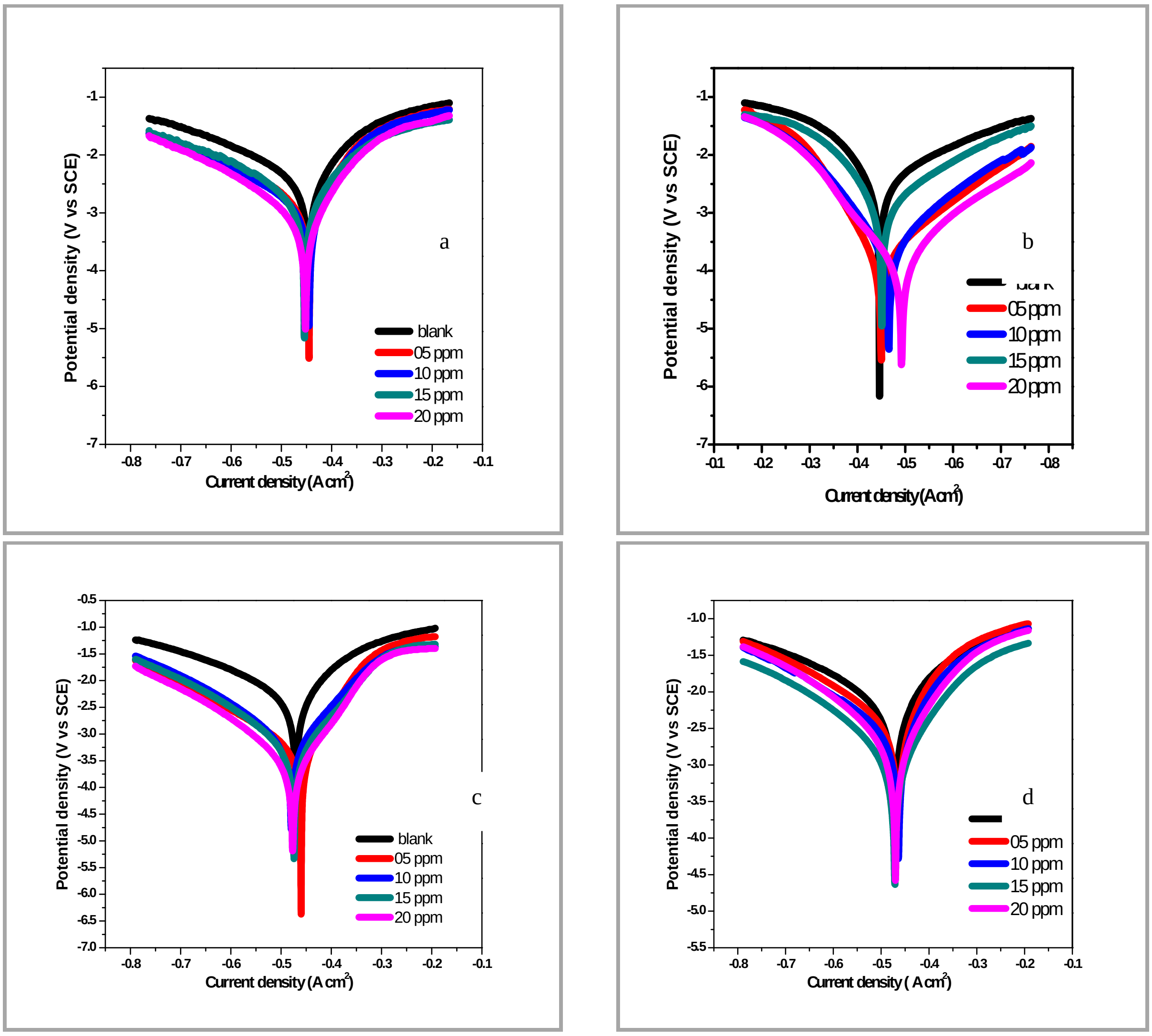


Figure 1. Potentiodynamic polarization (Tafel) curves for mild steel in 1N HCl solution in the absence and presence of different concentration of *TG* extracts of (a) leaves (b) barks (c) fruits (d) seeds.

Electrochemical impedance studies: The characterization of electrode behavior in 1N HCl solution without and with the addition of plant extracts was also studied using electrochemical impedance spectroscopy. Figure 2 displays Nyquist plots of leaves, fruits, barks, and seeds from *Terminalia* genus plants at different concentrations (5–20 ppm). Table 3 shows the parameters derived from the Nyquist diagram fit for 1N HCl medium containing varying concentrations of *Terminalia* genus. The Nyquist plots in the figure have a nearly semicircular form, showing that the charge-

Table 2. Electrochemical parameters from polarization measurement and calculated valuesof inhibition efficiency.

Parts of *Terminalia* genus plant	Conc. (ppm)	E_{corr}/ (mV/ SCE)	I_{corr}/ (mA/cm^2)	b_c (mV/dec.)	b_a (mV/dec.)	IE (%)
Terminalia genus leaves	Blank	-0.446	$3.781x10^{-3}$	203.95	132.52	*
	5	-0.445	$1.469x10^{-3}$	197.55	104.54	61.14
	10	-0.445	$1.255x10^{-3}$	192.49	101.64	66.80
	15	-0.454	$1.609x10^{-3}$	184.84	124.28	95.74
	20	-0.452	$6.914x10^{-4}$	159.97	097.62	81.71
Terminalia genus bark	Blank	-0.471	$5.220x10^{-3}$	199.01	140.52	*
	5	-0.460	$4.524x10^{-4}$	174.71	070.51	91.33
	10	-0.479	$6.154x10^{-4}$	146.57	094.24	88.21
	15	-0.474	$4.642x10^{-4}$	145.47	091.02	91.10
	20	-0.477	$2.308x10^{-4}$	136.70	074.16	95.57
Terminalia genus fruits	Blank	-0.466	$3.785x10^{-3}$	203.95	132.52	*
	5	-0.450	$1.061x10^{-3}$	147.32	073.13	71.96
	10	-0.466	$7.255x10^{-4}$	133.36	091.72	80.83
	15	-0.464	$3.236x10^{-4}$	137.74	075.71	91.45
	20	-0.492	$6.071x10^{-4}$	133.29	102.65	83.96
Terminalia genus seeds	Blank	-0.472	$6.488x10^{-3}$	208.25	168.62	*
	5	-0.464	$4.022x10^{-3}$	205.53	132.84	38.01
	10	-0.464	$2.819x10^{-3}$	199.36	126.98	56.58
	15	-0.472	$1.145x10^{-5}$	168.30	111.51	98.23
	20	-0.470	$1.735x10^{-3}$	166.61	111.27	97.32

transfer mechanism is primarily responsible for mild steel corrosion [32-36]. The frequency dispersion of interfacial impedance is typically used to describe deviations from ideal circular forms.

Table 3. Impedance parameter for mild steel in 1 N HCl acid solution in the absence and presence of varied concentration of inhibitor

Parts of *Terminalia* genus plant	Concentraion (ppm)	R_{ct} ($ohm\ cm^2$)	C_{dl} ($\mu F/cm^2$)	IE (%)
Terminalia genus leaves	Blank	7.642	$6.763x10^{-3}$	*
	5	21.239	$9.549x10^{-4}$	64.06
	10	22.006	$8.723x10^{-4}$	65.27
	15	15.465	$1.241x10^{-3}$	50.58
	20	31.034	$4.487x10^{-4}$	75.53
Terminalia genus barks	Blank	6.384	$1.162x10^{-3}$	*
	5	36.672	$3.183x10^{-4}$	82.59
	10	31.751	$4.246x10^{-4}$	79.89
	15	42.888	$2.358x10^{-4}$	85.11
	20	72.732	$8.604x10^{-5}$	91.22
Terminalia genus *fruits*	Blank	7.469	$6.835x10^{-3}$	*
	5	111.248	$3.481x10^{-5}$	93.28
	10	82.984	$6.332x10^{-5}$	90.99
	15	203.45	$1.026x10^{-5}$	96.32
	20	166.375	$1.621x10^{-5}$	95.51
Terminalia genus seeds	Blank	4.670	$2.148x10^{-2}$	*
	5	8.557	$6.276x10^{-3}$	45.43
	10	10.060	$4.140x10^{-3}$	53.57
	15	28.959	$6.961x10^{-4}$	83.87
	20	14.375	$2.194x10^{-3}$	67.54

This strange occurrence might be due to electrode surface inhomogeneity caused by surface roughness or interfacial phenomena. In fact, in the presence of plant extracts, charge transfer resistance (R_{ct}) values increased while double-layer capacitance (C_{dl}) values decreased to their lowest levels. The drop in C_{dl} indicated that the inhibitor is adsorbing to the metal surface in an acidic solution. The irregular value of C_{dl} at the inhibitor concentration was not defined, according to impedance experiments. The findings of weight loss and electrochemical approaches were found to be in good agreement.

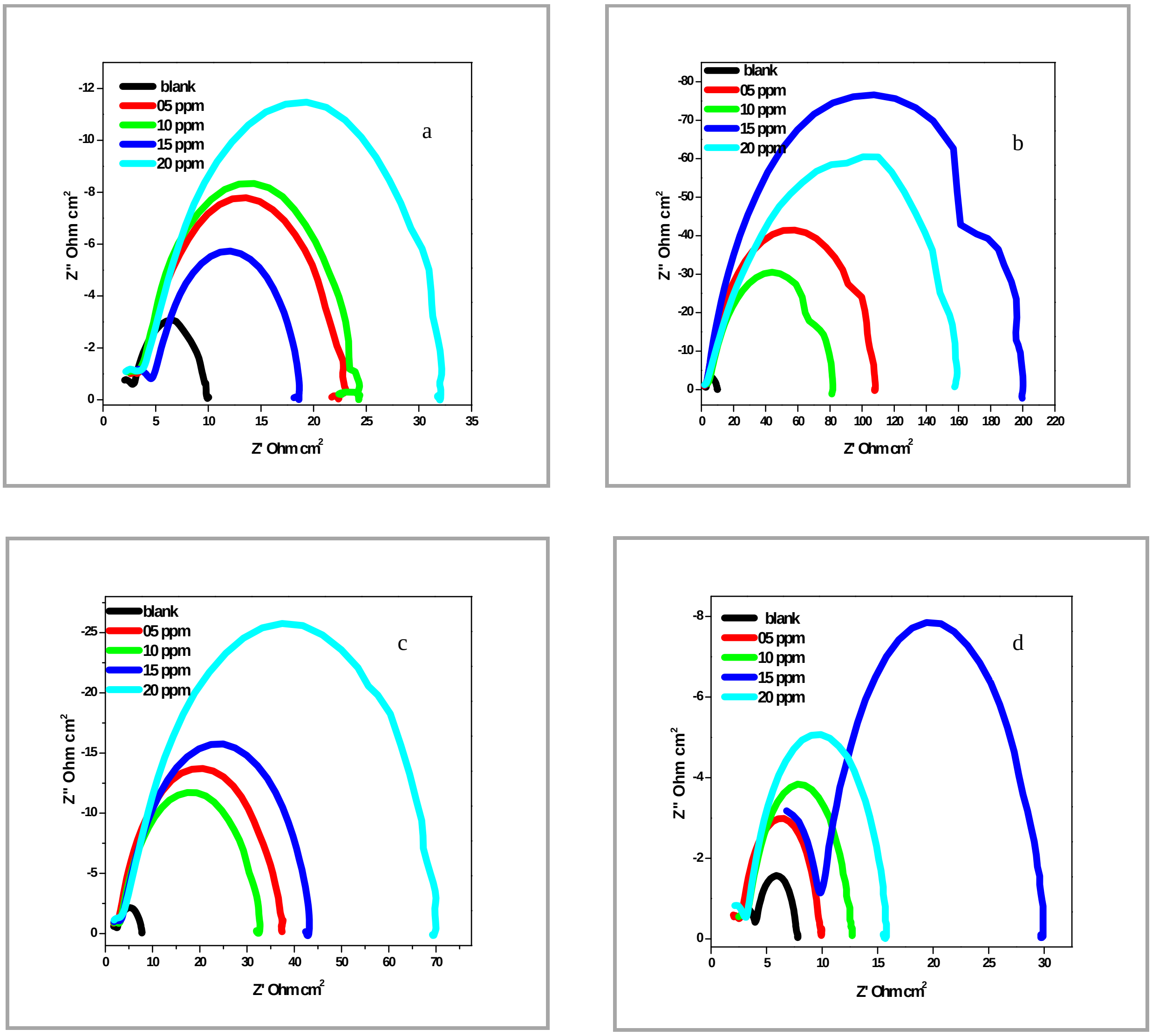


Figure 2. Nyquist plots for mild steel in 1N HCl acid solution without and with presence of different concentration of *TG* extract of (a) leaves (b) bark (c) fruits (d) seeds

Phytochemical screening method: The existence of several chemical constituents such as alkaloids, carbohydrates, proteins, saponins, triterpenoids, and tannins was examined by the phytochemical screening of the aerial sections of the plant's powder (aqueous) extract, and the findings are presented in table 4.

Surface examination studies: A JOEL scanning electron microscope was used to examine the surface of a mild steel specimen (SEM). After one day of immersion in 1N HCl solution in the presence of optimal concentrations of plant extracts at room temperature, the mild steel specimens were removed, dried, and stored in desiccators. Figure 3 shows SEM pictures of mild steel submerged in 1N HCl in the presence and absence of the inhibitor. According to SEM experiments, the plant extract that was adsorbed on the metal surface reduced corrosion attack on the metal surface.

Table 4. Phytochemical screening test for the extract of *Terminalia genus*

Phytochemical test	leaves	bark	fruit	Seeds
Alkaloids	+	+	+	+
Carbohydrates	+	+	_	-
Proteins	+	+	+	-
Saponins	-	-	+	+
Thiols	+	-	_	-
Tannins	-	-	+	-
Flavanoids	-	+	+	+
Phenol	-	+	+	-
Glycosides	-	+	+	+

(+).. Presence (-)... Absence

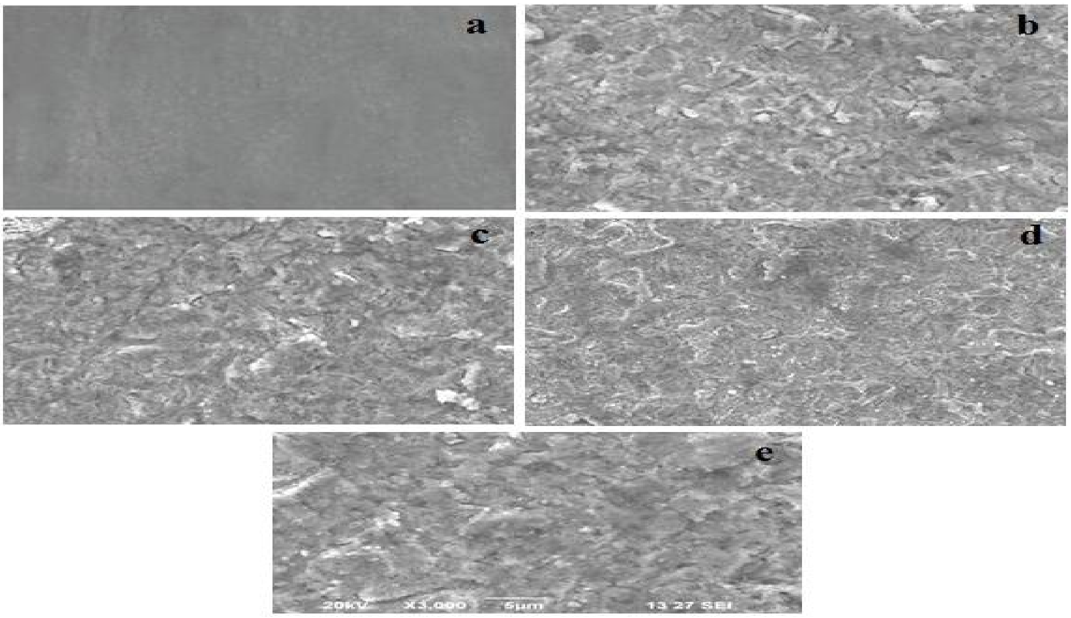


Figure 3. SEM image of the surface of mild steel after immersion for 24 hrs in 1N HCl solution (a) blank and in the presence of an optimum concentration of the plant extracts from (b) leaves (c) bark(d) fruits and (e) seeds.

Effect of immersion time: Table 5 shows the variance in inhibitory effectiveness for different concentrations of TG plant extract. At 12 h with a 20 ppm concentration of the inhibitor, the maximum inhibition effectiveness for 1N HCl was determined to be 98.96 percent. This behavior might be explained by the extract's increased surface covering, which slows mild steel corrosion. Increased inhibitory effectiveness from 12 h demonstrates substantial adsorption of components found in the plant extract on the mild steel surface, providing a protective barrier. This clearly shows that TG plant extract acts as a very excellent mild steel corrosion inhibitor in HCl solution.

Effect of temperature: The influence of temperature on the corrosion prevention characteristics of TG extract was investigated by exposing mild steel to 1N HCl containing 5, 10, 15, 20 ppm of the plants extract at temperatures ranging from 303 to 323K, with the results reported in table 6. The findings in table 6 clearly showed that the leaves extract is an efficient mild steel inhibitor in 1N HCl up to 303K and thereafter decreases. The leaves extract in 1N HCl demonstrated a maximal inhibition of 91.02 percent at 303K.

Table 5. Inhibition efficiency as a various immersion time

Parts of *Terminalia* genus plant	Conc. of the extract (ppm)	Inhibition efficiency (%)					
		1h	3h	5h	7h	9h	12h
Terminalia genus Leaves	5	57.98	59.48	64.56	54.39	64.22	54.56
	10	65.39	69.59	70.54	66.76	70.14	78.72
	15	74.95	81.36	77.16	77.96	82.49	87.95
	20	83.16	92.16	84.15	80.37	93.76	98.19
Terminalia genus barks	5	70.11	70.30	60.53	76.46	65.78	72.12
	10	74.08	85.19	77.28	83.12	66.28	83.38
	15	79.35	91.06	86.19	87.22	77.92	92.02
	20	91.93	93.83	95.05	90.09	89.78	96.91
Terminalia genus fruits	5	70.81	78.90	72.44	74.21	80.89	75.02
	10	76.15	86.16	77.63	76.78	89.28	79.53
	15	87.34	94.56	84.60	82.59	94.19	88.98
	20	94.21	97.89	92.19	93.65	95.66	97.16
Terminalia genus Seeds	5	68.10	70.93	72.65	75.78	76.87	79.21
	10	79.98	84.24	85.33	86.98	82.96	83.56
	15	88.98	89.94	89.89	87.48	89.08	91.33
	20	95.62	96.37	97.25	93.09	94.54	98.60

Table 6. IE at various temperatures

Parts of *Terminalia* genus plant	Conc. of the extract (ppm)	IE (%)		
		303K	313K	323K
Terminalia genus leaves	5	59.48	60.24	46.48
	10	69.59	77.54	55.36
	15	81.36	83.74	68.04
	20	91.02	87.22	73.66
Terminalia genus bark	5	65.71	56.58	59.58
	10	73.89	62.24	64.86
	15	77.48	74.41	69.24
	20	80.45	77.13	75.50
Terminalia genus fruits	5	66.12	59.90	47.41
	10	67.90	61.55	60.55
	15	73.65	66.86	66.27
	20	74.97	72.12	79.80
Terminalia genus seeds	5	39.25	50.29	40.02
	10	64.48	60.73	54.82
	15	71.49	66.69	68.18
	20	77.59	74.78	73.10

Adsorption isotherms: The findings of the weight-loss trial (Table 6) reveal that when the inhibitor concentration rises, the proportion of IE rises as well. This suggests that the anticorrosion activity of the analyzed plant species is primarily due to the adsorption of various components of plant species on the MS surface, particularly adsorption of basic constituents such as alkaloids, flavonoids, polyphenols, hydrolysis products of proteins, and amine compounds present in the plant extract. In the case of TG (leaves, barks, fruits, and seeds), increasing the temperature raises the IE, but in most circumstances, the IE decreases as the temperature rises. It's possible that the inhibition was caused by phytoconstituents chemisorbing on the MS surface. As the temperature rises, the hydrogen evolution overvoltage drops, causing the cathodic reaction to spike. Increased temperature, on the other hand, hastens the chemisorption of the inhibitor on the metal surface. When the latter effect dominates, the inhibitory impact increases, as was shown in the majority of the plants studied. In order to determine inhibitor adsorption qualities, weight loss data is quite important. Such information is used to create adsorption isotherms, which provide extensive information on the adsorption mechanism. For all of the data, the well-known Temkin isotherm was used. Surface coverage (deta) was plotted versus ln C for the Temkin isotherm (Figure 4). All of the plants produced a straight line, demonstrating that the green inhibitors follow Temkin isotherms.

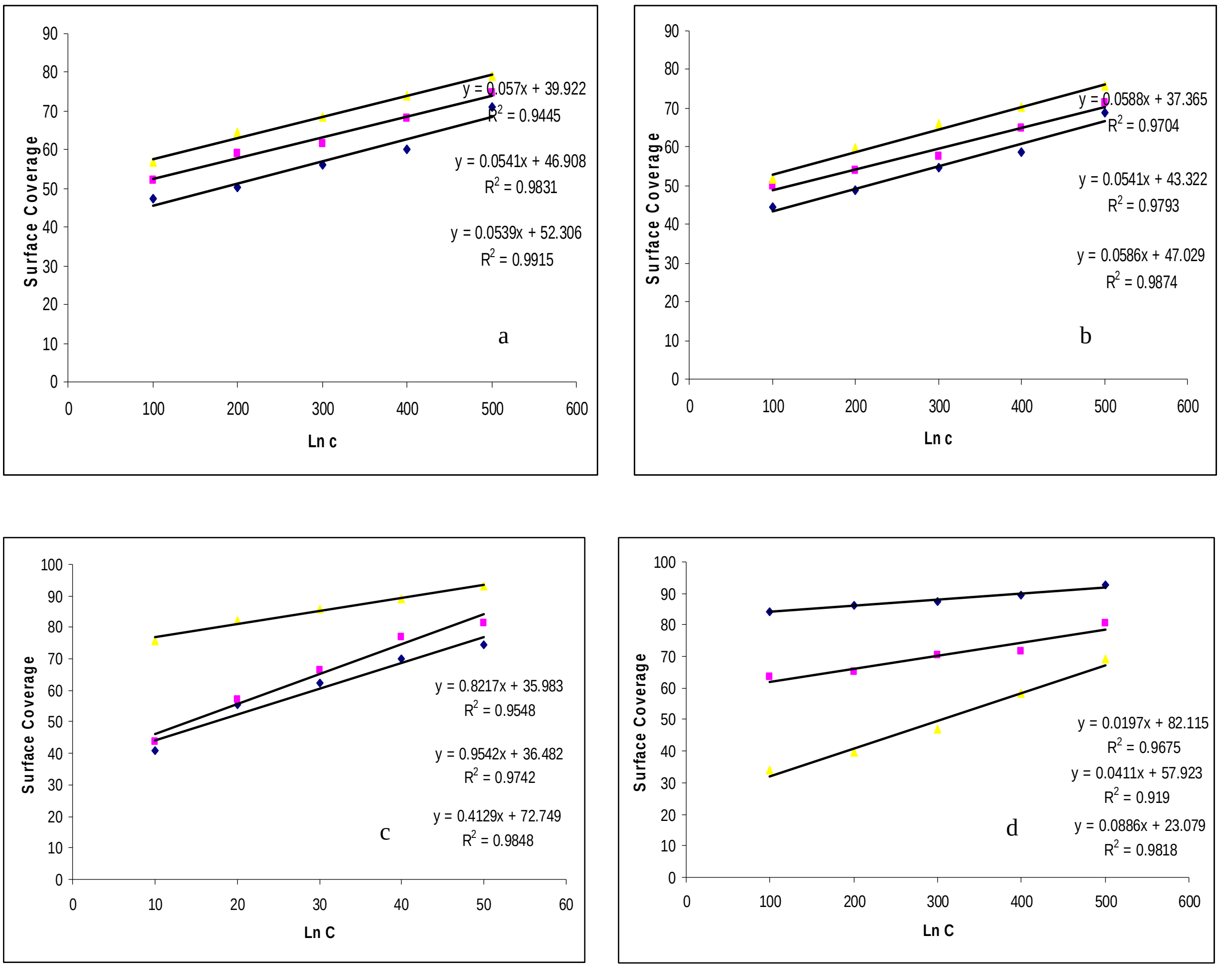


Figure 4. Temkin adsorption isotherm plot for mild steel in 1N HCl containing different concentration (a) leaves, (b) fruits, (c) barks, (d) seeds of the extract.

Mechanism of corrosion inhibition: It may be extrapolated from the results of several electrochemical and mass loss experiments that TG plants prevent mild steel corrosion in 1N HCl through adsorption at the mild steel interface. The presence of natural inhibitors at the metal surface contact is thought to be the initial step in the inhibitor action process. Natural molecules may be adsorbed on metal surfaces in four ways: I electrostatic contact between charged molecules and charged metal, (ii) interaction of unshared electron pairs in molecules with metal, (iii) interaction of pi-electron with metal, and (iv) all of the above [37]. Alkaloids, amino acids, proteins, carbohydrates, tannins, and heteroatoms such as N, O, and others are found in TG plants, and they may function as reaction centers for the adsorption process. The adsorption of inhibitor molecules on the metal surface forms a protective coating, which inhibits the active dissolving of the metal. To construct a co-ordinate type connection, the inhibitor molecules can be adsorbed onto the metal surface through electron transfer from the adsorbed species to the unoccupied electron orbital of low energy in the metal. The number of adsorption centers, mechanism of interactions with metal surfaces, molecule size, and shape all influence inhibitory efficacy. It is commonly known that iron has a co-ordinate affinity for ligands containing nitrogen, sulfur, and oxygen. As a result, adsorption on iron can be attributed to carbonyl linkage, heteroatom (N and O), and pi-electron of aromatic ring coordination. These are electron pairs on N and O that can form a coordination bond with iron if they are not shared. The extract of TG plants is more efficiently absorbed. All of the foregoing evidence suggests that the researched TG plants use type (iv) mechanism [38-60].

CONCLUSION

In 1N HCl acid, plants of the *Terminalia* genus operate as an effective corrosion pickling inhibitor on mild steel. The use of plants from the *Terminalia* genus as corrosion inhibitors was ecologically acceptable, nontoxic, cost effective, and readily available. At the optimal concentration of 15 ppm for one-day immersion duration at room temperature, the extracts of *Terminalia* genus plants demonstrated maximum effectiveness of 98.50 percent for leaves. The results of non-electrochemical methods (weight loss method) are quite similar to those of electrochemical methods. On the metal surface, extracts from the *Terminalia* genus function as a mixed type inhibitor. SEM analysis revealed that the surface morphology of the as corroded inhibited mild steel samples was improved as compared to uncontrolled samples. The Temkin adsorption isotherm suits the adsorption nicely. The physisorption mechanism appears to be based on the temperature investigated. The findings imply that a plant from the *Terminalia* genus is a mild steel corrosion inhibitor in HCl, and that it may be utilized to replace toxic and non-biodegradable inhibitors [**61-62**].

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