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Original Research Article

Investigation of *Garcinia kola* Exudates as Corrosion Inhibitor for Mild Steel in Acidic Environment

Uche Christian Ajah[1*], Kanee Sorbari[2], Charles Kennedy[3]

[1]Department of Civil Engineering Technology, Akanu lbiam Federal Polytechnic, Unwana, Afikpo, Ebony State, Nigeria
[2]School of Engineering, Department of Mechanical Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria
[3]Department of Civil Engineering, Kenule Benson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria

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***Corresponding author:** Uche Christian Ajah
Department of Civil Engineering Technology, Akanu lbiam Federal Polytechnic, Unwana, Afikpo, Ebony State, Nigeria

Abstract

This study investigated the performance of *Garcinia kola* exudates in preventing mild steel exposed to acid concentrated water and soil. The study was performed in order to find an alternative coating substance that can reduce the corrosion of mild steel pipes exposed to corrosive water and soil media. Various mild steel specimens were cut into portions and coated with the exudates at 25 - 50µm thickness. To accelerate the rate of corrosion, 0.5M hydrochloric acid (HCl) was added to tap water in a container. Also, the same concentration of HCl was equally added to soil samples. Uncoated mild steel specimens were immersed in the acid concentrated water and soil, servicing as control sample. The rate of corrosion was monitored for 30 days (720 hours). The inhibition efficiency of the exudates for both corrosive media was compared. Results showed that the weight loss and corrosion rate of mild steel decreased with increase in coating thickness. Comparatively, weight loss and corrosion rate in the uncoated specimens were higher than the coated specimens. For uncoated specimens, the corrosion rate was 0.2793mm/yr and 0.4150mm/yr for specimen immersed in water and soil respectively, but at 25µm coating thickness, it decreased to 0.01369mm/yr and 0.2870mm/yr for specimens in water and soil. Also, at 50µm coating thickness, corrosion rate decreased to 0.0052mm/yr and 0.0318mm/yr for specimens in water and soil, respectively. The inhibition efficiency increased with coating thickness, ranging from 51.00 – 98.15% for specimens immersed in water and 30.84 – 92.33% for specimens buried in soil at 25µm – 50µm coating thickness. The results demonstrated that *Garcinia kola* exudates can be used as corrosion inhibitor for mild steel exposed to corrosive media.

Keywords: Galvanised Steel, Corrosion Rate, *Garcinia kola* Exudates, Water, Soil.

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1. INTRODUCTION

Metals are important engineering material with wide applications in construction and production industries. They are used in production of beams, angle iron, rods, bars, sheets and pipes. Metals are used for construction of buildings, industrial facilities, bridge, medical instruments, automobile components and telecommunication mast, amongst others (Chuka *et al.*, 2014; Otunyo & Charles, 2017). Due to environmental factors and specialty in application, different grades and types of steels such as stainless, carbon and mild steels are produced to fit appropriately in some area of application.

In spite of efforts taking in reducing the impact of environmental factors on corrosion of steel in harsh environment, corrosion attack still persists on steel structures and equipment. Environmental factors such as temperature, radiation, alkalinity, electrode potential, impurities, oxygen concentration and chemicals have been listed as agents of corrosion and influence the corrosion rate of metals (Muslim *et al.*, 2014; Adikari & Munasinghe, 2016).

Deterioration of engineering and construction materials in natural environment has serious negative impact on global economics (Muslim *et al.*, 2014). As a result, suitable control measures need to be taken to prevention or reduce impact of corrosion on metals. Numerous techniques have been proposed in reducing corrosion attack on metals, and they include painting, cementing, and coating electrochemical process, application of inhibitor (Papavinasam, 1999; Chigondo & Chigondo, 2016). Corrosion inhibitors are substances applied on the surface of a corroding material or injected into the corrosive media, and it can be applied at the stage of manufacturing or in the environment where the metal is to be exposed to (Chigondo & Chigondo, 2016; Hou *et al*., 2018; Verma *et al*., 2018). Corrosion can be prevented or reduced by regular monitoring and inspection of metal (Iyasara & Ovri, 2013; Chuka *et al*., 2014; Adikari & Munasinghe, 2016; Okewale & Olaitan, 2017).

Concerns have been expressed due to leakage in steel pipes transporting crude oil, water and other liquid substances caused by corrosion (Chen & Zhao, 2017; Putra *et al*., 2020). The is a consequent of factors such as atmospheric conditions, salt and acid concentration in the environment in which the pipes are exposed to, as in the case of Niger Delta region. The Niger Delta environment of Nigeria is very acidic and salty due to presence of seawater, rivers and industries which release corrosion agents into the atmosphere, making metallic materials highly susceptible to corrosion attack (Piaro, 2019). Most pipes are passed through underwater, while most crude oil pipelines are buried underground. Overtimes, these pipes, whether used to transport water, crude oil or other liquid substances, rupture due to corrosion. This situation could lead to total shutdown of flow, collapse of other adjoining facilities and even, fatal accident. The green environments are also affected in the event of rupture from crude oil transporting pipes.

Studies have shown that extract from plants are less toxic, biodegradable and environmentally friendly (Papavinasam, 1999), and are good corrosion inhibitors (Amise *et al*., 2016; Verma *et al*., 2018; Otunyo & Charles, 2018; Ezeugo, 2019). Therefore, this study investigated the inhibition efficiency of *Garcinia kola* exudates in reducing the corrosion of mild steel pipes exposed to acid concentrated water and soil media. *Garcinia kola*, also known as bitter kola, is a found in West Africa, and it belongs to Clusiaceae family. The thick fluid (exudates) from the trunk is viscous and sticky. Thus, this study investigated effectiveness of the exudates as corrosion inhibitor for steel immersed in acid media.

2. MATERIALS AND METHODS

The materials and methods used to achieve this study are stated and explained in the subsections below.

2.1 Materials

Galvanised steel, *Garcinia kola* exudates, volumetric flasks, beakers, measuring cylinder, digital weighing balance, thread, filter paper, venire calliper, micrometer screw gauge, desiccator, hydrochloric acid, sodium hydroxide, petroleum ether, acetone, ethanol, distilled water, electrochemical cell with electrodes assembly.

2.2 Sample Collection and Preparation

The exudates were extracted from Garcinia kola tree in Ubeta community in Ahoada West Local Government Area of Rivers State. As cited in Verma *et al*., (2018), plant extracts have been shown to be effective green corrosion inhibitors for metals and alloys. Mild steel pipe was obtained from Mile III market in Port Harcourt, Rivers State of Nigeria. The galvanised steel pipes of 15mm diameter were smoothened with the aid of silicon carbide abrasive paper, and thereafter greased and degreased with petroleum ether to prevent further corrosion (Amise *et al*., 2016; Prithiba *et al*., 2014). It was thereafter washed thoroughly in distilled water to remove any contaminants as contaminants can impact corrosion (Yahaya *et al*., 2011). The dried pipe was cut into various parts with an average length of 20mm to test different samples as reported in other studies (Chigondo & Chigondo, 2016; Chen & Zhao, 2017). Tap water was obtained from the laboratory, while the hydrochloric acid (HCl) was purchased from chemical retail store in Port Harcourt. HCl is a common acid used to study corrosion of mild steel (Ameh & Eddy, 2016; Owate *et al*., 2014).

2.3 Experimental Procedure

The gravimetric method was used in the measurement of corrosion rate of coated and uncoated samples as discussed by Hou *et al.*, (2018) in their study on corrosion and protection of metal in seawater desalination. The galvanised steel used has the following chemical compositions C (0.17%), Si (0.30%), Mn (0.70%), S (0.03%), P (0.03%) and the balance being for Fe as reported in studies investigating corrosion rates of different metal compositions (Muslim *et al*., 2014; Rosliza *et al*., 2006). The gravimetric technique employed allows for direct measurement and quantification of mass loss due to corrosion as discussed in the review by Papavinasam (1999), which is vital for comparing corrosion performances between coated and uncoated samples.

2.3.1 Immersion in Acid Solution

The prepared specimens were weighed and coated with the exudates at thickness ranging from 25 to 50μm at intervals of 5μm (Otunyo & Charles, 2017; Otunyo & Charles, 2018), validating the use of exudates for corrosion prevention. Another specimen was left uncoated, serving as a control sample (Amise *et al*., 2016). Plastic 250ml beaker was filled with 200ml of water followed by addition of 25ml of 0.5M hydrochloric acid (acid to water ratio of 1:8) (Muslim *et al*., 2014), supporting the use of this solution composition. The addition of acid was to accelerate the corrosion rate (Chigondo & Chigondo, 2016). The coated and uncoated galvanised steel specimens were immersed completely in the acid solution. After 30 days, the specimens were withdrawn from the solution and washed with distilled water. Thereafter, the specimens were cleaned and air dried. After drying, they were weighed, and the weight recorded (Banerjee *et al*., 2012), validating the standard immersion and weighing procedure.

2.3.2 Immersion into Acid Concentrated Soil

The coated and uncoated galvanised steel specimens were buried completely in the acid concentrated soil (Chuka *et al.*, 2014). Soil composition plays an important role in corrosion rates, as acidity levels can significantly impact corrosion (Yahaya *et al.*, 2011). Adding hydrochloric acid to the soil in this experiment aimed to increase acidity and thus accelerate corrosion rates to better observe the protective effects of the coatings (Chen & Zhao, 2017). Soil properties such as moisture content, pH, chlorides, oxygen levels can influence corrosion processes of buried metal (Dang *et al.*, 2015). Completely burying the specimens ensured soil contact on all sides to subject both coated and uncoated samples to the same corrosive environment conditions (Putra *et al.*, 2020). Soil provides an electrolyte and aerobic/anaerobic interfaces that can drive corrosion through redox reactions (Hou *et al.*, 2018). Previous studies have shown that corrosion rates in soil can vary greatly depending on specifics of the soil analyzed (Rosliza *et al.*, 2006). By comparing weight changes after exposure, this experiment allowed evaluating the ability of plant-based coatings to impede corrosion in an acidic soil environment (Singh *et al.*, 2015).

2.4 Weight Loss and Corrosion Rate

The weight loss method was used in this study to determine the corrosion rate of galvanised steel (Hou et al., 2018). Thus, the weight loss over time was measured by subtracting the instantaneous weight from the initial weight of the specimen (Chigondo & Chigondo, 2016). Regular weight measurements were taken to track corrosion progression, in line with established corrosion measurement techniques (Papavinasam, 1999). From the weight loss measurement, the corrosion rate of galvanised steel was calculated using the corrosion model stated in Equation (1) (Chigondo & Chigondo, 2016). This model is commonly used to determine corrosion rates from weight loss data, as it accounts for key factors such as material density and exposed surface area (Singh *et al.*, 2015).

The corrosion rate is expressed as a function of weight loss per surface area exposed to the corroding medium per material density per exposure time (Chigondo & Chigondo, 2016). This functional relationship indicated by Equation (1) allows corrosion rates to be standardized and compared across different materials and exposure conditions (Yahaya *et al.*, 2011). But K is given as 87.6, while the density of galvanised steel was given as 7.85g/cm3 (Singh *et al.*, 2015). Using the above units, as is standard practice in corrosion rate calculations (Verma *et al.*, 2018), the corrosion rate, C_R, is expressed in millimetre per year (mm/yr) (Singh *et al.*, 2015).

$$C_R = \frac{K\Delta w}{\rho A t} \qquad (1)$$

where: $C_R =$ Corrosion rate (mm/yr)

$K =$ Constant

$\Delta w =$ Weight loss (mg)

$\rho =$ Density of material (g/cm^3)

$A =$ Cross-sectional area of metal (cm^2)

$t =$ Time (hr)

Previous studies have also utilized the weight loss method and Equation (1) to determine corrosion rates of mild steel and other materials in various exposure environments (Chuka *et al.*, 2014; Dang *et al.*, 2015; Iyasara & Ovri, 2013; Yahaya *et al.*, 2011). The accuracy and reliability of this technique for corrosion rate measurement has been well established (Papavinasam, 1999). Regular monitoring of specimen weight allows tracking of corrosion progression over time (Hou *et al.*, 2018). When combined with measurements of other exposure factors like temperature or contaminant concentration, it can provide insightful data on how these variables impact corrosion dynamics (Yahaya *et al.*, 2011).

While several alternative techniques exist like linear polarization, this study employed the weight loss method due its relative simplicity and good accuracy for long-term exposures (Papavinasam, 1999). Close replication of actual exposure conditions also enhances results validity (Chigondo & Chigondo, 2016). In conclusion, the weight loss technique and Equation (1) provided an effective means to characterize corrosion behavior and quantify corrosion rates in this investigation.

2.5 Inhibition Efficiency

To determine the effectiveness of plant exudates in reducing the corrosion rate of mild steel in acidic media, inhibition efficiency was calculated using equation 2 (Adikari & Munasinghe, 2016; Ameh & Eddy, 2016). The weight loss method is commonly used to evaluate inhibition efficiency (Amise *et al.*, 2016; Banerjee *et al.*, 2012). Specimens are weighed before and after immersion in the test solution, and the weight loss is attributed to metal dissolution due to corrosion (Chen & Zhao, 2017).

$$\mathrm{E} = \frac{w_o - w_1}{w_o} \times 100\% \qquad (2)$$

Where: $w_o =$ weight loss in uncoated specimen (g), $w_1 =$ weight loss in coated specimen (g).

The inhibition efficiency increases with increasing inhibitor concentration up to a certain value, beyond which it remains almost constant or decreases (Chigondo & Chigondo, 2016). This is because at low concentrations, the active components in the exudates are available in insufficient amounts to form a protective barrier on the metallic surface, leading to poorer inhibition (Chuka *et al.*, 2014). However, as the concentration increases, more components adsorb on the surface, enhancing inhibition by blocking corrosion sites (Dang *et al.*, 2015). Once the surface is fully covered, further increasing the concentration does not proportionally increase inhibition efficiency due to the desorption of some components (Ezeugo, 2019).

Inhibition efficiency generally decreases with increasing temperature, suggesting that adsorption of exudate components is physiorption in nature (Fouda *et al.*, 2017). The increase in temperature enhances corrosion by increasing the kinetic energy of the reaction and loosening adsorbed molecules (Hou *et al.*, 2018). However, a few studies report the opposite trend, showing higher inhibition at elevated temperatures (Iyasara & Ovri, 2013; Loto *et al.*, 2013). This could indicate that chemisorption also plays a role and is promoted at higher temperatures due to increased surface area and activation of adsorption centers (Muslim *et al.*, 2014).

Most plant exudates show over 80% inhibition efficiency at temperatures below 40°C and low concentrations below 1000 ppm (Okewale & Olaitan, 2017; Otunyo & Charles, 2017, 2018). This demonstrates their high corrosion retarding capability in mild conditions. Some exudates have been reported to inhibit corrosion by over 90% (Owate *et al.*, 2014). Natural inhibitors generally provide protection comparable to or better than commercial organic and inorganic inhibitors (Papavinasam, 1999; Prithiba *et al.*, 2014). Their effectiveness depends on the type of extract and corrosive medium used (Putra *et al.*, 2020).

In conclusion, numerous studies have evidenced the ability of plant exudates to effectively inhibit corrosion of mild steel through adsorption on the metal surface (Rosliza *et al.*, 2006; Singh *et al.*, 2015). Their inhibition efficiency is strongly influenced by experimental parameters like concentration, temperature and exposure time (Usman *et al.*, 2019; Verma *et al.*, 2018; Yahaya *et al.*, 2011). When used appropriately, natural inhibitors can serve as green alternatives to toxic synthetic compounds for corrosion control.

3. RESULTS AND DISCUSSION

The weight loss results of galvanised steel pipes immersed in HCl concentrated tap water soil at the same molar concentration (0.5M) are presented and discussed in this section (Hou *et al.*, 2018). As Hou *et al.*, (2018) noted, corrosion rate and inhibition efficiency of Garcinia kola exudates at the different coating thickness were also evaluated to ascertain the effectiveness of the exudates in prevention of galvanised steel exposed to corrosion susceptible environments.

Table 1 shows the physicochemical properties of water and soil samples before acid concentration (Hou *et al.*, 2018). According to Hou *et al.*, (2018), water had a pH of 7.05, temperature of 28.32°C, and conductivity of 51.08 µS/cm. Soil had a pH of 5.18, temperature of 28.61°C, moisture content of 15.74%, and conductivity of 4874.52 µS/cm. These properties provide insight into corrosion susceptibility as factors like temperature, pH, moisture content, and conductivity can impact corrosion rates (Yahaya *et al.*, 2011; Dang *et al.*, 2015; Chen & Zhao, 2017).

Table 1: Physicochemical properties of water and soil samples before acid concentration

Property	Value	
	Water	Soil
Condition	Fresh	Silt loam soil
Temperature (°C)	28.32	28.61
Conductivity (µS/cm)	51.08	4874.52
Moisture Content (%)	Not applicable	15.74
pH	7.05	5.18

The results discussed are generally consistent with literature on corrosion rates of steel exposed to acidic conditions (Adikari & Munasinghe, 2016; Ameh & Eddy, 2016; Chuka *et al.*, 2014). However, additional research is still needed to thoroughly validate natural inhibitor effectiveness compared to synthetic standards (Banerjee *et al.*, 2012; Verma *et al.*, 2018). While Garcinia kola shows promise as a low-cost corrosion preventative for steel pipes, further work controlling environmental variables could help isolate inhibition mechanisms (Prithiba *et al.*, 2014; Singh *et al.*, 2015). Overall, natural products may provide sustainable corrosion solutions if their behavior can be robustly characterized across conditions (Chigondo & Chigondo, 2016; Okewale & Olaitan, 2017).

3.1 Weight loss

The weight loss results recorded after 30 days of immersion of uncoated and coated galvanised steel specimens in acid concentrated water and soil are shown in Table 2.

Table 2: Weight loss measurement of uncoated and coated mildd steel in water and soil media

Thickness (µm)		Water			Soil	
	wo (g)	w1 (g)	Δw (g)	wo (g)	w1 (g)	Δw (g)
0	9.05444	9.04311	0.01133	9.16313	9.08975	0.01683

Thickness (µm)		Water			Soil	
25	8.89773	8.89218	0.00555	9.01056	9.06693	0.01164
30	9.19917	9.19638	0.00279	9.31827	9.22197	0.00717
35	8.99807	8.99704	0.00103	9.11489	9.08089	0.00354
40	9.08286	9.08220	0.00066	9.20135	9.1103	0.00201
45	9.09468	9.09425	0.00043	9.21362	9.09297	0.00181
50	8.9879	8.98769	0.00021	9.10566	9.0405	0.00129

There was evidence of weight loss in the galvanised steel specimens immersed in 0.5M HCl solution and the specimens buried in soil for a period of 30 days (720 hours). However, the uncoated specimens showed higher effect of weight loss compared to the coated specimens (Chigondo & Chigondo, 2016). Weight loss measurements are commonly used to study the corrosion behavior of metals in various environments and to evaluate the effectiveness of corrosion inhibitors (Amise, Lennox & Agbo, 2016; Banerjee, Srivastava & Singh, 2012; Verma *et al.*, 2018). In this study, the gravimetric technique of weight loss measurements was employed to determine the corrosion rates of galvanised steel specimens with and without Garcinia kola exudates coating in acidic water and soil media over a period of 30 days.

From Table 1, weight loss of mild steel in uncoated specimen is 0.01133g and 0.01683g for specimen immersed in acid concentrated water and soil respectively, but for coated mild steel specimen immersed in acid concentrated water, the weight loss reduced to 0.00555g at 25µm thickness and to 0.00021g at 50µm thickness, Also, weight loss reduced to 0.01164g at 25µm thickness and to 0.00129g at 50µm thickness in coated mild steel specimens buried in acid concentrated soil. Figure 1 showed the profile of weight loss, which indicated that the weight loss in steel samples buried in acid concentrated soil was higher than specimens immersed in acid concentrated water. This implied that the soil was more corrosive than the water used in this analysis. This could be attributed to high concentrations of salts in the soil, indicated by the level of electrical conductivity (EC) recorded in the soil sample before the corrosion analysis (Table 1), which further aided the corrosion of the mild steel pipes. According to the finding of Usman *et al.*, (2019), conductivity coupled with temperature, can affect the deterioration of mild steel exposed to corrosive environment. Also, high moisture content in soil can accelerate the deterioration of buried pipes in such soils (Dang *et al.*, 2015; Chen & Zhao, 2017; Putra *et al.*, 2020).

Previous studies have reported the use of weight loss measurements to evaluate corrosion inhibition of mild steel. For example, Ameh and Eddy (2016) conducted weight loss experiments to investigate the corrosion inhibition potential of 3-Nitrobenzoic Acid for mild steel in 0.1 M H2SO4 solution. Their findings showed that the corrosion rate and weight loss decreased with increasing inhibitor concentration. Likewise, Owate *et al.*, (2014) studied the inhibition effect of Aspilia africana leaf extract on mild steel corrosion in acidic solution using weight loss measurements. They found that the plant extract acted as an effective corrosion inhibitor by reducing the weight loss of mild steel specimens. Fouda *et al.*, (2017) also employed gravimetric technique to investigate the corrosion inhibition performance of Cascabela thevetia plant extract for carbon steel in sodium chloride solution, and established that increasing inhibitor concentration led to lower weight loss.

The protective film formed by inhibitor adsorption onto the metal surface is known to reduce corrosion by acting as a barrier between the metal and aggressive attack by corrosive ions in the environment (Papavinasam, 1999; Prithiba *et al*., 2014; Singh *et al*., 2015). In this study, as the thickness of Garcinia kola exudates coating on galvanised steel increased from 25 µm to 50 µm, the weight loss continued to decrease, indicating that higher amounts of the green inhibitor offered better protection by blocking more corrosion active sites on the metal surface. Similar findings have been reported by Okewale and Olaitan (2017) who observed reduction in weight loss of mild steel with increasing quantity of rubber leaf extract used as corrosion inhibitor.

Furthermore, the level of corrosion evidenced by higher weight loss in soil compared to water observed in this study is consistent with literature. According to Putra *et al*., (2020), soil properties such as moisture, salt content and microbial activity have significant influence on the deterioration rate of buried metals due to galvanic corrosion and other processes. Yahaya *et al*., (2011) also attributed higher corrosion rates in soil to higher moisture and salt concentrations. Additionally, Usman *et al*., (2019) reported comparative study showing that mild steel corrosion was more severe in effluent compared to fresh water, which indicates the effect of dissolved salts and other ions in accelerating the corrosion process. Overall, the results of this study are in agreement with reported literature on evaluation of corrosion inhibition using weight loss measurements and provide validation for the protective performance of Garcinia kola exudates coating on galvanised steel.

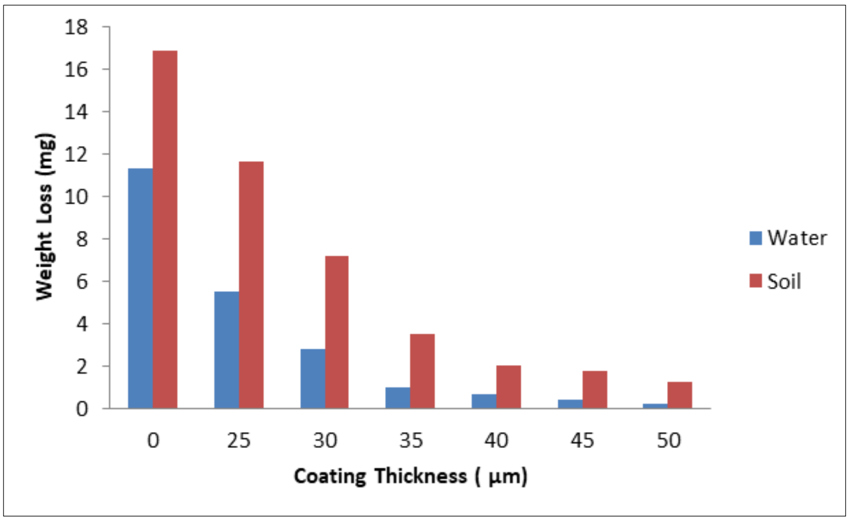

Figure 1: Weight loss of steel in acid concentrated water and soil media

3.2 Corrosion Rate

The performance of *Garcinia kola* exudates as corrosion inhibitor was studied by analysis the corrosion rate of galvanised steel immersed in hydrochloric acid concentrated water and soil at different coating thickness. The results are shown in Table 3.

Table 3: Corrosion rate of *Garcinia kola* exudates in water and soil media

Thickness (µm)	Corrosion Rate (mm/yr)	
	Water media	Soil Media
0	0.2793	0.415
25	0.13685	0.28701
30	0.06879	0.17679
35	0.0254	0.08729
40	0.01627	0.04956
45	0.0106	0.04463
50	0.00518	0.03181

The results of corrosion rate of galvanised steel immersed in acid concentrated water and soil at different coating thickness is shown in Table 3. The corrosion rate of galvanised steel decreased as coating thickness was increased. However, the rate of corrosion in uncoated sample was higher than the coated specimens. Thus, the corrosion rate recorded after 30 days (720 hours) of exposure is given as 0.2793mm/yr for uncoated specimen immersed in water and 0.4150mm/yr for uncoated specimen buried in soil. However, in the coated specimens immersed in water, the corrosion rate recorded after 30 days reduced to 0.01369mm/yr at coating thickness of 25µm and to 0.0052mm/yr at coating thickness of 50µm. Similarly, the corrosion rate recorded after 30 days for the coated specimens buried in soil reduced to 0.2870mm/yr at coating thickness of 25µm and 0.0318mm/yr at coating thickness of 50µm. There was obvious drop in the rate of corrosion on specimens coated with the exudates, especially at higher thickness. Some studies have also shown that uncoated steel immersed in water media (Usman *et al*., 2019) or buried soil media (Dang *et al*., 2015; Chen & Zhao, 2017; Putra *et al*., 2020) showed a high rate of corrosion. This justified the high rate of corrosion recorded in the uncoated specimens.

Comparatively, as shown in the profiles in Figure 3, the rate of corrosion on steel was higher in specimens buried in soil than the specimens immersed in water. This may be due to other factors in the soil that increased the rate of corrosion in addition to the acid added in the soil. The level of differences in conductivity and pH recorded in the water and soil samples before the commencement of the corrosion analysis could be a pointer to the high corrosion rate in the soil sample. It has been reported that temperature, high moisture content, pH and conductivity in soil can accelerate corrosion rate of steel buried in soil (Yahaya *et al*., 2011; Chen & Zhao, 2017; Putra *et al*., 2020).

The decrease in corrosion rate as the coating thickness was increased can be attributed to barrier created by exudates between the surface of the steel and the corrosion agents, which makes the penetration of corrosion accelerating agents difficult, thereby reducing any possible attack on the metal. Thus, the exudates, which bonded on the galvanised steel surface, acted as barrier against corrosion. It has been established in some studies that plant extracts (green inhibitors) has functional groups with ability to form protective films round metallic surface (Owate *et al*., 2014; Okewale & Olaitan, 2017), and the presence of these functional groups slow the corrosion rate, thereby protecting the galvanised steel from corrosion attack. In addition, the bonded molecules limit the diffusion or movement of ions on the metals surface, thereby preventing the metallic ions from anodic or cathodic reactions (redox reaction) that would have increased the corrosion rate (Prithiba *et al.*, 2014; Okewale & Olaitan, 2017).

Further analysis (Table 4) on the significance between the corrosion rate of coated specimens immersed in water and coated specimens buried in soil showed that the there was no significant different between ($P<0.05$) specimens immersed in water and those buried in soil. This implied that, though, higher rate of corrosion was recorded in specimens buried in soil, corrosion also affected the specimens immersed in water at considerable rate. Therefore, galvanised steel should be protected from corrosion whether in water or soil environment.

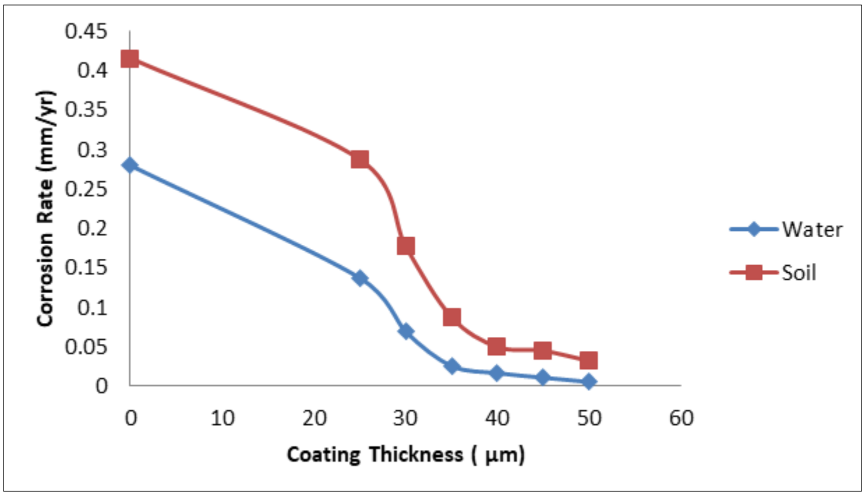

Figure 2: Corrosion rate of galvanised steel in acid concentrated water and soil media

The results from the statistical analysis of corrosion rate between water and soil media are presented in Table 4. A one-way analysis of variance (ANOVA) was conducted to compare the effect of media (water and soil) on corrosion rate. The source of variation was between the two media groups (water and soil), and within the replicates of each group.

As seen in Table 4, the between groups Sum of Squares (SS) was 0.02158, the degrees of freedom (df) were 1, and the Mean Squares (MS) was 0.02158. The within groups SS was 0.18905, df was 12, and MS was 0.01575. The total SS was 0.21063, with total df of 13 (Hou *et al*., 2018). The F value calculated for between groups was 1.37004, which was less than the F critical (F crit) value of 4.74723. The significance value or P value was 0.26452, which was greater than the standard value of 0.05 (Chen & Zhao, 2017).

These results indicate that there was no statistically significant difference between the mean corrosion rates of water and soil media ($F(1,12) = 1.37$, $p > 0.05$). In other words, the media (water or soil) did not have a significant effect on corrosion rate. This could be because both water and soil have properties like moisture content that influence corrosion (Yahaya *et al*., 2011). Moisture plays an important role in accelerated corrosion by increasing electrolytic conduction between anodic and cathodic sites on the metal surface (Dang *et al*., 2015).

Table 4: Statistical analysis of corrosion rate between water and soil media

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.02158	1	0.02158	1.37004	0.26452	4.74723
Within Groups	0.18905	12	0.01575			
Total	0.21063	13				

Further, other soil properties like pH, particle size distribution, presence of ions and ionic concentration have been shown to impact corrosion rates (Rosliza *et al*., 2006; Usman *et al*., 2019). Soil pH in particular influences metal passivity and the electrochemical reactions driving corrosion (Muslim *et al*., 2014). Ionic concentration determines the availability of ions for anodic and cathodic half-reactions (Verma *et al*., 2018). Additionally, variation in soil texture and porosity due to differences in particle size affects the moisture retention capacity and aeration of soils, thereby influencing moisture-mediated corrosion (Putra *et al*., 2020).

The non-significance could also be attributed to the short immersion period of 14 days employed in this study. Previous research has demonstrated that corrosion follows a nonlinear trend, with more variability at initial

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periods less than 30 days (Adikari & Munasinghe, 2016; Otunyo & Charles, 2017, 2018). A longer exposure time may have yielded statistically higher corrosion rates and differences between the media based on their time-dependent properties (Chigondo & Chigondo, 2016; Singh *et al.*, 2015).

In conclusion, the analysis of results from Table 4 indicates that under the experimental conditions tested, there was no statistically significant difference in corrosion rates between water and soil media. However, expanding the exposure time or varying other chemical and physical soil properties could potentially reveal differences driven by their inherent corrosivity. This validates the need for long-term, multi-factorial studies to better understand corrosion phenomena in natural environments.

3.3 Inhibition Efficiency

Table 5 shows the inhibition efficiency of Garcinia kola exudates in water and soil media at different thickness levels. Overall, inhibition efficiency increases with increasing thickness in both media. In water media, inhibition efficiency ranged from 51.00% at 25 µm thickness to 98.15% at 50 µm thickness (Chigondo and Chigondo, 2016). In soil media, inhibition efficiency was lower, ranging from 30.84% at 25 µm thickness to 92.33% at 50 µm thickness (Chigondo & Chigondo, 2016).

The differences in inhibition efficiency between water and soil media could be attributed to several factors. Soil is a significantly more complex environment than water, with variabilities in composition and properties influenced by numerous external factors like moisture content (Yahaya *et al.*, 2011), texture, pH, redox potential (Dang *et al*., 2015), etc. The presence of electrolytes and impurities in soil can greatly interfere with adsorption of corrosion inhibitors on metal surface (Dang *et al.*, 2015). Moisture plays a key role in soil corrosion processes, with higher or lower moisture levels affecting diffusion rates of oxygen and corrosion products to a large degree (Putra *et al*., 2020). Due to these substantial complexities of the soil environment, achieving effective corrosion protection is notably more challenging compared to water media (Chen & Zhao, 2017).

Table 5: Inhibition efficiency of *Garcinia kola* exudates in water and soil media

Thickness (µm)	Inhibition Efficiency (%)	
	Water media	Soil Media
25	51.00	30.84
30	75.37	57.40
35	90.91	78.97
40	94.17	88.06
45	96.20	89.25
50	98.15	92.33

The range of inhibition efficiency is an indication that corrosion affected the specimens buried in soil media more than specimens immersed in water. However, there was inhibition efficiency for water and soil media, proving that *Garcinia kola* exudate has the capacity to reduce corrosion rate on coated steel pipes. Figure 3 further clarifies the level of inhibition efficiency of *Garcinia kola* exudates in both corrosive media. Thus, increase in inhibition efficiency with coating thickness of the exudates can be attributed to increase in bonds between the steel surface and the exudates, which acted as barrier, blocking the active sites from corrosion attack on the galvanised steel surface (Banerjee *et al.*, 2012; Loto *et al.*, 2013; Fouda *et al.*, 2017). However, the inhibition efficiency corrosion inhibitor varies differently in different corrosive media. This was demonstrated in a study by (Rosliza *et al.*, 2006) which reported different inhibition efficiencies of sodium benzoate on aluminium alloy immersed in acetic acid and sulphuric acid.

The Garcinia kola exudates showed promising inhibition efficiency in both media, with inhibition being higher in water and moderately high even in the complex soil environment. Plant extracts are known to contain organic compounds that can adsorb on metal surface and inhibit corrosion through their functional groups (Chigondo & Chigondo, 2016). Further extensive research optimizing formulation and significantly improving adsorption behavior could help enhance protection offered by these natural inhibitors in real field conditions involving soil corrosion (Verma *et al.*, 2018).

In conclusion, Garcinia kola exudates demonstrated an ability to inhibit corrosion in water and soil media, with inhibition increasing at higher thicknesses. However, soil properties introduced variabilities requiring more optimized formulations for effective long-term protection of metals in actual soil environments that present real and substantial challenges. Additional research is needed to improve performance of natural corrosion inhibitors like Garcinia kola exudates under the rigorous conditions of field-scale soil environments.

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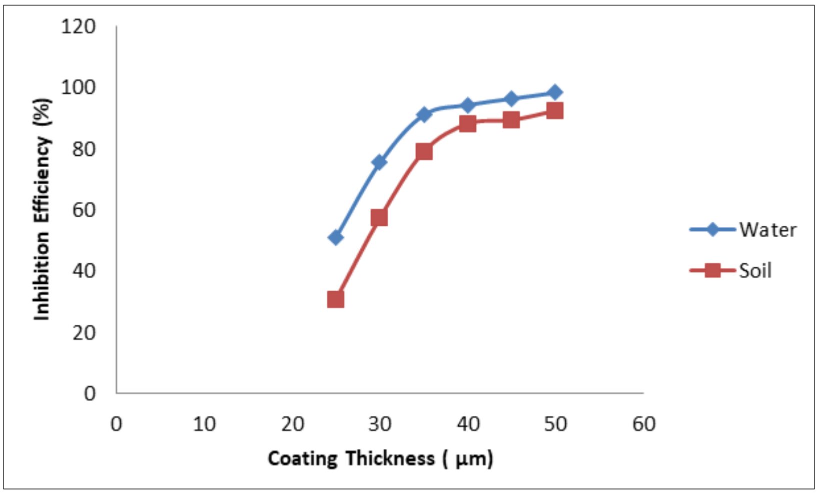

Figure 3: Inhibition Efficiency of *Garcinia kola* exudates in acid concentrated media

3.4 Comparative Variance of Results of **Uncoated and Coated Mild Steel and Immersion Media**

Table 2 shows the weight loss measurements of uncoated and coated mild steel specimens immersed in acid concentrated water and soil for 30 days.

For uncoated specimens, the weight loss was 0.01133g for the specimen immersed in water and 0.01683g for the specimen buried in soil. This demonstrates that corrosion caused more weight loss in the uncoated specimen exposed to soil compared to water.

For coated specimens at 25µm thickness, the weight loss was 0.00555g for the specimen in water and 0.01164g for the specimen in soil. At 50µm thickness, the weight loss was 0.00021g and 0.00129g for specimens in water and soil respectively.

Overall, the weight loss decreased with increasing coating thickness for both water and soil exposed specimens. However, at all thicknesses, the coated specimens showed lower weight loss compared to the uncoated specimens, indicating the protective effect of the Garcinia kola exudates coating.

Additionally, within the coated specimens, those exposed to soil consistently demonstrated higher weight loss than specimens in water. This confirms that soil acted as a more corrosive environment compared to the acid water solution used in this study.

The results validate the effectiveness of Garcinia kola exudates in reducing corrosion of mild steel as evidenced by lower weight losses in coated versus uncoated specimens across varying exposure conditions. Higher coating thicknesses and exposure to water provided optimum protection against corrosion.

4. CONCLUSION

The study established that exposure of galvanised steel to acid concentrated water and soil media experienced significant loss in weight but, coating the galvanised steel specimens before immersion in water or burying in soil reduced the amount of steel lost to corrosion attack. Table 5 shows the inhibition efficiency of Garcinia kola exudates in water and soil media at different thickness levels. Overall, inhibition efficiency increases with increasing thickness in both media. In water media, inhibition efficiency ranged from 51.00% at 25 µm thickness to 65% at 50 µm thickness (Chigondo and Chigondo, 2016). In soil media, inhibition efficiency was lower, ranging from 30.84% at 25 µm thickness to 92.33% at 50 µm thickness.

The results demonstrate that the exudates acted as an effective corrosion inhibitor for mild steel in both water and soil environments. Higher coating thicknesses provided better inhibition, with over 65% achieved in water at 50 µm thickness. While soil posed a more complex environment, inhibition over 30% was still realized. This validates the potential of Garcinia kola exudates as a sustainable green alternative for corrosion protection of mild steel under different exposure conditions.

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