

Eco-Friendly Piper cubeba official extract corrosion inhibition of c-steel in 1M sulphamic acid

Aya. M. Salem (✉ ayasalem993@gmail.com)

Higher Institute of Electronic Engineering (HIEE)

Merfat S. Al-Sharif

College of Sciences, Taif University

Research Article

Keywords: Corrosion inhibition, C-steel, $\text{H}_2\text{NSO}_3\text{H}$, Piper cubeba official extract

Posted Date: September 8th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-3322263/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

The examination of the inhibitory rates of Piper cubeba official extract (P. cubebaOE) on C-steel in 1.0 M $\text{H}_2\text{NSO}_3\text{H}$ solution is covered in the research article. Utilizing chemical and electrochemical methods in addition to theoretical calculations such as DFT, Fukui function, the study produced results that indicated up to 96.0% inhibition at 300 ppm at 25°C., P. cubebaOE is an inhibitor of mixed kind. Through increasing concentration, Nquist diagrams showed that the charge transfer resistance elevated and the capacitance of the double layer decreased. It was also discovered that the inhibition process follows the Langmuir isotherm, demonstrating the generation of a monolayer on the surface of the C-steel.

1. Introduction

Metal corrosion is now a serious concern to a variety of sectors as well as the environment as a whole. As a result, efforts must be undertaken to lower corrosion risks across many businesses. Inhibitors are added in small amounts to the corrosive media to protect metals against corrosion-induced dissolution, which has a significant practical benefit[1, 2]. Thus, it reduces and in some cases prevents the interaction of aggressive ions on the surface of the metal or performs both processes[3, 4]. rusting of numerous metals as well as alloys[5, 6]. The high toxicity of these compounds has led to a limitation in their inhibitors and the search for more environmentally friendly alternatives that contain functional groups containing atoms of oxygen, nitrogen, or sulfur which have been approved as corrosion inhibitors[6, 7]. The interest in green alternatives has increased in the last decade as a result of increased environmental awareness and the adoption of many strict regulations to preserve the environment. Natural alternatives have been used as antimicrobial[8–10], antifungal[11], anticancer[12], and antibacterial activities[13]. Several efforts are being made to develop compounds suitable for use as anti-corrosion agents in various forms of entertainment. The foundation of this research is the use of plant extracts that are safe for the environment to prevent metal and alloy corrosion. The application of plant extracts as barriers to corrosion, as the following research indicates this role. Calicotome extract[14], Hibiscus rosa-sinensis Linn [15] Beet root extract in well water[16], spirulina solution which confirms with electrochemical techniques[17], spirulina[18]. Finding a naturally occurring, inexpensive, and ecologically friendly chemical that might be utilized to prevent corrosion of c-steel is the goal of the current research. Utilizing natural resources will enable the achievement of both economic and environmental objectives. In several research, plant extracts have been mentioned as prospective agents to lessen corrosion in different industrial solutions[19, 20]. As reported previously, the ethanolic extract of (P.cubebaOE) contains major levels of Yatein, Cbenin, cubebinone, cubebinolide, Hinokinin and cubebinin, single aldehyde, α , β -unsaturated ketone. From Piper cubeba, several phenolic acids and flavonoids have been found and extracted. In addition to rutin (8 ppm) and catechin (5 ppm), researchers found that the aqueous extract of piper cubeba fruits also contained gallic acid (8 ppm), caffeic acid (13 ppm), syringic acid (3 ppm), and ferulic acid (11 ppm[21]. The aqueous extract from the same study contained 2.11 mg/g of total phenols [22].In some literature, oxygen atoms, and aromatic rings are considered the centers of adsorption in the four ingredients[22, 23]. As a result, (P.cubebaOE) may be studied as an environmentally

friendly corrosion inhibitor. Our work examined the inhibitory effect of this extract on c-steel in 1.0 M H₂NSO₃H acid using weight loss (WL), (PP), (EIS), (FTIR) and (AFM) Analysis.

2. Experimental Section

2.1. Preparation of (P. CUBEBA)OExtract

To prepare the plant extract, dried leaves of the P. CUBEBA plant were used and soaked in an ethanol solution. After 48 hours, using filter papers, the unwanted objects were removed and then heated to get rid of the ethanol. Deionized water was used to prepare the different concentrations used in the research. The molecular structures of the major constituents in P.cubebaOE which are caffeic acid, ferulic acid, gallic acid, syringic acid, (-)- catechin and rutin are shown in Fig. 1.

2.2. Materials preparation

Table 1 lists the chemical details contents of the pieces of C-steel that were used. where the coupons were formed with different dimensions of (2 × 2 × 0.1 cm) and dimensions (1 × 1 × 0.1 cm) for the electrochemical measurement's studies. All of the specimens were scrubbed with deionized water and then alcohol to remove dirt and greases. Deionized water was used in all preparations. The samples were polished with sandpaper of various sizes. A solution of 1.0 M sulphamic acid was used as a corrosive medium for all measurements. The P. cubeba extract was diluted in 1.0 M H₂NSO₃H corrosion medium to prepare (50, 100, 150,200, 250, and 300 ppm) test solution, respectively.

Table 1

lists the chemical details contents of the pieces of C-steel.

Element	Fe	C	Mn	P	Si	Cr	Co
Weight %	Balance	0.200	0.600	0.024	0.098	0.026	0.245

2.3 Mass loss

C-steel specimens with a thickness of 2.0 * 2.0 * 0.2 cm were used for mass degradation measurements, and they were polished to varying degrees with sanded before being scrubbed with double distilled water, followed by alcohol for eliminating debris, and then adequately dried and counted. The weight is followed by the use of traditional methods for measuring WL at temperatures of (25–450C), this data was computed using the formula below. [24–27]:

$$\%IE = \; x100 = 1 - \frac{W}{W_*}x100$$

1

The diminution in mass of metal absent from and along with the evaluated extract is shown by W and W*, consequently.

2.4 Electrochemical laboratory tests

Electrochemical laboratory tests were performed using a traditional platinum, calomel, and C-steel three-electrode cell at an average temperature of 25°C. In this model, the calomel conductor served as an indicator, the platinum-based electrode functioned as a sort of counter, and the C-steel electrode operated as the actual working electrode. The C-steel wire was submerged at a closed loop to attain a semi-stable condition. In the present situation, impedance was recorded at multiple points, with attribute hz from 10^{-2} to 10^{-5} Hz, in addition to the presence of intermittent current signals of 5 mv, employing the Gamry Instrumentation category G 750TM -Potentiostat/ Galvanostat/ ZRA device. In order to verify the reliability of what was found, the technique was executed out three times and all output were gathered.

2.5 Theoretical calculations

The Gaussian 09 program (Gaussian, Inc., CT, USA) was used to perform quantum chemical calculations utilizing generalized density functional theory (DFT) and the Becke three parameters Lee, Yang, and Parr (B3LYP). The electrical attributes and geometries of many organic compounds can be computed perfectly using 6-311G++ (d,p)

2.6 Surface characterization

Using the Scanning Electron Microscope (SEM - Quattro S) approach, the C-steel interface was completely screening with respect to its inhibitor- and inhibitor-free variations. In the purpose of this research, two C-steel pieces were left submerged for 48 hours in sulphamic acid alone (Blank) alongside one in sulphamic acid with 300 ppm of P.cubebaOE blends .[24, 25]

2.7 AFM Technique

The AFM approach works well because it can measure the roughness of a variety of surfaces[28, 29]. Through the use of AFM, it was possible to gain a clear understanding of the changes in surface shape that occur at a distance of several hundred nanometers as a result of the development of consumption and the placement of minding successive layers on the metallic substrate when inhibiting agents have been added. The Pico SPM2100 is the AFM device model. An AFM device working in contact mode in air was used to create images in three and two dimensions at the nano unit of the College of Engineers at Mansoura Univ. 5 m × 5 m AFM imagery portions were generated at an average of 2.4 lines per second.

2.8 FT-IR technology Spectra

The spectral data from of the P.cubebaOE extract (crude) has been employed with IR affinity (Perkin-Elmer). They were completed in the university's school of pharmacy's core labs at Mansoura Univ.

3. Results and Discussion

3.1. Mass Loss Method

Equation (1) was used to obtain the inhibition ratios at temperatures between (25 and 45°C). According to the findings, values for the (P.cubebaOE) extract's CR and% IE were determined. Table 2 and Fig. 2 display the findings. The findings demonstrated that adding more (P.cubebaOE) extract raises the inhibition ratios, which were observed to decrease with rising temperature. This is because the plant extract occurs to desorb from the metal's surface. It was determined that the optimal concentration for the inhibition process was 300 ppm, which yielded the maximum inhibition rate of 96%. These findings allow us to draw the conclusion that this the high efficiency of this plant extract in the process of inhibiting corrosion C-steel in 1.0 M H₂NSO₃H solution.

Table 2
 states several levels of
 prevention for 1 M H₂NSO₃H's
 aggressive effects on C-steel at
 different levels either together
 with and with no P.cubebaOE.

[conc.], ppm	θ	%IE
50	0.856	85.6
100	0.877	87.7
150	0.897	89.7
200	0.920	92.0
250	0.938	93.8
300	0.960	96.0

3.2 Adsorption Isotherm

The corrosion process is considered by thermal isotherms to be primarily dependent on the amount of surface coverage , making it another component of IE, where = IE/100. The Langmuir adsorption isotherm has been proven to be the best curve to characterize the inhibitory performance after numerous attempts to adopt a relationship between the degree of coverage and the greatest concentration of the inhibitor at a specific temperature. For the plant extract (Fig. 3), The concept that the metallic surface has a certain amount of adsorption cores and that each center has a particular kind of adsorbent can be summed up in the equation [31]below.:

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

2

The net energy G⁰_{ads} signifies were derived using the formula after the adsorption factor K_{ads} ' quantity had been established.:

$$K = \frac{1}{55.5} \exp \frac{-\Delta G_{ads}}{RT}$$

3

The level of concentration of water on the metal surface is 55.5 in mol/L. The distributions of G_{ads} as a reflection of temperature are shown in Table 4 at an average temperature around 298 & 318 K. As a direct consequence of the findings, we derived an association between G_{ads} and T (Fig. 3), which means that G_{ads} is strongly influenced on temp. This formula [32] can be used to compute the entropy (S_{ads}) and enthalpy of Adsorption capacities (H_{ads}):

$$\Delta G^{\circ}_{ads} = \Delta H^{\circ}_{ads} - T \Delta S^{\circ}_{ads}$$

4

The negative G_{ads} values increased with the increase of %IE values, which confirm the stability of the adsorbent layer physical adsorption, can indicate the extract's spontaneous sorption on the outer layer that covers C-steel. We discover that as G_{ads} increases, the values of the inhibition ratios rise as well, and as H_{ads} has a sign that is negative, we infer that the adsorption of the extract on the surface of the C-steel is an exothermic operation., meaning that %IE decreases as temperature rises. On the other hand, the rise in solvent entropy when disorder develops at the metal/solution interface is what is responsible for the positive value of S°_{ads} . This is a result of P.cubebaOE molecules dislodging H_2O molecules from the metal surface in the test medium.

Table 3
Data on P.cubebaOE adsorption at multiple temperatures on a C-steel
outer layer in 1 M H_2NSO_3H

Temperature, °C	$K_{ads} \times 10^{-3}$ M ⁻¹	$-\Delta G^{\circ}_{ads}$ kJ mol ⁻¹	ΔH°_{ads} kJ mol ⁻¹	ΔS°_{ads} J mol ⁻¹
25	2.02	15.32	118.60	44.2
30	1.96	15.60		48.90
35	1.93	21.00		65.05
40	0.98	21.14		68.62
45	0.940	21.50		68.79

3.3 Potentiodynamic Polarization (PDP) tests

The usual curves that characterize the polarization of C-steel in a 1M H_2NSO_3H medium are shown in Fig. 4. The voltage and current have both increased in value until they have reached their highest peak without being inhibited, as seen by the curve of polarization[30, 33]. With the inhibitor, there was noticeably less cathodic and anodic current density as well. Additionally, the E_{corr} value is altered by the

presence of (P.cubebaOE). An inhibitor can be classified as cathodic or anodic if the E_{corr} movement has a value higher than 85 mV; otherwise, if the displacement is lower than 85 mV, it can be classified as mixed. The present investigation's experimental inhibitor showed an optimal E_{corr} shift value of 85 mV, indicating that it is a mixed-type inhibitor. Increased (P.cubebaOE) concentration prevents anodic corrosion of C-steel electrodes, as seen in Fig. 3. Additionally, (P.cubebaOE) suppresses the cathodic response less than the anodic reaction when it is present. As demonstrated in Table 6, (P.cubebaOE) elevates the values of β_a for (P.cubebaOE) above those obtained using a blank in the event that there is no of (P.cubebaOE). As a result, the oxidation mechanism is suppressed by the (P.cubebaOE), thus regulating the anodic processes on the metal's outermost layer. [34]

Table 4

illustrates the corrosive potential (E_{corr}), corrosive density of current (i_{corr}), the Tafel slopes (a, c), degree of surface coverage (θ), and the inhibition effectiveness (%IE) of C-steel for P.cubebaOE in 1M H_2NSO_3H at 25°C.

Inhibitor	[conc.] ppm	- E_{corr} Mv vs SCE	$I_{corr} \times 10^{-4} \mu A cm^{-2}$	β_a , mV dec ⁻¹	β_c , mV dec ⁻¹	θ	%IE
Blank	0	867	301.0	366	390.0	0.0	0.0
P.cubebaOE	50	847	173.0	319	281	0.425	42.5
	100	852	149.0	277	250	0.504	50.4
	150	742	69.7	340	130	0.768	76.8
	200	938	47.8	82	93	0.841	84.1
	250	854	39.7	157	59	0.868	86.8
	300	552	25.8	64	57	0.914	91.4

3.4 Electrochemical Impedance Spectroscopy (EIS) tests

We additionally utilized the EIS approach to assess the rusting behavior of C-steel in 1M sulphamic acid solution, as well as zero concentration and addition a variety of P.cubebaOE doses[35]. The hard exterior of the C-steel electrode generated unfinished circular shapes with a time variable to appear on Nyquist plots. The capacitive ring's dimensions substantially increases when the inhibitor gets added to the 1M concentrations of H_2NSO_3H , and this growth strengthens as the inhibitor's level rises. The observations point to a shielding layer has formed and those inhibitory molecules are bound to the surface of C-steel. This layer substantially reduces the surface area that is actively oxidizing of C-steel, promotes its durability against corrosion, and diminishes rust start in due to the presence of a 1M H_2NSO_3H solution[36]. While the R_{ct} value goes up as the inhibitor dosage rises, the impedance values shown in Table 5 demonstrates that the inhibitory action turns into more intense in acidic conditions. As a consequence of this, as C-steel disintegrates a barrier develops at the metal solution interface. This

barrier implies that just a single charge transfer process utilized place, and that the connected molecule had no impact on this mechanism. As the inhibitor conc. rises the capacitance value of the double layer drops. The densities of the shielding layer and the electrical double layer varies. Both the weight loss and polarization procedures achieve comparable consequences in terms of IE adoption.

(CPE_s), specifically CPE_f and CPE_{dl}, have been used in place of all capacitance elements in Fig. 4. R_s stands for the solution resistance, and CPE_f for the capacitance of a passive film. R_f is equivalent to the ionic resistance in passive films. CPE_{dl} stands for the capacitive action of the two-layer corroded region, while R_{ct} symbolizes for the amount of charge transmit barrier. Furthermore demonstrated in Fig. 6 (a and b[37], Nyquist and Bode diagrams for C-steel rusting in 1M H₂NSO₃H solution are highlighted according to phase angle and frequency. Find the circuit's double-layer capacitance, C_{dl}, using the following equation.

$$C_{dl} = Y_O \left(\omega_{max} \right) n - 1$$

5

where fmax is the resonance frequency at which the simulated portion of the impedance is full, Y0 is the absolute value of the CPE, max = 2fmax, and factor n a varies from 0.50 to 1.0[38]. The general curves' similarity (with or without an inhibitor) demonstrates that the corrosion mechanism remains unchanged. As additional proof, it was demonstrated that Bode plots prevented by a phase angle increase had a higher degree of phase angle. With a rise in phase angle values, shielded surfaces' morphology got better. Nyquist curve diameters and phase angle values in Bode plots increase when P.cubebaOE is concentrated (Fig. 6b).

Table 5
P. cubebaOE doses with and without respect to the kinetics of C-steel electrochemistry in H2NSO3H.

Inhibitor	inh ,ppm	R _{ct} ,Ω cm ²	C _{dl} x10 ⁻⁴ ,μFcm ⁻²	Θ	% IE
Blank	0	110.5	9.77	0.0	0.0
P.cubebaOE	50	339.7	8.03	0.674	67.4
	100	498.5	3.91	0.778	77.8
	150	544.5	3.62	0.797	79.7
	200	1219	0.231	0.909	90.9
	250	1397	0.129	0.921	92.1
	300	1492	0.112	0.926	92.6

3.5 Molecular modelling

3.5.1 HOMO-LUMO molecule orbital

The LUMO and HOMO density profiles of the studied chemical in the aqueous phase are shown in Fig. 7. It demonstrates that whereas green has a low electron density, red has a high electron density. In situations where there is a high electron density, the metal surface can donate electrons. Electrons are attracted to the metal surface in the green region. Since resonance is primarily brought on by the bonds between the oxygen and nitrogen atoms on the benzene ring, the distribution of these two locations must be carefully considered. In the interim, the carbon atoms are the core of the LUMO. Improved inhibitory efficiency may be indicated by lower E values. The inhibitor molecule's reactivity to the metal atom can be evaluated using the E value. Lower E values may indicate improved inhibition efficiency. The E value can be used to assess the reactivity of the inhibitor molecule to the metal atom. The DFT simulations have shown that – (-) catechin (E = 2.79) is the most stable.

Table 6
Determined quantum for P.cubebaOE

Compound	E _{HOMO}	E _{LUMO}	$\Delta E = E_{LUMO} - E_{HOMO}$
Rutin	-4.514eV	-3.486eV	1.028
Caffeic Acid	-5.223eV	-3.549eV	2.738
Ferulic Acid	-5.198eV	-3.490eV	1.708
Gallic Acid And	-5.575eV	-3.444eV	2.131
Syringic Acid	-5.461eV	-3.290eV	2.202
Catechin	-5.112eV	-2.322eV	2.79

3.5.2 2D maps of electrostatic potential

The distribution of electrons and, subsequently, where they are concentrated within each molecule can be seen using ESP maps. According to the electron density contour maps, oxygen atoms on the examined molecule inhibitor appear to be favorable interaction locations, which is in line with the different functions of oxygen and the other atoms. The contact regions that provide the bonding contacts between metal surfaces and inhibitor are surrounded by a dark red outline. The distribution of electrons and, subsequently, where they are concentrated within each molecule can be seen using ESP maps.

3.6 SEM examination

SEM research has verified the P.cubebaOE layer's adsorption on the surface of C-steel. Figures (9 a- c) depict SEM images of C-steel's surface before and after 48 hours of immersion in 1 M H₂NSO₃H with a dosage of 300 ppm of P.cubebaOE. Without having P.cubebaOE, H₂NSO₃H corrosion has clearly harmed the C-steel surface, but the metallic edge is still discernible (Fig. 9b). The metal surface, in variance with the material under assessment, appears not to rust (Fig. 9c). It was found that the extract created a slight film on the C-steel's outside that restricted corrosion.[39]

3.7 Atomic Force Microscope (AFM)

The metal surface of the C-steel without the investigated P.cubebaOE inhibitor has reportedly been repeatedly corroded by the corrosive attacks of the 1M sulphamic acid (Fig .10b), according to the 3D picture of the C-steel. The 3D images (Fig. 10c) that reveal smoother surfaces than the blank, however, show that the addition of an inhibitor lessens C-steel corrosion in the aggressive solution. Table 6 shows the mean roughness (Sa) and average RMS roughness (Sq) of the films generated on the Cu surface in accordance with the modular program Gwyddion. The RMS roughness and mean roughness of the blank are greater than those of the inhibitor under study and pure metal, as shown by the data in Table 6, demonstrating the effectiveness of the compound in shielding C-steel 's surface from corrosive medium. The AFM data add to the body of information supporting the sequence of inhibitory efficacy discovered by weight loss research and electrochemical tests.

Table 7

AFM parameters of P.cubebaOE compounds

Sample	RMS roughness (Sq), nm	Mean roughness (Sa), nm
a	22.97	17.64
b	1234.9	993.76
c	285.83	180.68

3.8 Fourier transforms infrared spectroscopy (FT-IR) studies

Figure 11 confirms that "the -C = O stretching frequency occurs at 1640 cm⁻¹, with the acute one at 1608 cm⁻¹ referring to -C = C stretching, the O-H stretching has changed from 3225 cm⁻¹ to 3365 cm⁻¹, and the -C = C stretching frequency shifts from 1647 cm⁻¹ to 1640 cm⁻¹ in the film generated on the C-steel submerged in sulphamic acid."The alterations in the IR spectra hint that the bonding of P.cubebaOE with C-steel was accomplished through groups of functions that had already existed in it.

Rusty Inhibition Process

Some plant-based extracts have a restrictive acting characteristic that has been speculated to be attributed to the adsorption of the Phyto-chemical components found in the extract of leaves on the metal surface, which maintains the metal's outermost layer and stops the corrosion process from proceeding. How the inhibitor adsorbs is influenced by the chemical composition of the Phyto-components present, the charge on the metal surface, and the nature of the corrosive media. The inhibitor molecules in our work are electrostatically drawn to the metal surface because the C-steel surface bears a positive charge under acidic conditions. Due to the electrostatic interaction (physical adsorption), (SO3-) ion adsorption on the outermost layer of the metallic substance increases the amount of inhibitor molecules that can adsorb on the C-steel surface by generating an additional negative charge close to the corrosive solution. The chemisorption processes, on the other hand, are made possible by the donation of electron lone pairs on heteroatoms like N, O, and the aromatic ring contains electrons in order to attach to the open d-orbital of C-steel ions. The surface becomes more negatively charged when the surface is

saturated with one electron[40]. The electron in C-steel's d-orbital is then moved (retro-donated) to the open -antibonding orbital of the inhibitor molecules in order to remove the extra electron from the surface[41, 42]. Thus, the C-steel's anodized and either cathodic process in the H_2NSO_3H medium are effectively inhibited by the formation of a durable barrier film. All of this leads us to the conclusion that a number of fundamental mechanisms that the high proportion of %IE is a consequence of chemicals adhering to the metal's surface[43, 44]. In Table 9, the percentage of P.cubebaOE in the current investigation is contrasted with values previously reported in the literature in acidic media[45, 46]. The P.cubebaOE clearly produced 96.0% IE at 300 ppm, indicating that it functions effectively as a sulphamic acid corrosion-preventing agent for C-steel[1].

Table 7

A comparison of P.cubebaOE with some other studied (%IE is reported at the maximum) extracts

Source of extract	Test medium	Metal/Alloy	% IE	References
Orange peels	HCl and H_2SO_4	Cu	43.0	[42]
Mangrove tannin	HCl	Cu	82.4	[44]
Myrtus communis	H_2SO_4	Cu	> 85.0	[47]
Alhagi Mauro rum plant extract	H_2SO_4	Cu	33.0–83.0	[43]
Egyptian licorice extract	HCl	Cu	55.0–89.0.0	[45]
Exudate gum from Dacryodes edulis	HCl	Al	42.0	[46]
Opuntia ficus indica	HCl	C-steel	70.0–91.0	[48]
Piper cubeba official extract	H_2NSO_3H	C-steel	96.0	Our results

Conclusions

It has been demonstrated through experiments that (P.CubebaOE) effectively prevents C-steel corrosion in 1.0 M H_2NSO_3H solution as a mixed-type inhibitor. When this substance was adsorbed on C-steel surfaces, it displayed these isotherms of Langmuir adsorption, which are similar to inhibitory. Due to the fact that G^0_{ads} has a value which is negative, it was assumed that the reaction was spontaneous. It was discovered that temperature and inhibitor concentration regulate the inhibitory process. A protective coating that shields the brass alloy from corrosive fluids was discovered by SEM analysis of the surface of the metal.

Declarations

Author Contributions: Conceptualization, Methodology, project administration and funding acquisition, Merfat S. Al-Sharif; software, validation, and formal analysis, writing, editing and data analysis, supervision, A.M.Salem; All authors have read and agreed to the published version of the manuscript.

Funding: The researchers would like to acknowledge the Deanship of Scientific Research, Taif University for funding this work

Data Availability Statement: The authors confirm that the data supporting this study are available.

Acknowledgments: The researchers would like to acknowledge the Deanship of Scientific Research, Taif University for funding this work.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Umoren, S., et al., Studies on the inhibitive effect of exudate gum from *Dacryodes edulis* on the acid corrosion of aluminium. *Portugaliae Electrochimica Acta*, 2008. **26**(2): p. 199-209.
2. Jones, D.A., Principles and Prevention of Corrosion Second Edition. Prentice Hall. Inc: United States of America, 1996.
3. Jones, D.A., Principles and prevention. Corrosion, 1996. **2**: p. 168.
4. Raja, P.B. and M.G. Sethuraman, Natural products as corrosion inhibitor for metals in corrosive media –a review. *Materials letters*, 2008. **62**(1): p. 113-116.
5. Muñoz, A.I., et al., Inhibition effect of chromate on the passivation and pitting corrosion of a duplex stainless steel in LiBr solutions using electrochemical techniques. *Corrosion Science*, 2007. **49**(8): p. 3200-3225.
6. Orubite, K. and N. Oforka, Inhibition of the corrosion of mild steel in hydrochloric acid solutions by the extracts of leaves of *Nypa fruticans* Wurmb. *Materials Letters*, 2004. **58**(11): p. 1768-1772.
7. Oguzie, E.E., Corrosion inhibition of aluminium in acidic and alkaline media by *Sansevieria trifasciata* extract. *Corrosion science*, 2007. **49**(3): p. 1527-1539.
8. Chauhan, L. and G. Gunasekaran, Corrosion inhibition of mild steel by plant extract in dilute HCl medium. *Corrosion science*, 2007. **49**(3): p. 1143-1161.
9. El-Etre, A., M. Abdallah, and Z. El-Tantawy, Corrosion inhibition of some metals using lawsonia extract. *Corrosion science*, 2005. **47**(2): p. 385-395.
10. Mangale Sapana, M., G. Chonde Sonal, and P. Raut, Use of *Moringa oleifera* (drumstick) seed as natural absorbent and an antimicrobial agent for ground water treatment. *Research Journal of Recent Sciences - ISSN*, 2012. **2277**: p. 2502.
11. Kanak, S. and A. Verma, Evaluation of antimicrobial and anticancer activities of methanol extract of in vivo and in vitro grown *Bauhinia variegata* L. *International Research Journal of Biological Sciences*, 2012. **1**(6): p. 26-30.
12. Hegde Chaitra, R., et al., Evaluation of antimicrobial properties, phytochemical contents and antioxidant capacities of leaf extracts of *Punica granatum* L. *ISCA J of Biological Sciences*, 2012. **1**(2): p. 32-7.

13. Philippe, S., et al., In vitro Antifungal activities of Essential oils extracted from Fresh Leaves of *Cinnamomum zeylanicum* and *Ocimum gratissimum* against Foodborne pathogens for their use as Traditional Cheese Wagashi conservatives. *Research Journal of Recent Sciences _ ISSN*, 2012. **2277**: p. 2502.
14. Sribhurathy, V. and S. Rejendran, Corrosion inhibition by green inhibitor: sodium metavanadate-spirulina system. *Chem. Sci. Rev. Lett*, 2012. **1**(1): p. 25-29.
15. Fouda, A., et al., Calicotome Extract as a friendly corrosion inhibitor for Carbon steel in polluted NaCl Solution: chemical and electrochemical studies. *Egyptian Journal of Chemistry*, 2019. **62**(10): p. 1879-1894.
16. Antony, N., H.B. Sherine, and S. Rajendran, Inhibition and biocide actions of sodium dodecyl sulfate-Zn²⁺ system for the corrosion of carbon steel in chloride solution. *Port. Electrochim. Acta*, 2010. **28**(1): p. 1-14.
17. Wang, Y., et al., Evaluating the synergistic effect of maple leaves extract and iodide ions on corrosion inhibition of Q235 steel in H₂SO₄ solution. *Journal of Industrial and Engineering Chemistry*, 2023. **117**: p. 422-433.
18. Wang, Q., et al., Synergistic Effect of Benincasa hispida Peel Extract and KI on the Corrosion Inhibition of Mild Steel in HCl. *Sustainability*, 2023. **15**(14): p. 11370.
19. Al Jahdaly, B.A., Rosmarinus officinalis extract as eco-friendly corrosion inhibitor for copper in 1 M nitric acid solution: Experimental and theoretical studies. *Arabian Journal of Chemistry*, 2023. **16**(1): p. 104411.
20. Begum, A.A., et al., Corrosion mitigation on orthodontic wire made of SS 18/8 alloy using esomeprazole tablet (Esiloc-40 mg) in artificial saliva. *Journal of Saudi Chemical Society*, 2023. **27**(4): p. 101681.
21. Tan, B., et al., Insight into anti-corrosion nature of Betel leaves water extracts as the novel and eco-friendly inhibitors. *Journal of Colloid and Interface Science*, 2021. **585**: p. 287-301.
22. Ahmad, K., et al., Green synthesis and characterization of silver nanoparticles through the Piper cubeba ethanolic extract and their enzyme inhibitory activities. *Frontiers in Chemistry*, 2023. **11**: p. 1065986.
23. Dwita, L.P., et al., BRAIN ANTIOXIDANT PROPERTIES OF PIPER CUBEBA L. EXTRACTS AND ESSENTIAL OIL. *Farmacia*, 2023. **71**(2): p. 296-302.
24. Xiao, J., et al., Influence of sulfuric acid corrosion on concrete stress–strain relationship under uniaxial compression. *Measurement*, 2022. **187**: p. 110318.
25. Kadhim, A., et al., Corrosion inhibitors. A review. *International Journal of Corrosion and Scale Inhibition*, 2021. **10**(1): p. 54-67.
26. Drissi, B., et al., Cubeb (*Piper cubeba* Lf): A comprehensive review of its botany, phytochemistry, traditional uses, and pharmacological properties. *Frontiers in Nutrition*, 2022. **9**: p. 1048520.
27. Gusson-Zanetoni, J.P., et al., Effect of Piper cubeba total extract and isolated lignans on head and neck cancer cell lines and normal fibroblasts. *Journal of Pharmacological Sciences*, 2022. **148**(1): p.

28. Saleh, T.A., et al., Synthesis of Amine Grafted Poly (Acrylic-Maleic) as an efficient inhibitor against stainless steel corrosion in a highly saline medium. *Progress in Organic Coatings*, 2022. **170**: p. 106974.
29. Sherine, B., A.A. Nasser, and S. Rajendran, Inhibitive action of hydroquinone-Zn²⁺ system in controlling the corrosion of carbon steel in well water. *International Journal of Engineering Science and Technology*, 2010. **2**(4): p. 341-357.
30. Abd El Aziz, S.F., S.E.H. Etaiw, and S. Sobhy, Metal-organic frameworks based on heterocyclic ligands and some transition metals as effective carbon steel corrosion inhibitors in aqueous environment. *Journal of Molecular Liquids*, 2022. **348**: p. 118402.
31. Abdel-Rahim, S., K. Khaled, and N. Abd-Elshafi, Electrochemical frequency modulation as a new technique for monitoring corrosion inhibition of iron in acid media by new thioureas derivative. *Electrochim. Acta*, 2006. **51**: p. 3269-377.
32. Ismail, M.A., et al., Novel cationic aryl bithiophene/terthiophene derivatives as corrosion inhibitors by chemical, electrochemical and surface investigations. *Scientific Reports*, 2022. **12**(1): p. 3192.
33. Yang, F., et al., Electrochemical corrosion mechanisms of nickel-aluminium bronze with different nickel contents using the rotating disc electrode. *Corrosion Science*, 2019. **157**: p. 438-449.
34. Benarioua, M., et al., Mild steel corrosion inhibition by Parsley (*Petroselinum Sativum*) extract in acidic media. *Egyptian Journal of Petroleum*, 2019. **28**(2): p. 155-159.
35. Zhang, Y., et al., Solvothermal synthesis of functionalized carbon dots from amino acid as an eco-friendly corrosion inhibitor for copper in sulfuric acid solution. *Journal of Colloid and Interface Science*, 2021. **604**: p. 1-14.
36. Charoen-amornkitt, P., T. Suzuki, and S. Tsushima, Effects of voltage-dependence of the constant phase element and ohmic parameters in the modeling and simulation of cyclic voltammograms. *Journal of The Electrochemical Society*, 2020. **167**(16): p. 166506.
37. Laschuk, N.O., E.B. Easton, and O.V. Zenkina, Reducing the resistance for the use of electrochemical impedance spectroscopy analysis in materials chemistry. *RSC advances*, 2021. **11**(45): p. 27925-27936.
38. Fouda, A., A. Wahba, and A.M. Al-Bonayan, Corrosion inhibition of stainless steel in 1.0 M hydrochloric acid solution using novel nonionic surfactant: electrochemical and density functional Theory/B3LYP/6-31G* analysis. *Surface Engineering and Applied Electrochemistry*, 2021. **57**: p. 689-702.
39. Haldhar, R., D. Prasad, and N. Bhardwaj, Extraction and experimental studies of *Citrus aurantifolia* as an economical and green corrosion inhibitor for mild steel in acidic media. *Journal of Adhesion Science and Technology*, 2019. **33**(11): p. 1169-1183.
40. Shahini, M., et al., Superior inhibition action of the Mish Gush (MG) leaves extract toward mild steel corrosion in HCl solution: Theoretical and electrochemical studies. *Journal of Molecular Liquids*, 2021. **332**: p. 115876.

41. El-Haddad, M.N., A. Fouda, and A. Hassan, Data from chemical, electrochemical and quantum chemical studies for interaction between Cephapirin drug as an eco-friendly corrosion inhibitor and carbon steel surface in acidic medium. *Chemical Data Collections*, 2019. **22**: p. 100251.
42. Saleh, R., A. Ismail, and A. El Hosary, Corrosion Inhibition by Naturally Occurring Substances: VII. The effect of aqueous extracts of some leaves and fruit-peels on the corrosion of steel, Al, Zn and Cu in acids. *British Corrosion Journal*, 1982. **17**(3): p. 131-135.
43. Bozorg, M., et al., Myrtus communis as green inhibitor of copper corrosion in sulfuric acid. *Industrial & Engineering Chemistry Research*, 2014. **53**(11): p. 4295-4303.
44. Shah, A., et al., Green inhibitors for copper corrosion by mangrove tannin. *International Journal of Electrochemical Science*, 2013. **8**(2): p. 2140-2153.
45. Abd-El-Nabey, B., et al., Inhibitive action of Alhagi maurorum plant extract on the corrosion of copper in 0.5 M H₂SO₄. *Physical Chemistry*, 2015. **5**(3): p. 49-62.
46. Deyab, M., Egyptian licorice extract as a green corrosion inhibitor for copper in hydrochloric acid solution. *Journal of Industrial and Engineering Chemistry*, 2015. **22**: p. 384-389.
47. El-Haddad, M.N., Chitosan as a green inhibitor for copper corrosion in acidic medium. *International journal of biological macromolecules*, 2013. **55**: p. 142-149.
48. Flores-De los Ríos, J., et al., Opuntia ficus-indica extract as green corrosion inhibitor for carbon steel in 1 M HCl solution. *J. Spectrosc*, 2015. **1**: p. 2015.

Figures

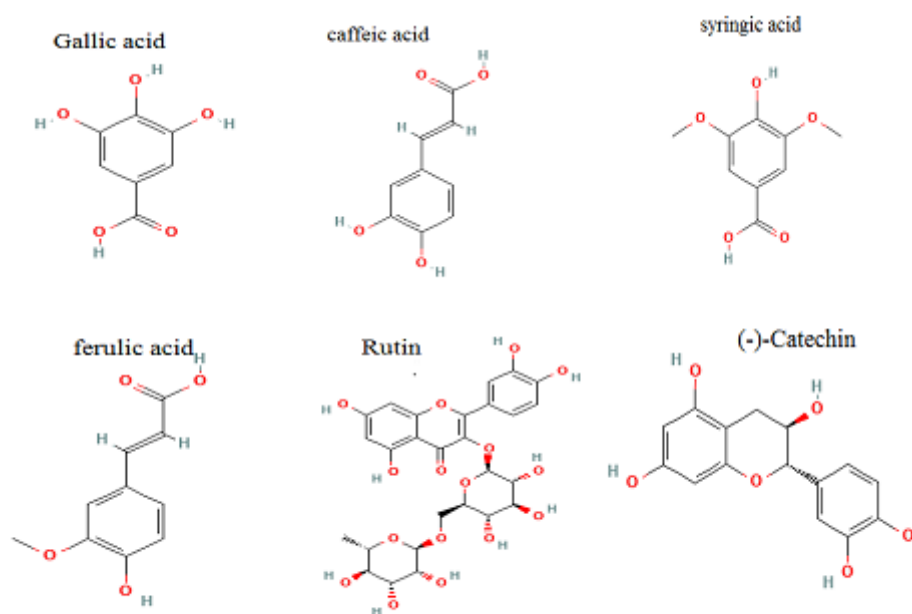


Figure 1

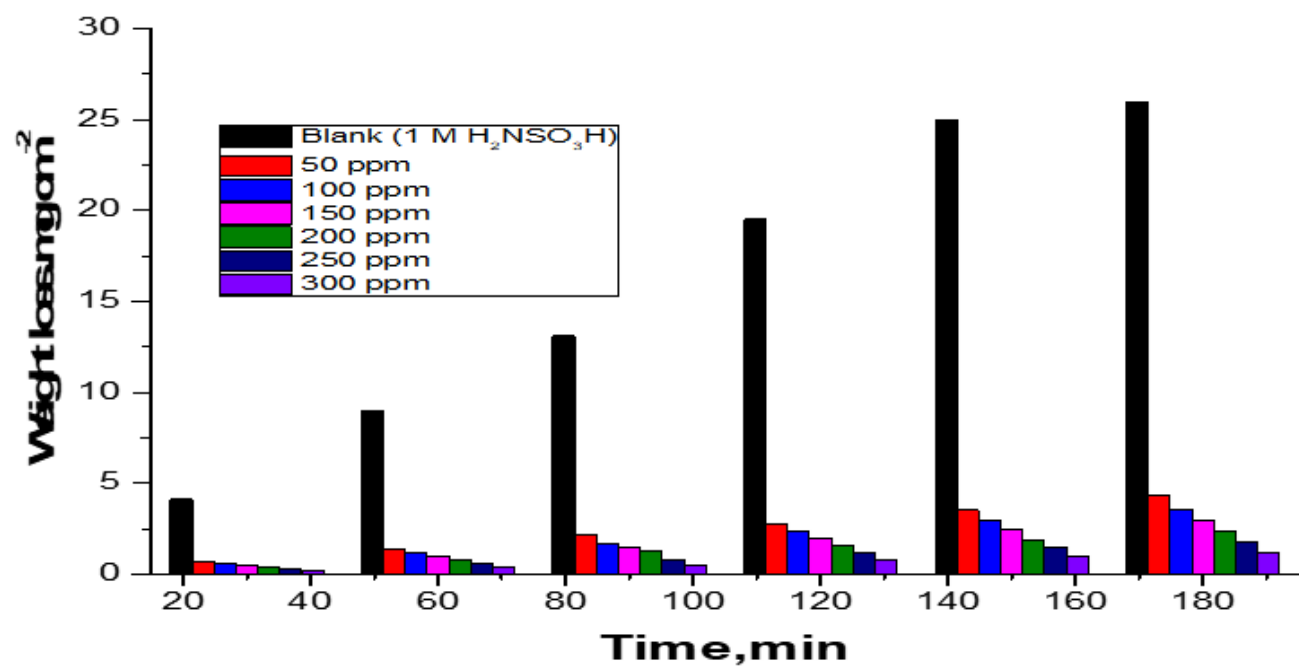


Figure 2

shows the impact of submerged intervals on the amount of mass loss of C-steel in 1 M H₂NSO₃H containing and not containing varied P. cubebaOE doses at 25°C.

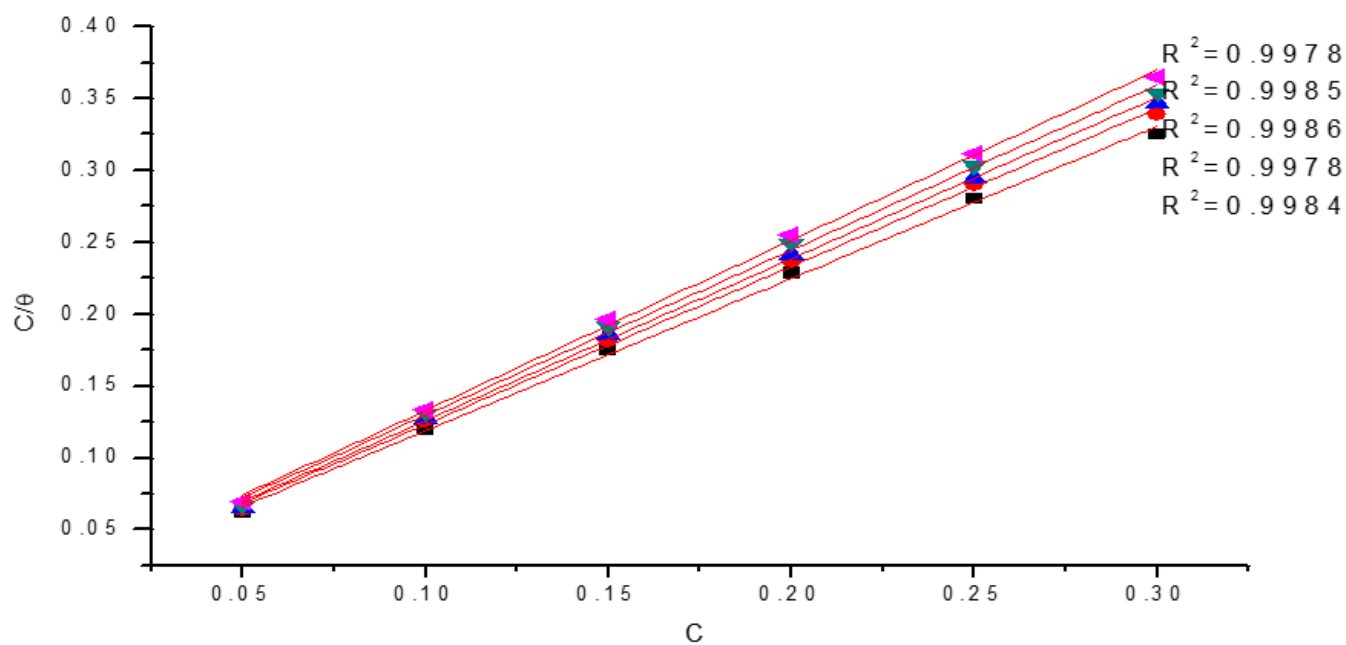


Figure 3

provides the Langmuir pattern produced by PcubebaOE for rusting of C-steel in 1M H_2NSO_3H solution at 25°C as C/θ vs. C , M.

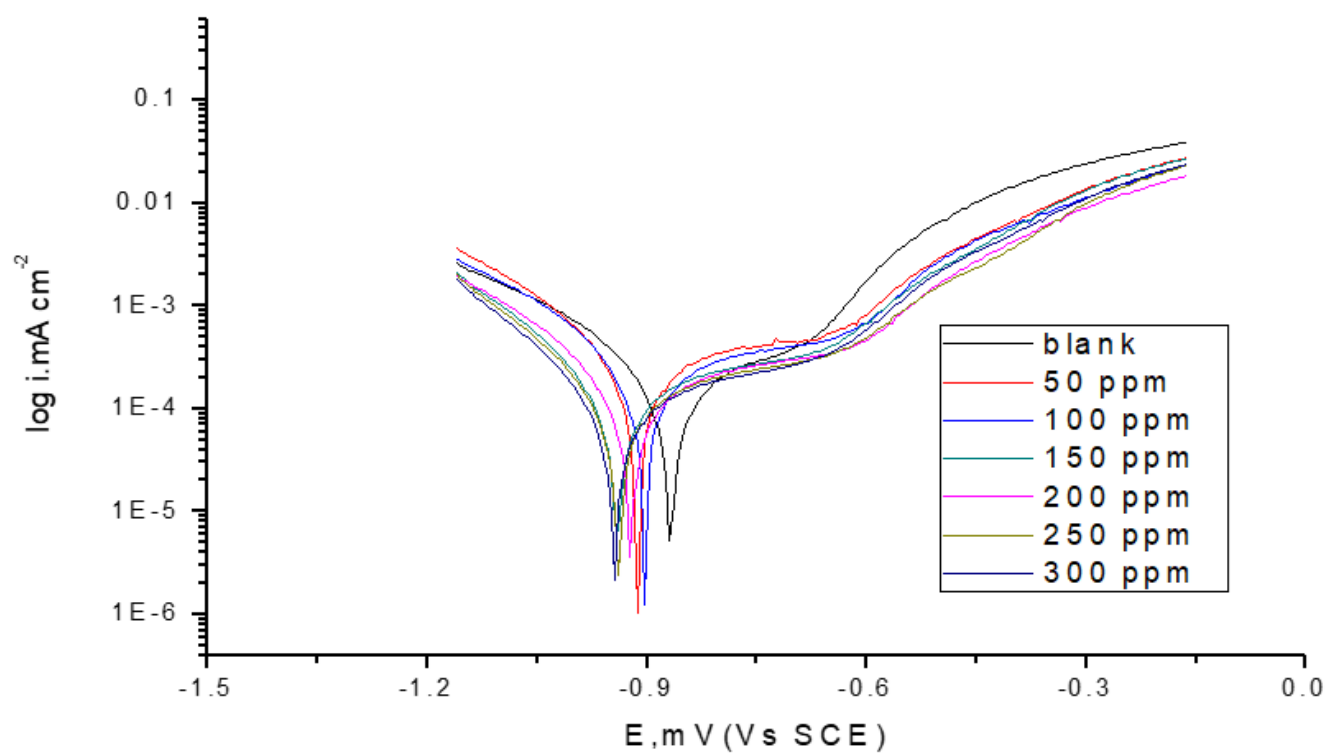


Figure 4

illuminates the potentiodynamic polarization diagrams for C-steel dissolving in 1M $\text{H}_2\text{NSO}_3\text{H}$ in both the existence and not-existence of a variety of P.cubebaOE at 25°C.

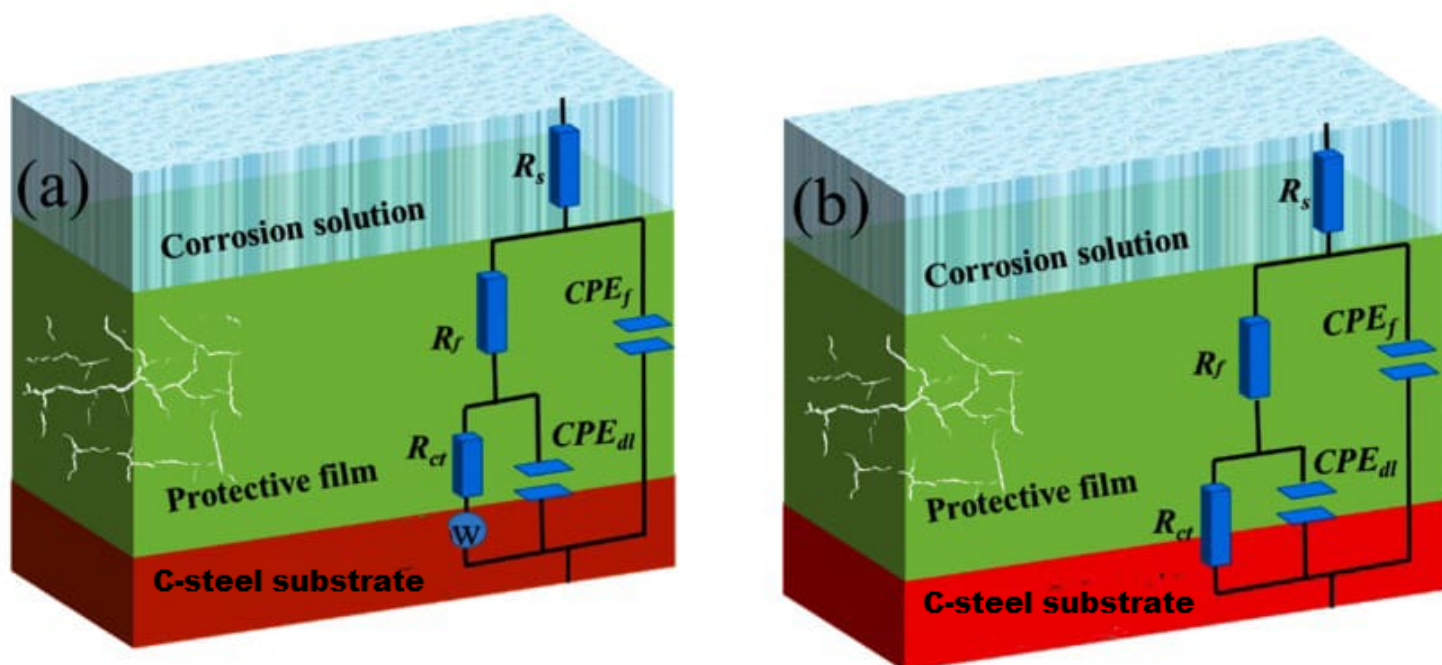


Figure 5

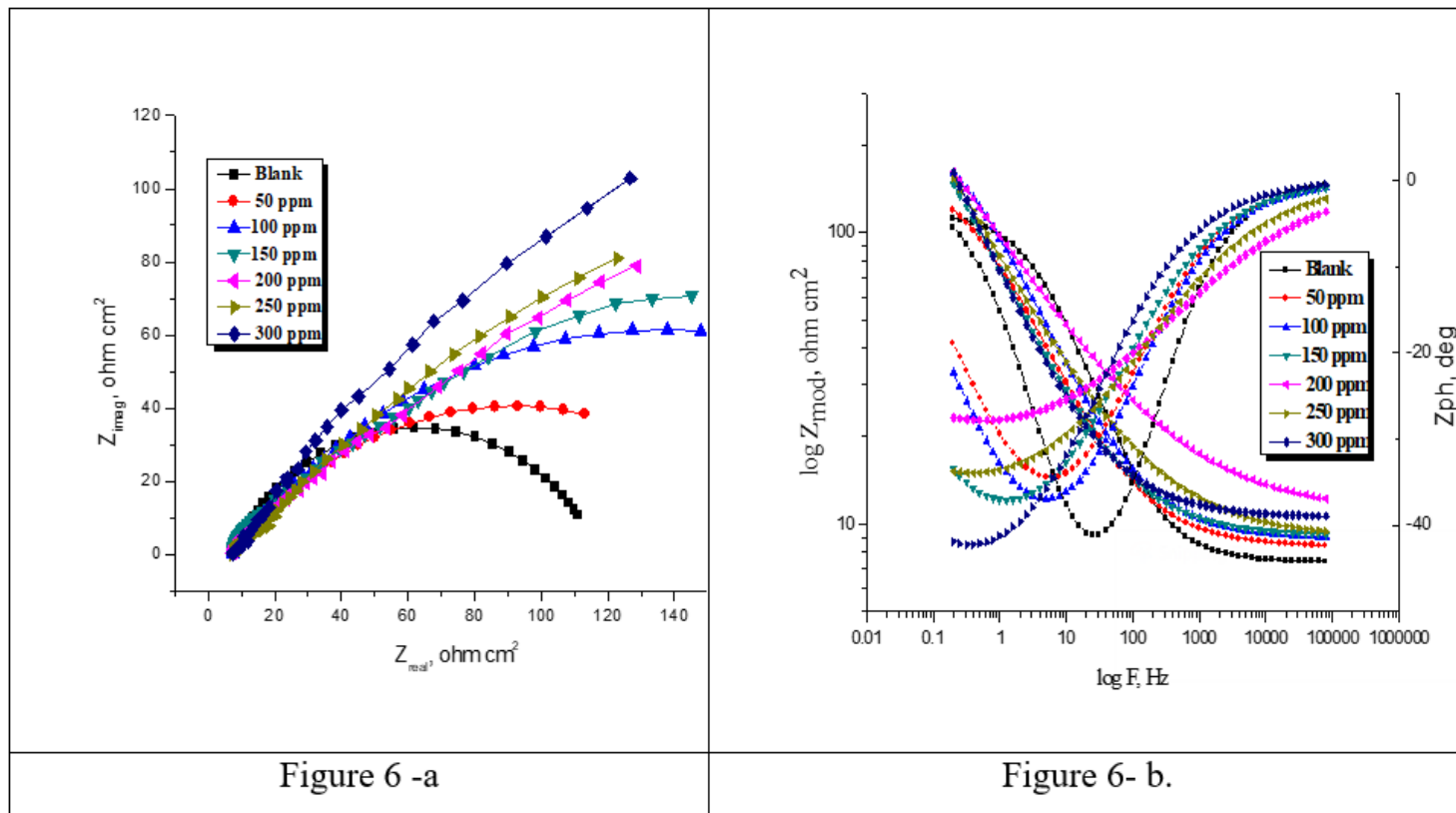


Figure 6

(a, b) shows the Nyquist and Bode plots for the corrosion of C-steel in 1M H_2NSO_3H in both the absence and the existence of multiple amounts of P.cubebaOE at 25°C.

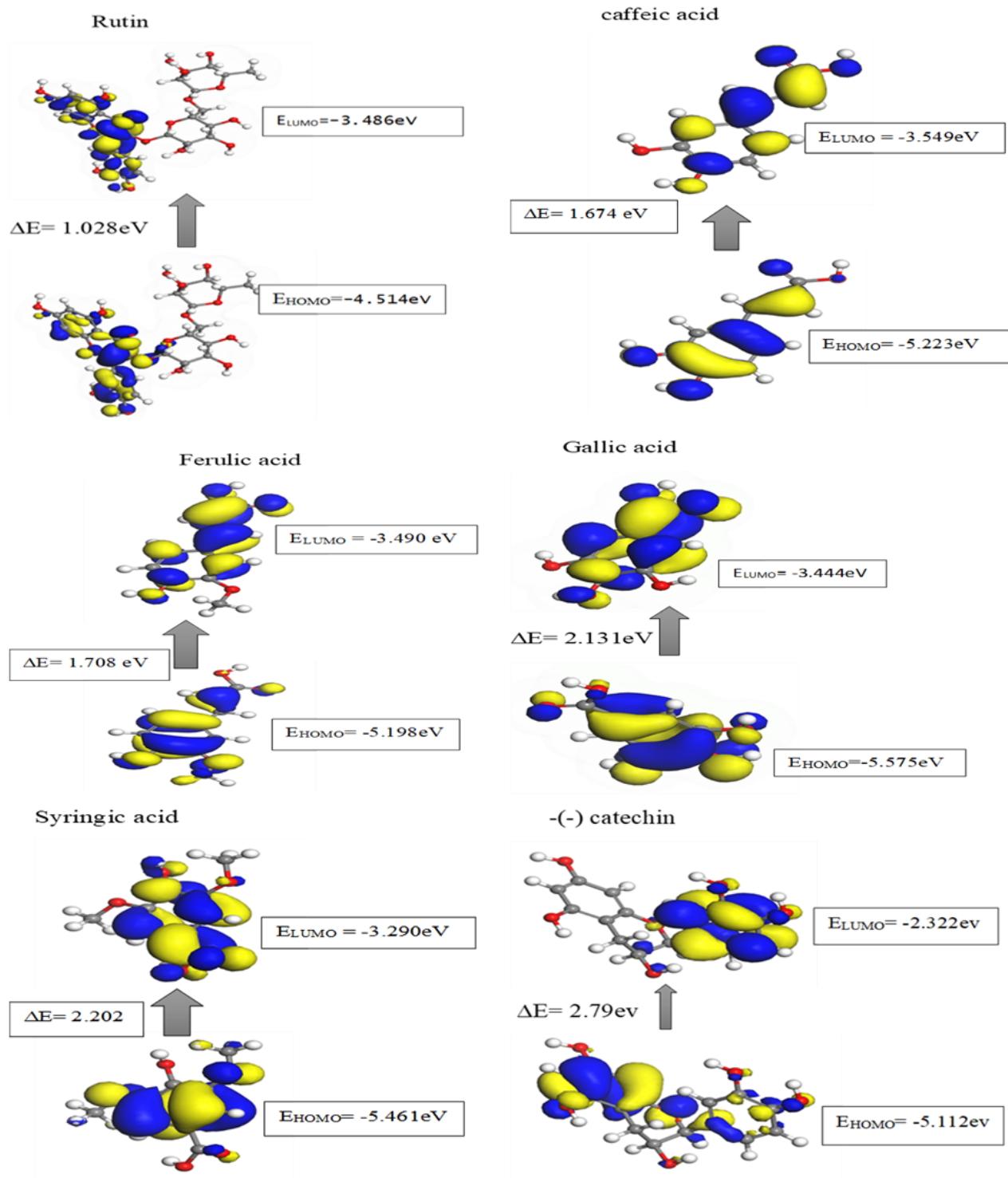
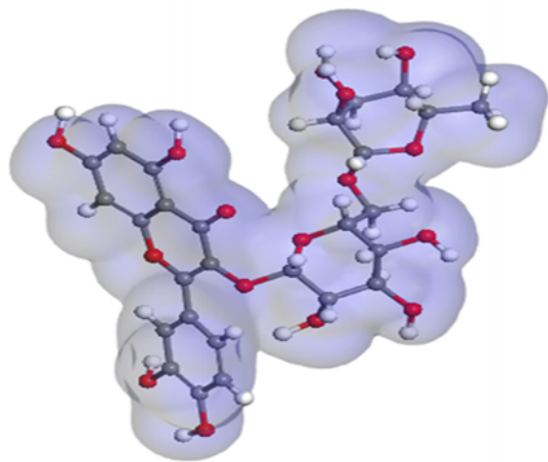
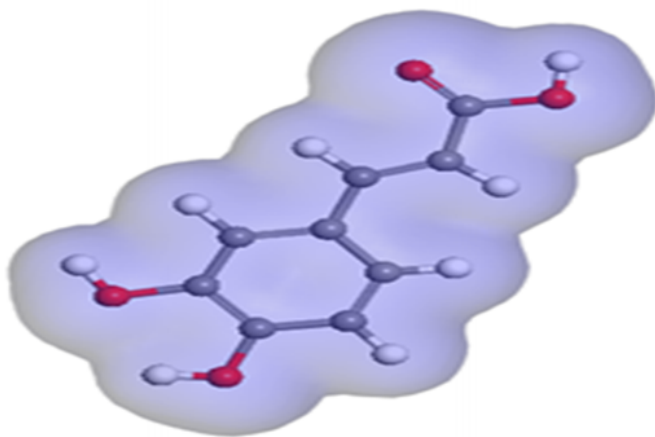


Figure 7

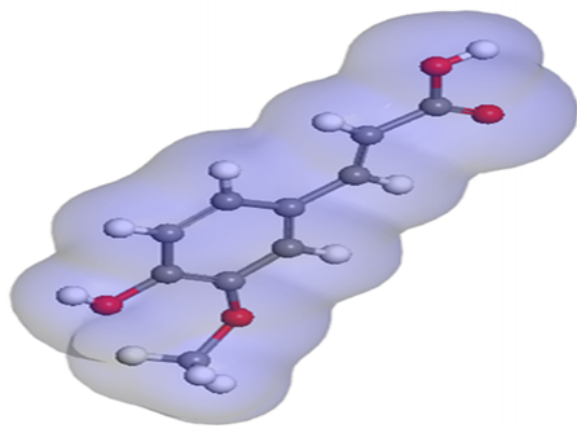
HOMO and LUMO molecular orbitals of major ingredients of P.cubebaOE



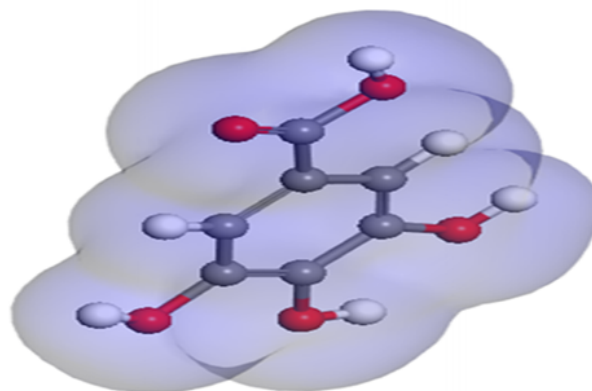
Rutin



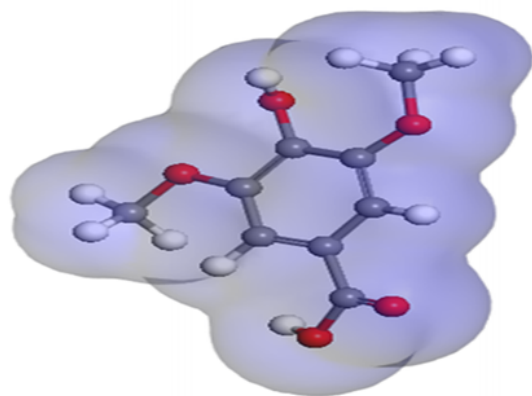
Caffeic acid



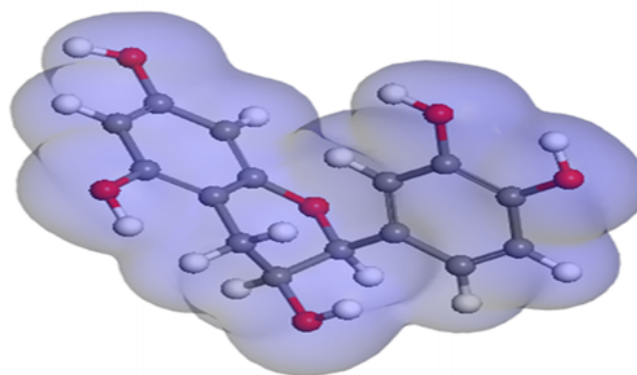
Ferulic acid



Gallic acid



Synergic acid



-(-) catechin

Figure 8

ESP pictures of P.cubebaOE

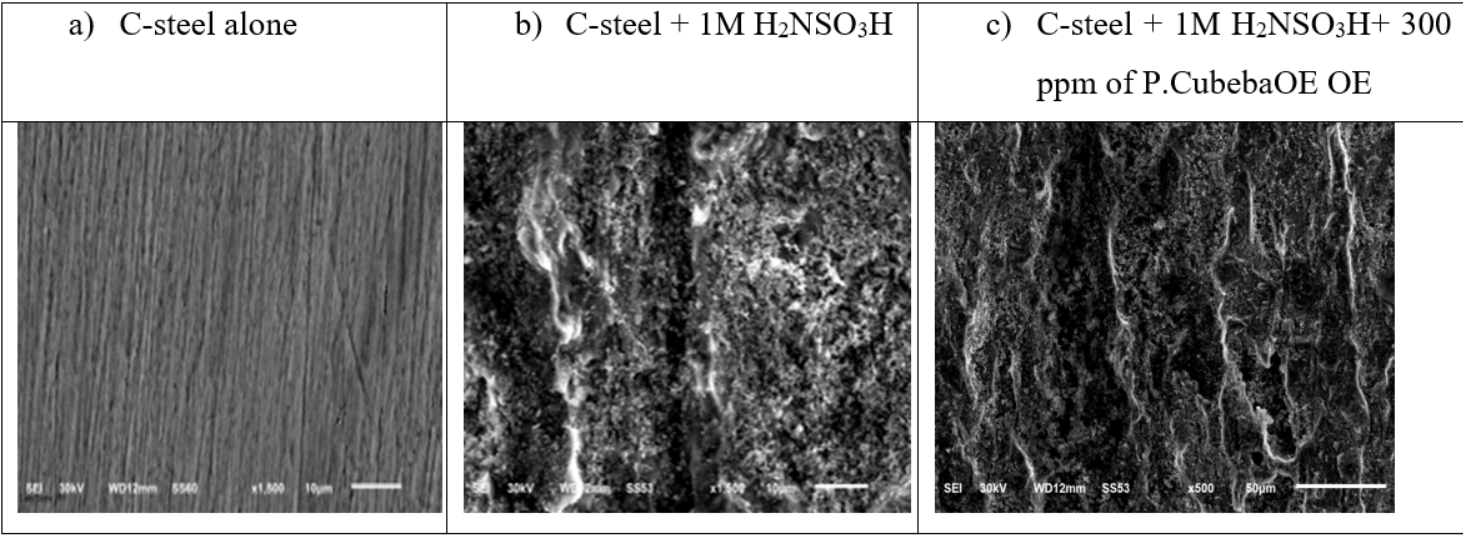


Figure 9

SEM image of pure C-steel in 1.0 M H₂NSO₃H solution (a), without P.cubebaOE at the optimal concentration (b), and with P.cubebaOE present (c).

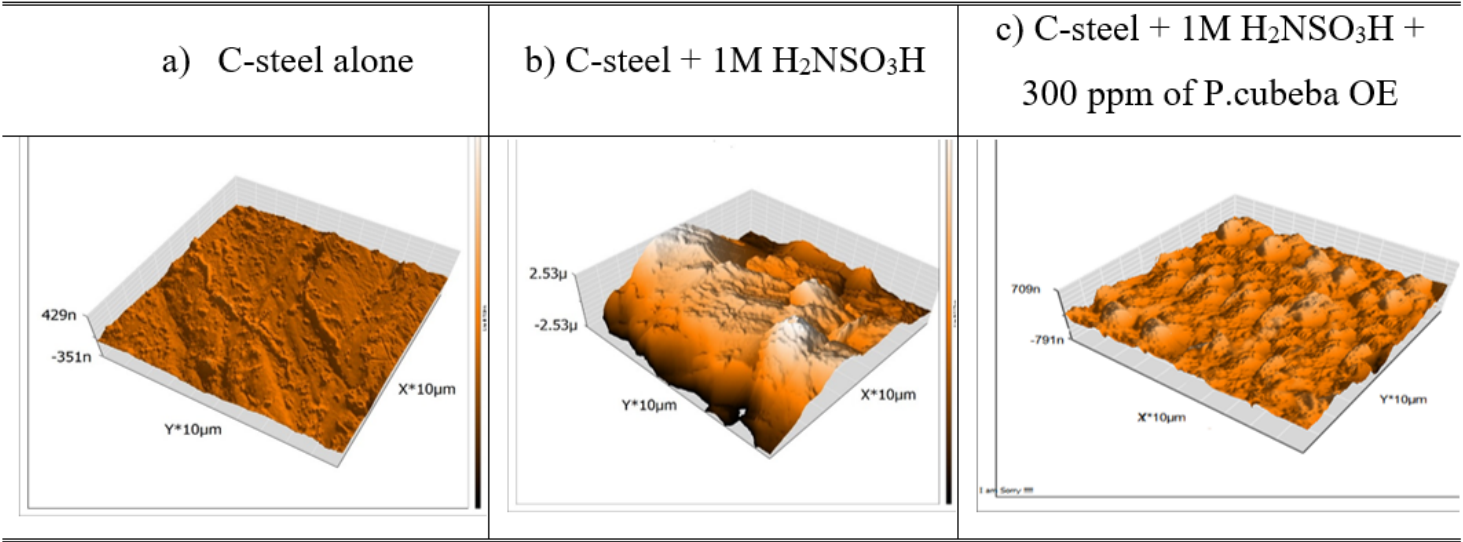


Figure 10

shows an AFM image of pure C-steel (a) and steel that has been submerged in 1.0 M H₂NSO₃H solutions without P. cubebaOE (b) and with it (c), respectively.

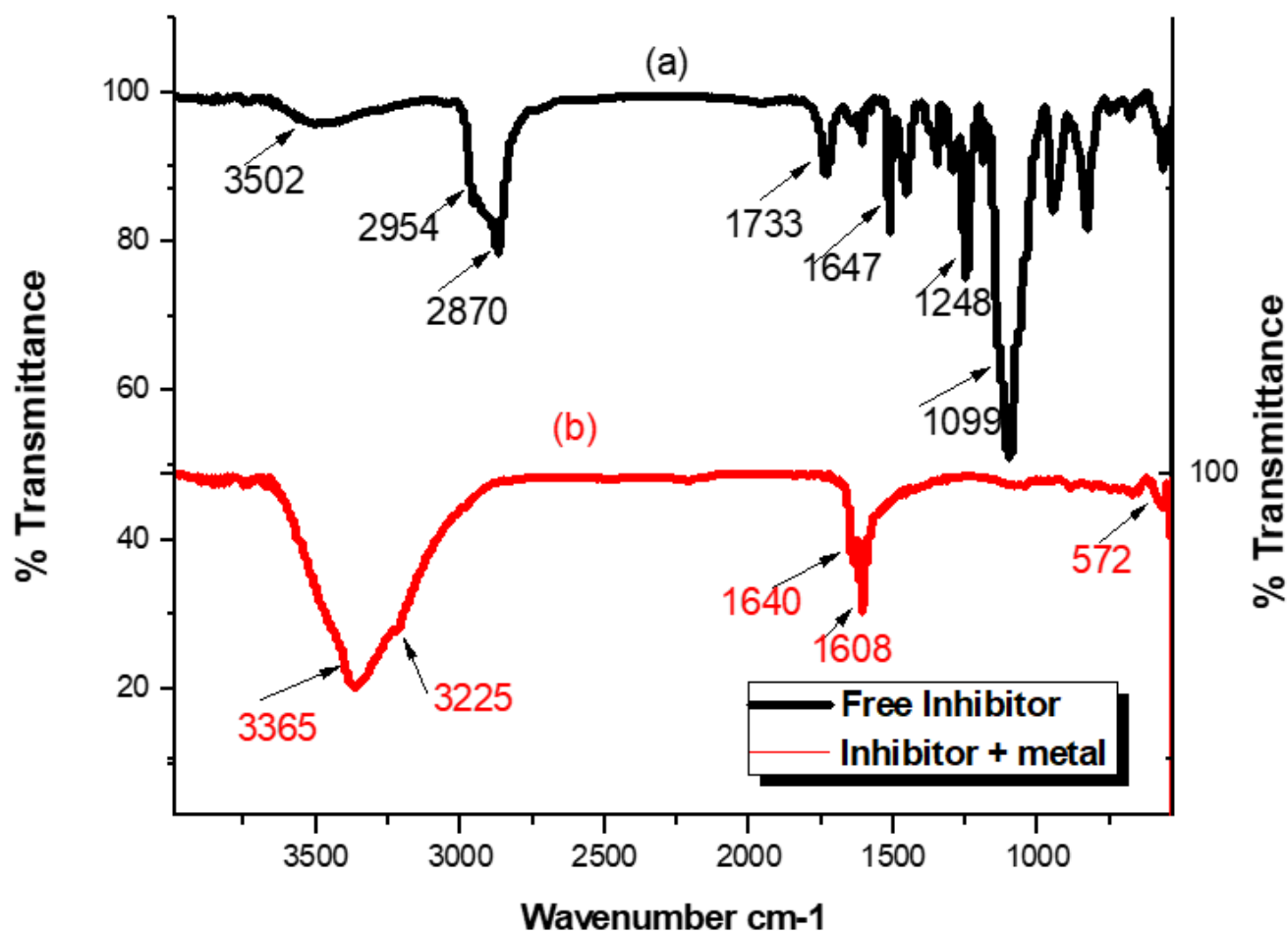


Figure 11

FTIR spectra of P.cubebaOE

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [GraphicalAbstract.png](#)