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ASSESSMENT OF *PHOENIX DACTYLIFERA* SEED EXTRACT AS A GREEN INHIBITOR FOR THE CORROSION OF MILD STEEL IN AN ACIDIC SOLUTION

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Abstract: Metal corrosion continues to be a major problem for a variety of sectors, prompting the investigation of innovative and environmentally acceptable corrosion prevention techniques. This study examined the potential of *Phoenix dactylifera* (date palm) seed extract as a green corrosion inhibitor for mild steel in an acidic environment (HCl). The study thoroughly investigated the inhibitory effects of various extract concentrations (0.2–1.0 g/l) on corrosion rate and efficiency across exposure times of 168 hours using both gravimetric and Tafel polarisation methods. According to experimental findings, extract concentration and corrosion inhibition effectiveness were strongly correlated. Corrosion rates were significantly reduced at higher extract concentrations, supporting the extract's potential as a powerful inhibitor. From the results, optimum inhibiting efficiency of 96.4% with concentration of 1.0 g/l after 72 hours of exposure and 61.99% from 1.0 g/l extract were observed for gravimetric and Tafel polarization, respectively. By emphasizing the extract's capacity to adsorb components onto the steel surface and create a shield that prevents corrosion, the research also contributes to the evolving field of corrosion science through introduction of a natural and eco–friendly corrosion inhibitor.
Keywords: Acidic medium, Corrosion inhibition, Phoenix dactylifera, Protective film, Seed extract

1. INTRODUCTION

Multiple studies have recognised corrosion as a hazard to our ecosystem that requires quick action to reduce its impacts on the overall environment (Badar *et al*., 2014; Adekola *et al*., 2017) According to the study of Hou *et al.* (2017) corrosion serves as an electrochemical process that degrades the characteristics of metals and it serves as a major issue in a variety of sectors, including infrastructure, manufacturing, and the oil and gas industry. Although it has been demonstrated that this corrosion happens in water, air, and other media, it is typically accelerated in acidic solutions such as hydrochloric acid (HCl), which poses a severe danger to the resilience and integrity of metallic structures (Khadom *et al*., 2018). Meanwhile, the corrosion problems may be avoided or minimised by using a variety of methods (Odusote *et al*., 2016; Shuaib–Babata *et al*., 2022), including electrochemical treatment of the metal through cathodic protection, conditioning the metal by coating it with another material, conditioning the corrosive environment by removing oxygen and using corrosion inhibitors.

From the standpoint of engineering material application, carbon steel is widely utilised in activities that have been demonstrated to be reactive in a corrosive environment and this has given it attention in various studies (Shuaib–Babata *et al*., 2023, 2022, 2018; Souza *et al.*, 2022). However, owing to its low cost, a wide variety of mechanical properties, and industrial usage, notably in steel structures, it is majorly used in engineering applications (Adejo *et al*., 2019). Due to carbon steel vulnerability, different uses of inhibitors have been proven to be useful in reducing the impact of corrosion and extending its life duration during application (Odewumi *et al*., 2015; Ahmed *et al*., 2019; Shuaib–Babata *et al*., 2019; Boughoues *et al*., 2020; Shuaib–Babata *et al*., 2022,2023).

In recent years, the effects of inorganic compound corrosion inhibitors used in many industrial applications on the environment have been a source of considerable concern for many researchers as emphasized in the study by Palou *et al.* (2014). This is due to a sharp increase in the production of waste and the usage of hazardous chemicals that are harmful to our ecosystem (Marzorati *et al*., 2018). However, organic natural chemicals are either created synthetically or derived from medicinal and aromatic plants (Singh *et al*., 2022). In the opinion of Shah *et al*., 2014; Kola & Carvalho, 2023), plant extracts are thought to be a very abundant source of naturally synthesised chemical compounds that may be extracted using straightforward techniques at minimal cost and are biodegradable in nature. Holding to this, researchers are looking at the possibility of using natural substances as green inhibitors in their quest for environmentally friendly substitutes. Organic inhibitors have successfully kept the metal away from chemicals that cause corrosion according to various studies (Arthur *et al.*, 2013; Umoren and Solomon, 2015; Wei *et al*., 2020; Shuaib–Babata *et al*., 2022,2023).

Phoenix dactylifera, sometimes known as the date palm, has seeds that may be used to make several interesting compounds (Bentrad and Hamida–Ferhat, 2020).The seeds are not properly kept and usually regarded to as waste product. According to Al–Daihan and Bhat (2012), the date palm, scientifically known as *Phoenix dactylifera*, is a perennial fruit plant belonging to the *Arecaceae* family. It is characterised by being a monocotyledonous woody plant. The fruit harvest in the dry parts of the Arabian Peninsula, North Africa, and the Middle East has always been highly important (Chao and Krueger, 2007). Even though date palms (*Phoenix dactylifera*) have been presented with numerous valuable items for humans (Harkat *et al*., 2022; Manai *et al*., 2024), this study assesses its oil extract further opportunities as a green inhibitor in an acidic solution.The current study investigates the possible appropriateness and efficiency of *Phoenix dactylifera* extract as a bio–corrosion inhibitor for mild steel in acidic medium at ambient temperature utilising different distinct characteristic methodologies.

2. MATERIALS AND METHODS

Mild steel sample preparation

Mild steel plate (Figure 1a) was obtained from the popular saw–mill steel market in Ilorin, Nigeria, and its elemental constituents (compositions) were determined using Optical Emission Spectroscopy (OES) analysis (Spectromaxx LMF06, Agilent Scientific Instruments). The samples of mild steel were produced using a guillotine machine (Figure 1b) by cutting the samples to the dimension of 2.50 x 2.00 x 0.10 cm (Figure 1c) for both gravimetric and gasometric techniques, and 1.0 x 1.0 x 0.1 cm dimension for the purpose of tafel polarization test. The samples were polished with emery paper, degreased in ethanol, dried in acetone, weighed and then kept in a desiccator, in accordance with ASTM G1–30 and G4 standards' guidelines and as was customary in the past (Shuaib–Babata *et al*., 2019; 2022,2023).

(a) (b) (c)

Figure 1: (a) Mild Steel plate (b) Guillotine Machine (c) Metal coupon

Oil extract preparation

(a) (b)

Figure 2: (a) Date fruit (b) Date seed

The date palm (*Phoenix dactylifera*) was commercially obtained from the Ipata market in Ilorin, Kwara State, Nigeria. The oil was extracted from the seed using the methods described in this study in order to conduct the corrosion investigation. The oil extraction (from the seeds of *Phoenix dactylifera*) processes involved manual removal of the edible part of the date fruits to obtain the naked seed (as shown in Figure 2 a & b), which is regarded as a waste product. The date seed was then sun–dried for 7 days (168 hours) and subsequently grinded into a fine powder using a locally fabricated grinder. The extraction of the oil was carried out with a Soxhlet apparatus using n–hexane as the solvent (Figure 3) at the Department of Chemistry Laboratory, University of Ilorin, Ilorin, Nigeria. The extract was utilised to make the stock solution, which was used as an inhibitor throughout the corrosion test.

Figure 3: Soxhlet extraction set–up

Environment solution preparation

An acidic medium (hydrochloric acid, HCl) was prepared from its concentration to 1.0 molarity at the Department of Materials and Metallurgical Engineering Corrosion Laboratory, University of Ilorin, Nigeria using the relationship in equation 1.

$$\text{Molarity} = \frac{\text{Specific gravity of HCl} \times \text{Percentage of Purity}}{\text{Molecular Weight of HCl}} \quad (1)$$

The corrosion tests

The gravimetric (weight loss) and tafel polarisation techniques were employed to ascertain the corrosion degradation and inhibitory efficiency of *Phoenix dactylifera* oil extract in HCl medium.

— Gravimetric techniques

A 200 ml of 1.0 M hydrochloric acid was used to provide the environment for the weighed specimens (coupons) for the corrosion test. The specimens were fully immersed with the help of an inelastic thread to suspend each of the coupons with or without varying quantities of *phoenix dactylifera* oil extract protected from the atmosphere (Figure 4). The inhibitor was varied in concentrations (0.0, 0.2, 0.4, 0.6. 0.8 and 1.0 g/l). The immersion of the mild steel sample (coupon) was observed in the corrosion environment the period of 24 – 168 hours.

Figure 4: Immersion of specimen in hydrochloric acid

Subsequently, the specimens were thoroughly cleaned using the chemical medium as specified in ASTM G31 and immediately reweighted to ascertain the weight loss. The corrosion rates and inhibitory efficiency were derived using the equations as depicted in equations 2 and 3.

$$\text{Corrosionrate (mpy)} = \frac{kW}{ATD} \quad (2)$$

$$\text{Inhibition efficiency percentage } \mathrm{I.E}\,(\%) = \frac{CR_{Blank} - CR_{Inh}}{CR_{Blank}} \times 100 \quad (3)$$

where, k, W, A, T, D, $CR_{Blank}$and Cr_{Inh} are Constant (3.45 x 10^6 mils), mass loss (g), Area (cm^2), time of exposure in hours, steel density in (g/cm^3), corrosion rate without inhibitor and with inhibitors respectively.

— Tafel polarization

Aluminium foil was used to hold the specimen together while it was placed on a cup mould and a flexible cable was attached to it (Figure 5). A different cup mould was used to fully mix a polyester resin before adding the hardener to create a solution. The prepared solution was then poured into the mould containing the specimens and allowed to be set between 15 to 20 minutes. After they had solidified, they were taken out of the mould.The coupon was further polished with several emery paper grades to create a glossy, shiny surface. The Tafel polarisation was then performed at the open circuit using a versa STAT potentiostat that was computer controlled. This practice is in line with the practice of earlier researchers (Shuaib–Babata *et al*., 2020).

Figure 5: Samples of the Tafel specimens

Table 1: Elemental Composition of Mild Steel

S/No	Metal	%wt. Elemental Compositions
1	Fe	99.700
2	C	0.0112
3	Mn	0.1020
4	P	0.0222
5	Si	0.0052
6	Cr	0.0342
7	Al	0.0134
8	Ni	0.0015
9	Sn	0.0053
10	Co	0.0159
11	Ti	0.0002
12	V	0.0005
13	As	0.0049
14	W	0.0050
15	Ca	0.0042
16	Se	0.0034
17	Te	0.0025
18	Ta	0.0070
19	B	0.00097

3. RESULTS AND DISCUSSION

Characterisation of Mild Steel

The steel sample's elemental composition as presented in Table 1, shows that the carbon content is low (0.0112wt.%) and the steel falls within the class of low carbon steel. By the steel classification, the steel sample with carbon content < 0.25% is a low carbon steel (Kopeliovich Dmitri, 2024).

Gravimetric technique Corrosion Test

The disparity of weight loss (before and after the corrosion tests) recorded in the coupons at different concentrations of *Phoenix dactylifera* seed extract in 1.0 M HCl at different time of immersion are shown in Figures 6. Also, the variation of corrosion rates calculated and the derived inhibition efficiency of the *Phoenix dactylifera* seed extract against the time of exposure are shown in Figures 7 and 8, respectively. The results, as presented in

Figure 6, highlight the relationship between the concentrations of the seed extract and weight loss of the steel over the time of exposure with investigation conducted over a span of 168 hours. Consistent with prior research (Odusote *et al.*, 2016), the results demonstrated a clear correlation between inhibitor concentration and weight loss reduction. The most notable decrease in the weight loss occurred at an inhibitor concentration of 1.0 g/L.

Furthermore, a noteworthy observation was made regarding the impact of inhibitor concentration on longer exposure times. After 168 hours of exposure, the weight loss in the presence of 0.4 g/L inhibitor was significantly lower at 0.66 g/L compared to the absence of inhibitor at 1.89 g. This outcome underscores the trend identified in the study by Al–Amiery *et al*. (2022).

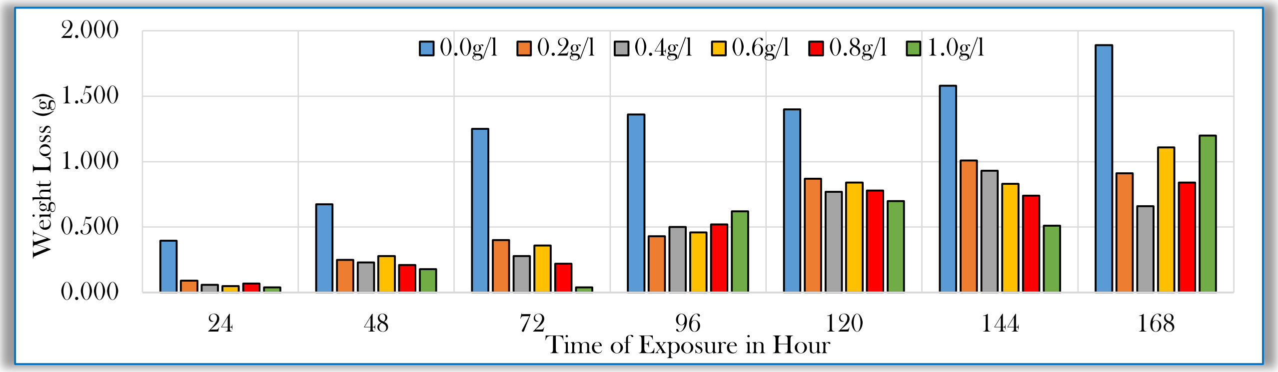

Figure 6: The weight loss of AISI 1018 steel after exposure in 1M HCl for varying time with and without *Phoenix dactylifera* seed extract

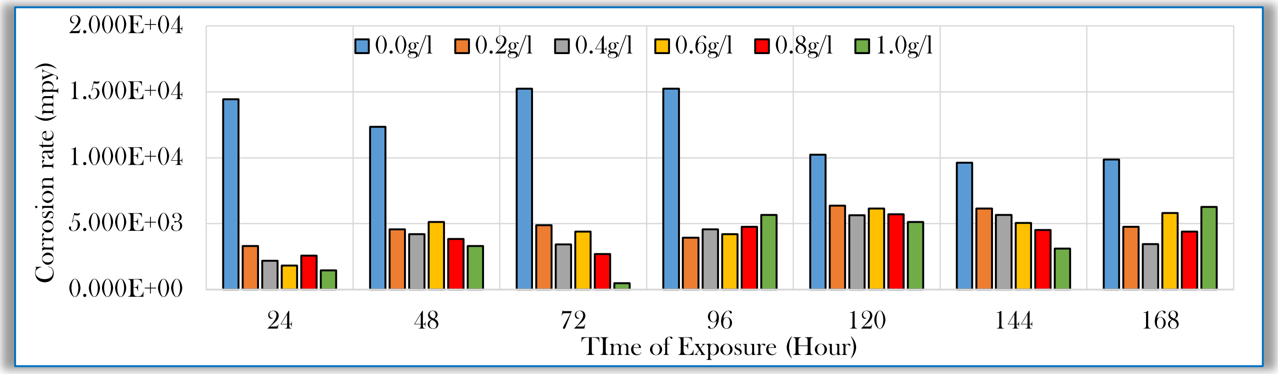

Figure 7: Variation of corrosion rates of the coupons over the period of exposure with or without *Phoenix dactilyfera* seed extracts

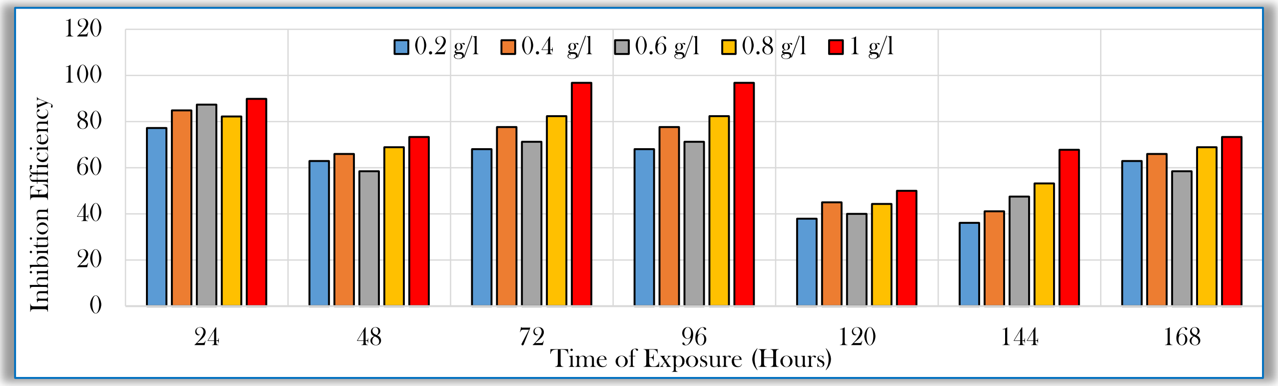

Figure 8: Inhibition efficiency (IE) of *Phoenix dactylifera seed* extracts on corrosion of mild steel in 1M HCl solutions

After the period 72 hours of immersion in the media of exposure, the corrosion rate exhibited distinct profiles, where the lowest corrosion rate was demonstrated for 1.0 g/L concentration of inhibitor as depicted in Figure 7. The corrosion rate demonstrated discernible fluctuations as the concentration of the extract was increased, as visualized in Figure 7. This might be the consequence of the corrosion products (layers) formed on the surfaces and edges of the coupons that fell out (as visually observed) to given room for fresh formation of another layer. It is an indication that protective period was short. This pattern highlights a significant correlation between the *Phoenix Dactylifera* seed extract content and its effect on the components' adsorption to the mild steel surface. The creation of a protective barrier on the steel surface is aided by an increase in adsorption with increasing extract concentration. The observed decrease in corrosion rate is directly related to this barrier development (Zulkifli *et al*., 2017). As depicted in Figure 8, the concentration directly affects the inhibition efficiency of the extracts. The findings demonstrate that the inhibitory effectiveness generally rises as the concentration increases, while it does not consistently correlate with an increase in time. Notably, optimum inhibiting efficiency of 96.4 % was recorded with the concentration of 1.0 g/l after 72 hours of exposure as depicted in Figure 8. Even after being exposed for 168 hours, the specimens in the HCl medium containing the *Phoenix dactylifera* seed extracts remained protected from the corrosion damage. This is an indication the the extractive is suitable as a corrosion inhibitor in the acidic medium. The creation of a protective coating on the specimens' surfaces and edges as a result of the metal interface changing from an active dissolving state to a passive one may be responsible for the efficacy (Odusote *et al*,. 2016; Shuaib–Babata *et al*., 2022; Mehmood *et al*., 2021).

Tafel Polarisation

The Tafel polarisation curves for mild steel in the presence and absence of *Phoenix dactylifera* seed extract (PDSE) at various concentrations are displayed in Figure 9. Table 2 lists the critical polarisation parameters for mild steel corrosion both in the presence or without the *Phoenix dactylifera* seed extract, including corrosion potential (Ecorr), cathodic (c) and anodic (a) Tafel slopes, corrosion density (Icorr), and surface coverage (ϴ).

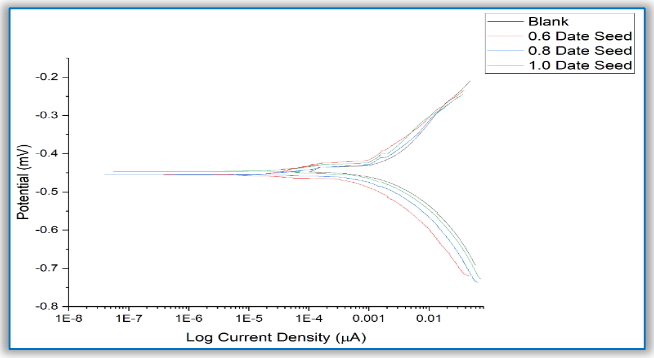

Figure 9: *Tafel*/Polarization curves of mild steel in 1M HCl with and without PDSE Inhibitor

Additionally, the PDSE Tafel polarisation analysis shows that for the test coupons in the PDSE inhibitor, the corrosion potentials (Ecorr) changed towards the negative potentials. However, the corrosion current density (Icorr) values decreased while the estimated (IE) of the inhibitor increased. The highest (IE) was observed at 1.0 g/l concentration, which was 61.99%. Figure 7 depicts the difference in Tafel slopes for cathodic (c) and anodic (a) interactions with and without the PDSE. This suggests that the inhibitor may have an effect on both the anodic and cathodic reactions.

Table 2: *Tafel*/polarization parameters for corrosion of mild steel in the absence and presence of varying concentration of PDSE in 1M HCl

Extracts	Conc. (g/l)	Icorr (μA)	Ecorr(mV)	βc (mV)	βa(mV)	CR (mmpy	IE%	ϴ
Blank	1M HCl	1274	–439.179	117.366	205.646	14.794		
Date	0.6	819.262	–449.304	140.355	133.186	9.5064	35.69372057	0.356937
	0.8	554.141	–449.685	74.012	74.139	6.4301	56.50384615	0.565038
	1	484.281	–446.362	93.431	11.171	5.6194	61.98736264	0.619874

4. CONCLUSION

In conclusion, this study has shed important light on the ability of date palm (*Phoenix dactylifera*) seed extract to prevent corrosion in mild steel when exposed to HCl. Several significant discoveries were made after an extensive series of observation and analyses as follows:

- The mild steel corrosion inhibition rate in HCl solution shows discernible fluctuation over the observed 168 hours, however with increase in the concentration of inhibitor extract (PDSE), the inhibiting rate rises.
- The Phoenix dactylifera seed extract demonstrated optimum inhibiting efficiency of 96.4% with concentration of 1.0 g/l after 72 hours of exposure in acidic media for mild steel and even despite the duration of observation, mild steel in the presence of inhibitor remained undamaged.
- The extract of *phoenix dactylifera* seed extract influences both the cathodic hydrogen evolution as well as the anodic dissolution of the mild steel. The percentage of inhibiting efficiency is therefore observed to increase with increase in concentration with optimum value of 61.99% from 1.0 g/l extract.
- The Phoenix dactylifera seed extract helps develop a green, sustainable method for inhibiting the corrosion of mild steel in an acidic environment.

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