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Chapter

Exploring *Musa paradisiaca* Peel Extract as a Green Corrosion Inhibitor for Mild Steel Using Factorial Design Method

Olusola S. Amodu, Moradeyo O. Odunlami, Joseph T. Akintola, Seteno K. Ntwampe and Seide M. Akoro

Abstract

The suitability of *Musa paradisiaca* (banana) peel extract as a green corrosion inhibitor for mild steel in acidic medium (1 M HCl) was investigated using factorial method of the design of experiment. The effects of two independent variables (concentration of banana peel extract and temperature) on the corrosion inhibition efficiency were investigated. The physicochemical properties of the extract such as surface tension, viscosity, flash point, and specific gravity were determined using standardized methods provided by the American System of Testing Materials (D-971). The relationship between the independent variables and the inhibitor efficiency was modeled by gasometric and thermometric methods. The statistical analysis of the inhibition efficiency was carried out using the "Fit Regression Model" of Minitab® 17.0, while the fitness of the models was assessed by the coefficient of determination (R^2) and the analysis of variance (ANOVA). From the results obtained, gasometric method achieved a maximum inhibition efficiency of 66.83%, with an R^2 of 90.76%, whereas thermometric method gave a maximum inhibition efficiency of 65.70%, with an R^2 of 95.56%. This study shows that banana peel extract has the capacity to prevent the corrosion of mild steel in acidic medium.

Keywords: banana peel extract, biomass, corrosion, inhibitors, factorial design

1. Introduction

In 2016, NACE International estimated the global cost of corrosion at US$ 2.5 trillion annually. This accounts for about 3.4% of the global gross domestic product (GDP). In the same study, it was discovered that if corrosion prevention best practices are implemented, there could be global savings of between 15 and 35% of the cost of damage [1]. In spite of the technological advancement of this generation, high profile cases of corrosion have continued to emerge [2–4]. Moreover, the extensive application of acid solutions in industrial cleaning and descaling of mild steel makes metal dissolution a common phenomenon Gadiyar et al. [5]. In order to prolong the lifespan of mild steel, to enhance its viability, and to reduce the high cost of production, practical steps need to be employed in corrosion prevention. Failure to prevent or manage corrosion can result to metal losses, loss of production time, leaking vessels, and unwarranted cleanup costs.

Corrosion is an electrochemical process; it is the propensity for metals to revert to their natural ore state. It takes place in the presence of moisture and oxygen, involving chemical reaction and the flow of electrons on the surface of the corroded cells, which greatly accelerate the transformation of metal back to the low-grade ore. The process involves the oxidation of a metal atom, whereby it loses one or more electrons. The resultant effect of corrosion is metal degradation, that is, the breakup of bulk metal, causing it to lose its useful properties [6]. This electrochemical process, often referred to as galvanic cell, occurs when two different metals in physical or electrical contact are immersed in a common electrolyte with different concentrations. Consequently, the more active metal (anode) gets corroded while the more noble metal (cathode) is protected [7, 8]. The fundamental chemical reactions occurring at the anode and cathode are:

$$\text{Anode surface: } F_e \rightarrow F_e^{2+} + 2e^-$$

$$\text{Cathode surface: } \frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$$

$$\text{At anode: } F_e^{2+} + 2OH^- \rightarrow F_eO.(H_2O)\text{–hydrated iron oxide (brown rust)}$$

Galvanic corrosion is the most common type of corrosion and it occurs regularly in marine vessels, metal structures, and oil pipelines. Furthermore, the phenomenon is commonly observed in water treatment plant, boilers, storage vessels, oil pipelines, etc. In fact, what makes corrosion challenging is that it starts on the internal part of the metal structure, which makes early detection difficult. Other than water and oxygen, galvanic corrosion is affected by: types of metal, agitation, the presence and type of inhibitors, and environmental factors (pH, temperature, humidity, salinity, etc.) [9]. In addition, the dissolution of mild steel in HCl is given as:

$$2F_e + H^+ \rightarrow F_e^{2+} + H_2$$

The rate of this reaction is dependent on: metal (its position in the electromotive series), acidity, ferrous ion concentration (by the law of mass action, the increase in ferrous ions should correspond to the decrease in rate of corrosion), and hydrogen gas evolution.

Three techniques are often used for the assessment of corrosion rates namely, weight loss technique, electrochemical impedance spectroscopy, and hydrogen gas evolution method. The weight loss method is considered the most fundamental, against which the accuracy of the other methods is determined. However, the limitations of this method are: (1) the weight loss expressed is the average of the weight of the corroding specimen over a period of time but the changes in corrosion rate over this period is not accounted for; (2) in order to accurately determine the weight loss caused by corrosion, all the corroded particles need to be removed from the specimen surface without removing the uncorroded metal, which practically is unrealistic. Electrochemical technique has been successfully used in many corrosion studies to determine the rate of corrosion [4, 7, 10]. Particularly, it has certain advantages over the weight loss method, due to its ease of corrosion rates determination. With this method, instantaneous corrosion rates as well as changes in corrosion rates over a period of time can be determined. However, during the electrochemical dissolution process for some metals and metal alloys, the atypical polarization performance at the anode is a challenge. Moreover, hydrogen removal can occur in two ways: hydrogen gas evolution and depolarization via oxidation by

dissolved oxygen or by some other oxidizing agent [11]. Hydrogen gas evolution method seems to be the most significant and reliable in assessing the rate of corrosion as the mole of metal dissolved directly correlates to the amount of hydrogen gas given off [12].

The application of inhibitors is one of the practical ways to protect metals against corrosion, especially in acidic media. Basically, they function by serving as integuments on metal surface thereby preventing it from chloride ions and oxygen dissolution. Corrosion inhibitors find application in minimizing metallic waste in engineering materials, in addition to the advantages of versatility and cost effectiveness when compared to other corrosion protection methods [10, 13]. Most of the effective inhibitors are either from biomass precursors or chemical compounds containing hetero-atoms such as oxygen, nitrogen, and sulfur with multiple bonds in their molecules through which they are adsorbed on the metal surface [14–16]. This adsorption depends on certain physiochemical properties of the inhibitors: functional group, electron density at the donor atom, n-orbital character, and the electron structure of the molecule. They contain electronegative functional groups and π-electrons in their double bonds, which facilitate their adsorption onto the metal surface. Hence, the strength of an inhibitor to either prevent corrosion reaction from being initiated or slow down the rate of corrosion, is dependent upon the molecular structure of the inhibitor molecules.

The major concern with most chemical inhibitors is their toxicity to the environment. Although many of these synthetic compounds have shown good anti-corrosive activity; their applications have been limited due to environmental considerations [17–20]. Particularly, inorganic corrosion inhibitors such as lead and chromium have been found to constitute significant health challenge to human when released into the environment. This has necessitated the quest for environmentally benign precursors as corrosion inhibitors, for which a plethora of organic materials have been reported. Some of these materials are plant extracts of kola nut, tobacco, *Rosmarinus officinalis*, *Cassia auriculata*, *Argemone Mexicana*, unripe fruit of *Musa acuminate*, roasted coffee seed (*Coffea arabica*), *Carica papaya* leaves, cannabis plant, pomegranate, etc. [14, 19, 21–23]. Furthermore, research has revealed that the basic components of plant extracts are alkaloids, steroids, sugars, gallic acid, tannic acid, and flavonoids, which have been found to improve the protection of metal surface against corrosion [24–26].

The use of natural organic plant extracts as corrosion inhibitors is sometimes referred to as green corrosion prevention. These natural organic compounds are relatively cheaper, nontoxic, and readily available, either as agro-waste and/or agro-industrial waste [27]. Therefore, the aim of this study was to investigate the effectiveness of *Musa paradisiaca* (banana) peel extract as a green corrosion inhibitor for mild steel in acidic medium. The rate of corrosion was assessed using the hydrogen gas evolution method. In addition, the interaction effects of concentration and temperature variation on the corrosion inhibition were assessed using full factorial design and analyzed with relevant statistical tools.

2. Materials and methods

2.1 Preparation of samples and corrosion test solutions

Banana peels were sourced locally. The peels were washed under running water and air dried until a constant mass was recorded. It was milled into powder using a hammer-mill and ball-mill to achieve finesse of powder (about 0.25 mm diameter size). The powdered peel was extracted using 95% ethanol. Five grams of powder

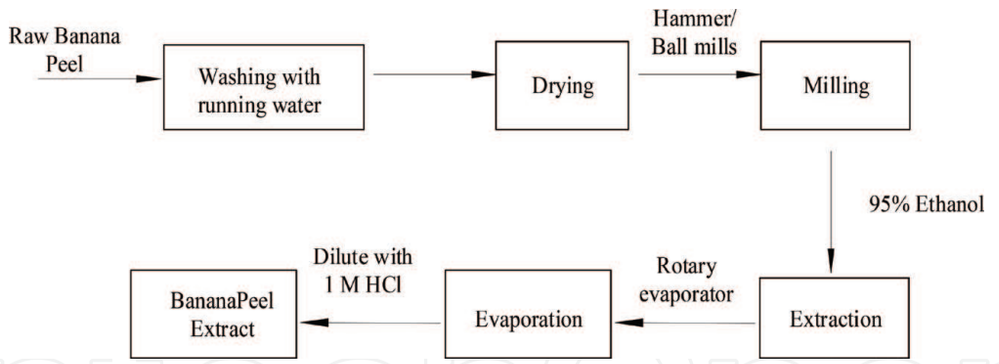

Figure 1.
Flow process for banana peel extract (BPE) as corrosion inhibitor.

was dissolved in 200 ml ethanol for 14 days and thereafter filtered. The filtrate was rotatory evaporated in order to remove excess ethanol, and then diluted with 1 M HCl in distilled water to obtain the corrosion inhibition test solutions in the concentration ratio of 1.0, 2.5, 5, 7.5, and 10% (v/v). **Figure 1** shows the various stages involved in the extraction of banana peels.

In addition, the mild steel used was mechanically press-cut into coupons of dimensions 4 × 2.5 × 0.1 cm. Each coupon was degreased by washing with ethanol, dried in acetone, and immediately transferred into the simulated test solutions. Note that the dried coupons can be preserved in a desiccator until use. Similarly, control experiments were set up but without the addition of the inhibitor. All reagents used were of analytical grade. Banana peel is composed of starch (3%), total dietary fiber (43.2–49.7%), crude fat (3.8–11%), crude protein (6–9%), polyunsaturated fatty acids, pectin, micronutrients (K, P, Ca, and Mg), and amino acid [28]. Also, the mild steel sheet used has the following compositions (% wt): Fe—99.3, Mn—0.34, Cu—0.069, Co—0.069, Ca—0.087, Ni—0.043 and Al—0.03.

2.2 Evaluating the physical properties of banana peel extract as a corrosion inhibitor

2.2.1 Viscosity measurement

This was determined by the Cannon-Fenske viscometer and a circulatory bath with temperature control. Viscosity was calculated using ASTM Method D445–97 [29]. The viscosity η of each sample was calculated using the formula below:

$$\eta = k\rho T, \tag{1}$$

where k is the instrument constant, ρ is the density of banana peel extract sample, and T efflux time (sec) for banana peel extract sample.

2.2.2 Specific gravity determination

The extract of banana peel was transferred into a narrow glass cylinder (SP0121-V Osaka, Japan) and a hydrometer was set into the sample and allowed to stabilize. The value of the specific gravity was taken from the markings on the stem of the hydrometer at the surface of the extract sample.

2.2.3 Surface tension determination

This study employed the American System of Testing Materials D-971 [29] method. Two grams of banana peel extract was added to 50 ml of distilled water in

a 100 ml beaker. A platinum ring was then lowered into the solution of banana peel extract in the beaker. It was then brought up to the water sample interface, where the actual measurement takes place. The force required to pull the ring through the interface was measured by a tension meter as the surface tension of the extract solution (dynes cm^{-1}).

2.2.4 Flash point measurement

The measurement of the flash point for the BPE sample was done using ASTM D-92 method [29]. An open cup containing BPE sample was heated at a specific rate while flame was periodically passed over its surface. The lowest temperature at which the BPE vapor ignites without sustaining the flame was recorded as the flash point.

2.3 Evaluating the corrosion inhibition efficiency of banana peel extract

2.3.1 Gasometric method

This method was adopted in this study as described by Ekpe et al. [23], and carried out at the following temperatures: 303, 308, 313, 318, and 323 K, which were achieved using a water bath. The coupons immersed in the prepared test solutions were recovered after 6 h, washed in detergent solution, and rinsed with distilled water, and air dried. The volume of gas evolved from the cathodic reaction during the corrosion process was determined. Hence, gasometric method correlates the quantity of gas evolved to the rate of corrosion. The graph of the volume of gas liberated per minute gives the rate of gas evolution, while the inhibition efficiency ($\mathcal{E}$) and degree of surface coverage (θ) were determined from Eqs. 2 and 3, respectively.

$$\mathcal{E} = \left(1 - \frac{V^*_H}{V^0_H}\right) \times 100 \tag{2}$$

$$\theta = \left(1 - \frac{V^*_H}{V^0_H}\right) \tag{3}$$

where V^*_H is volume of hydrogen gas evolved at time t in the presence of inhibitor and V^0_H is the volume of hydrogen evolved in the absence of inhibitor.

2.3.2 Thermometric method

Temperature determination was carried out as reported by Ebenso et al. [30]. Using the value for the rise in temperature per minute, the reaction number (RN) was calculated as shown in Eq. 4:

$$RN\left(^{\circ}C/min\right) = (Tm - Ti)/t \tag{4}$$

where T_m and T_i are the maximum and initial temperatures, respectively, attained by the system and t is the time. Similarly, the inhibition efficiency was determined by the reaction number correlation (Eq. 5).

$$\mathcal{E} = \left(\frac{RN_o - RN_i}{RN_o}\right) \times 100 \tag{5}$$

where RN_o is the reaction number of solution without inhibitor, while RN_i is the reaction number of solution with inhibitor.

2.4 Effects of concentration and temperature variations on corrosion inhibition

The data obtained from the banana peel extraction experiments were analyzed statistically using factorial method to obtain a linear fit for the inhibition of mild steel corrosion under varied concentration and temperature. The mathematical model was generated by a MINITAB 17.0. Regression analysis was performed to correlate the response variable to the independent variables. The quality of the fit of the model was evaluated using analysis of variance (ANOVA), where the response was the inhibition efficiency; while concentration and temperature of BPE solution were the input variables.

3. Results and discussion

3.1 Physical properties of BPE

The physical properties determined for the banana peel extract are presented in **Table 1**.

The viscosity of the banana peel extract (BPE) compares favorably well with those previously reported for BPE and other biomaterials. For instance, similar viscosities were reported for extracts from *Citrullus lanatus*, *Phyllanthus*, and banana peels [31, 32]. Viscosity is the property of a fluid that makes it resist flow and sustain frictional force. It is an important property of a good inhibitor, which makes it stick to the surface of metals thereby forming a protective barrier against corrosion. It represents the ability of the extract to adhere longer to metal surfaces, thus enhancing corrosion inhibition. Corrosion inhibitors often contain one or more surfactants, which lowers the surface tension of corrosive fluids [33]. Similarly, the flash point of BPE extract is within the range reported by Kliskic et al. [34] and Betiku et al. [35]. This indicates the flammability or combustibility of the inhibitor.

3.2 Evaluation of BPE efficiency as a corrosion inhibitor

3.2.1 Gasometric method

The efficiency of corrosion inhibition by BPE was determined using gasometric method according to Eq. 1, for the various concentrations of 1.0, 2.5, 5.0, 7.5, and 10.0 g/L (**Table 2**).

Density ($g/L\ cm^3$)	Dynamic viscosity (cp)	Surface tension (dynes cm^{-1})	Specific gravity	Flash point (°C)
1.56	32.04	18.0	1.55	237

Table 1.
Physical properties of banana peel extract (BPE).

Levels	1	2	3	4	5
Concentration (g/L), X_1	1.0	2.5	5.0	7.5	10.0
Temperature (K), X_2	303	308	313	318	323

Table 2.
Experimental design.

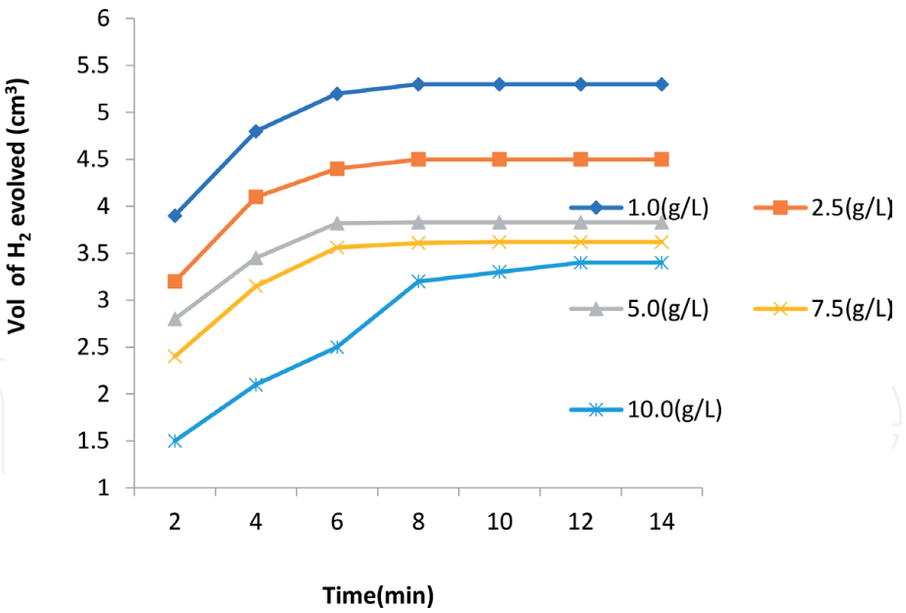

Figure 2.
Volumetric rate of hydrogen gas during corrosion of mild steel in 1 M HCl acid solution.

The volume of gas evolved from the cathodic reaction during the corrosion study (**Figure 2**) is correlated to inhibition efficiency by gasometric method.

As shown in **Figure 2**, the volume of H_2 evolved decreased with increasing concentration of the extract. This can be attributed to increased adsorption forces at higher concentrations. However, hydrogen gas evolution increased with time, until after 8 min before equilibration. This is expected since adsorption decreases with time. From the chemical equation, the dissolution of 2 M of ferrous generates one molecule of hydrogen gas. This means that the evolution of one molecule of hydrogen gas corresponds to the dissolution of 2 M of iron. Theoretically, by mole ratio, it implies that the rate of iron dissolution doubles the rate of hydrogen gas evolution. From the anodic and cathodic reactions, the flow of chloride ion from cathode caused the dissolution of iron at the anode and the metal gets corroded, which is the formation of hydrated iron (II) chloride. Hence, prevention of corrosion is possible if the chloride ion is prevented from having contact with the metal surface. The corrosion of mild steel in HCl solutions has been reported to be a first order reaction [36], which increases with increased acid concentration. In addition, the dissolution of iron steel in hydrochloric acid is dependent upon chloride ion over acidic range of pH. Also, the pH of HCl solution decreased with increased immersion time of the mild steel (**Figure 3**). This was obviously due to increased acidity of the solution.

Moreover, as described in Section 2.3, the volume of hydrogen gas evolution was used to determine the corrosion inhibition efficiency at different temperatures and concentrations of the biomass extract. Consequently, experimental design was used to assess the effects of these independent parameters that ultimately led to peak process performance and the discovery of optimum conditions. The experimental design was generated using a MINITAB 17.0 software (Stat-Ease Inc., USA). Each variable was analyzed at five levels with a total of 25 experiments being performed representing a full factorial. The system response, which is the corrosion inhibition efficiency, was determined by gasometric and thermometric methods (**Tables 3** and **4**).

3.2.2 Thermometric method

Similarly, using thermometric method given in Eq. 4, the percentage corrosion inhibition was evaluated for the concentrations 1.0, 2.5, 5.0, 7.5, and 10.0 g/L, and

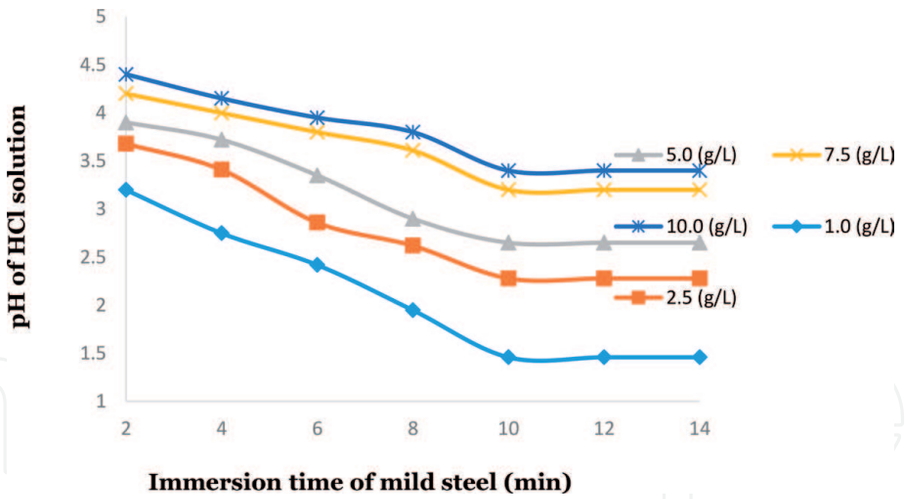

Figure 3.
Variation of pH of HCl solution with immersion time of mild steel in the presence of banana peel extract (BPE).

Run order	Concentration (g/L) (X_1)	Temperature (K) (X_2)	Inhibition, Ɛ (%)
1	7.5	303	64.14
2	5.0	313	51.11
3	1.0	303	44.40
4	10.0	313	61.75
5	2.5	308	49.53
6	7.5	318	49.25
7	7.5	313	53.14
8	2.5	318	40.28
9	5.0	308	56.31
10	2.5	313	44.43
11	10.0	323	49.21
12	1.0	323	24.75
13	2.5	303	54.73
14	10.0	303	72.03
15	1.0	313	34.00
16	7.5	308	59.00
17	7.5	323	44.17
18	1.0	318	29.15
19	5.0	323	41.62
20	5.0	303	61.51
21	1.0	308	39.20
22	5.0	318	29.15
23	10.0	308	66.83
24	10.0	318	54.62
25	2.5	323	34.92

Table 3.
Corrosion inhibition efficiency determination using gasometric method.

Run order	Concentration (g/L) (X_1)	Temperature (K) (X_2)	Inhibition, Ɛ (%)
1	7.5	303	62.4
2	5.0	313	41.93
3	1.0	303	41.58
4	10.0	313	59.85
5	2.5	308	49.25
6	7.5	318	44.98
7	7.5	313	51.73
8	2.5	318	33.94
9	5.0	308	54.13
10	2.5	313	40.31
11	10.0	323	48.77
12	1.0	323	21.75
13	2.5	303	51.75
14	10.0	303	71.56
15	1.0	313	29.95
16	7.5	308	57.92
17	7.5	323	40.86
18	1.0	318	24.86
19	5.0	323	37.72
20	5.0	303	60.01
21	1.0	308	35.32
22	5.0	318	41.93
23	10.0	308	65.70
24	10.0	318	53.62
25	2.5	323	31.56

Table 4.
Corrosion inhibition efficiency determination using thermometric method.

at various temperatures. The experimental results presented in **Tables 3** and **4** show that at constant concentration of the extract; say, at 10 or 7.5 g/L, corrosion inhibition efficiency decreased with increasing temperature. In the same vein, it was observed that at constant temperature; say, 303 K, corrosion inhibition efficiency increased with increasing inhibitor concentration. In a similar study, Gunavathy and Murugavel [37] have reported that the inhibition efficiency of mild steel corrosion in acid medium by *Musa acuminata* fruit peel extract increases with the increase in concentration but decreases with increase in temperature. The same trend was reported by Mayanglambam et al. [38] for *Musa Paradisiaca* extract on mild steel in sulfuric acid solution. Lai et al. [39] have also worked on the inhibition of mild steel in HCl acid solution with a synthetic inhibitor, and/or synthetic mixed-type inhibitors as revealed by potentiodynamic polarization measurement. It was equally reported that the efficiency of the inhibitors decreased with increasing temperature as well as acid concentration.

3.3 Modeling and statistical analysis

Suitable statistical models were chosen to model the interactions between the different experimental variables and their effect on the efficiency of corrosion inhibition, based on the "Fit Regression Model" of MINITAB 17.0 (Pen, USA). The response was modeled with a response surface quadratic model and

further analyzed by analysis of variance (ANOVA) to assess the significance of each variable on corrosion inhibition. An empirical model that could relate the response measured to the independent variables was obtained using multiple regression analysis. The response (Y), can be represented by the following quadratic model:

$$Y = \alpha_o + \sum_{i=1}^{n} \alpha_i X_i + \sum_{i=1}^{n} \alpha_{ii} X^2{}_i + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \alpha_{ij} X_i X_j + \varepsilon \quad (6)$$

where X_1, X_2, X_3, ..., X_n are the independent coded variables, α_0 is the offset term, and α_i, α_{ii}, and α_{ij} account for the linear, squared, and interaction effects, respectively, and ε is the random error. A model reduction may be expedient, if there are many redundant model terms [40].

The statistical model summary based on the Lack-of-Fit Test explained the fitness of quadratic models. Using ANOVA to assess the significance of each variable in the model, empirical quadratic models were obtained from Eq. 6. These models, Eqs. (7) and (8), for gasometric and thermometric methods, respectively, were used to predict the efficiencies of the corrosion inhibition at the various values of the independent variables.

$$Y = 376.0 + 2.660\ X_1 - 1.0910\ X_2. \quad (7)$$

$$Y = 376.4 + 2.928\ X_1 - 1.1038\ X_2. \quad (8)$$

The ANOVA of the quadratic regression model for the corrosion inhibition showed the significant level of the model at 90.72 and 95.56% for gasometric and thermometric methods, respectively (**Tables 5** and **6**). It indicates how well the model fits the experimental data, implying that the total variance in the response could be explained using this model. The closeness in the values of R-sq (adj) and R-sq (pred) in both methods also shows the significance of the model.

Source	**DF**	**Adj SS**	**Adj MS**	**F-value**	**P-value**
Regression	2	3372.9	1686.45	107.59	0.000
Conc. of BPE (g/L)	1	1885.6	1885.59	120.30	0.000
Temperature (K)	1	1487.3	1487.31	94.89	0.000
Error	22	344.8	15.67		
Total	24	3717.7			
Model summary					
S	R-sq	R-sq (adj)	R-sq (pred)		
3.95907	90.72%	89.88%			
Coefficient					
Terms	Coef	SE coef	T-value	P-value	VIF
Constant	376.0	35.1	10.72	0.000	
Conc. of BPE (g/L)	2.660	0.243	10.97	0.000	1.00
Temperature (K)	−1.091	0.112	−9.74	0.000	1.00

Table 5.
ANOVA for corrosion inhibition efficiency of BPE (gasometric method).

Source	DF	Adj SS	Adj MS	F-value	P-value
Regression	2	3807.7	1903.87	236.50	0.000
Conc. of BPE (g/L)	1	2284.8	2284.78	283.81	0.000
Temperature (K)	1	1523.0	1522.97	189.18	0.000
Error	22	177.1	8.05		
Total	24	3984.9			
Model summary					
S	R-sq	R-sq (adj)	R-sq (pred)		
2.83731	95.56%	95.15%	94.36%		
Coefficient					
Terms	Coef	SE coef	T-value	P-value	VIF
Constant	376.0	25.1	14.97	0.000	
Conc. of BPE (g/L)	2.928	0.174	16.85	0.000	1.00
Temperature (K)	−1.1038	0.0803	−13.75	0.000	1.00

Table 6.
ANOVA for corrosion inhibition efficiency of BPE (thermometric method).

Regression results often show the statistical correlation and importance between the predictor and response. The coefficient of determination (R^2) is the percentage of inhibition efficiency (%) variation that is explained by its relationship with concentration (g/L) and temperature (K). Therefore, the adjusted R^2 is the percentage of inhibition efficiency (%) variation that is explained by its relationship with concentration (g/L) and temperature (K), adjusted for the number of predictors in the model. This adjustment is important because R^2 for this model increases when a new independent variable is added. The adjusted R^2 is a useful tool for comparing the explanatory power of models with different numbers of predictors. P-value for each coefficient tests the null hypothesis that the coefficient has no effect [40].

3.4 Graphical representation of the model

Graphical representation allows easy interpretation of experimental results and the prediction of optimal conditions. From the contour plots, **Figures 4** and **5**, BPE was most efficient at temperatures below 307.5 K and concentrations above 8 g/L. The least inhibitory effect was observed at temperature of 318 K and at lower concentrations. This corroborated the experimental results where the highest corrosion inhibition was 72.03 and 71.56%, for gasometric and thermometric methods, respectively. This peak performance occurred when concentration was 10 mol/L and temperature 303 K. Other higher values determined for inhibition efficiency occurred in the neighborhood of 303 and 308 K, and 10 mol/L. Furthermore, the interactive effect of the concentration and temperature on the system's response (inhibition efficiency) was assessed by plotting three-dimensional curves of the response against the independent variables (**Figures 6** and **7**). The response distribution in this experiment with respect to the variation of the independent variables shows that temperature has a greater effect.

Similar corrosion inhibition efficiencies have been reported for biomass extracts [37, 41]. In some other studies, inhibition efficiencies in the range of

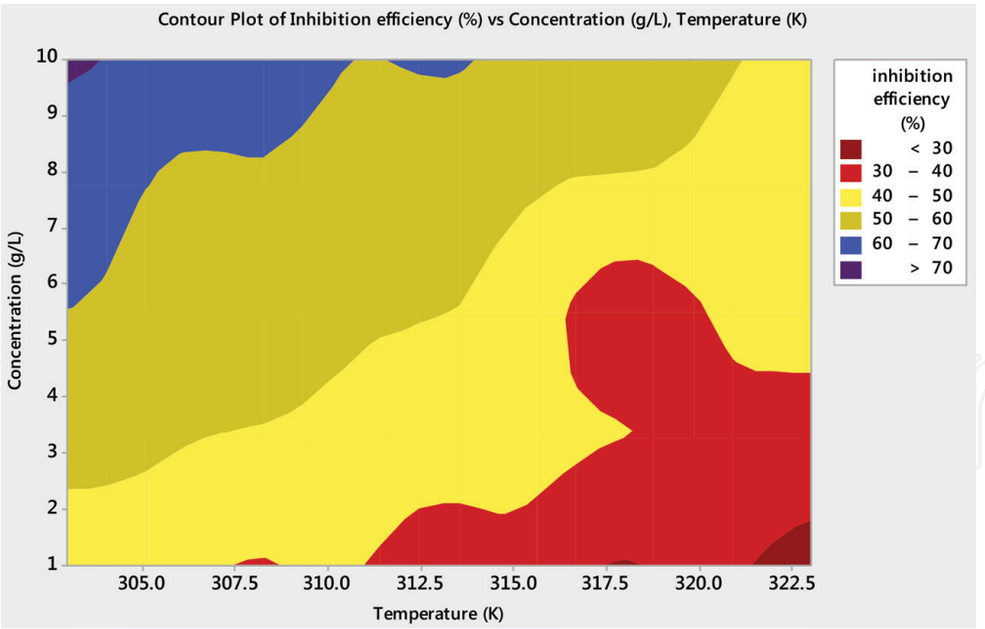

Figure 4.
Contour plot showing the effects of concentration and temperature on the efficiency of corrosion inhibition of BPE (Gasometric method).

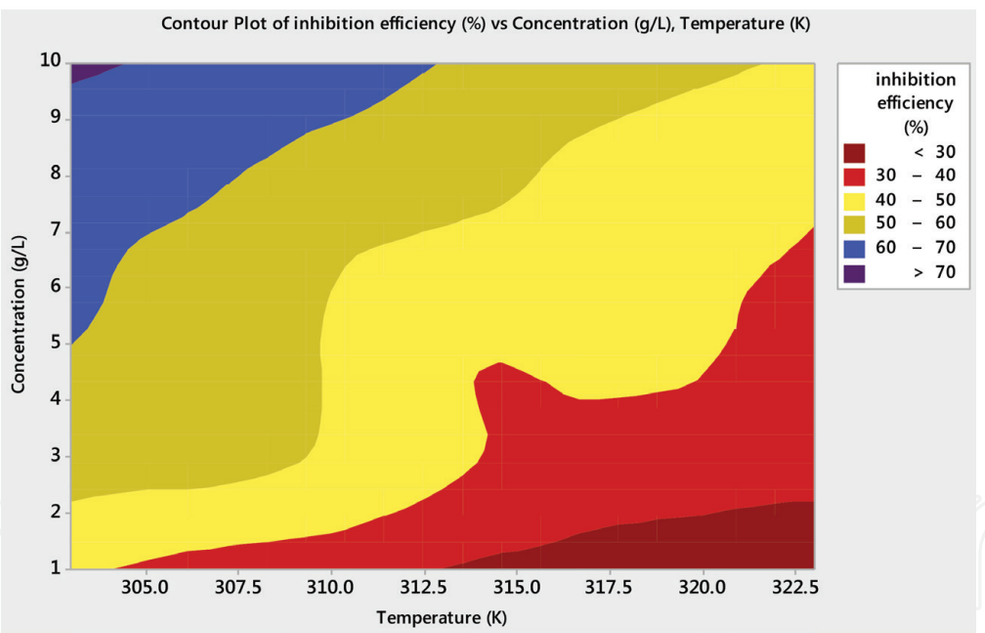

Figure 5.
Contour plot showing the effects of concentration and temperature on the efficiency of corrosion inhibition of BPE (Thermometric method).

80–90 have been reported for mild steel in HCl solution [42–45]. In a study carried out by Ong and Karim [46], where the extract of red onion was used to inhibit corrosion of mild steel in HCl solution, an inhibition efficiency of 90% was reported also at temperature of 303 K. Since a combination of factors such as temperature, concentration of inhibitors, and immersion time affects inhibition efficiency, it is pretty difficult to compare extracts of different biomass. However, reports have shown that temperature and concentration of inhibitors are the predominant factors [47].

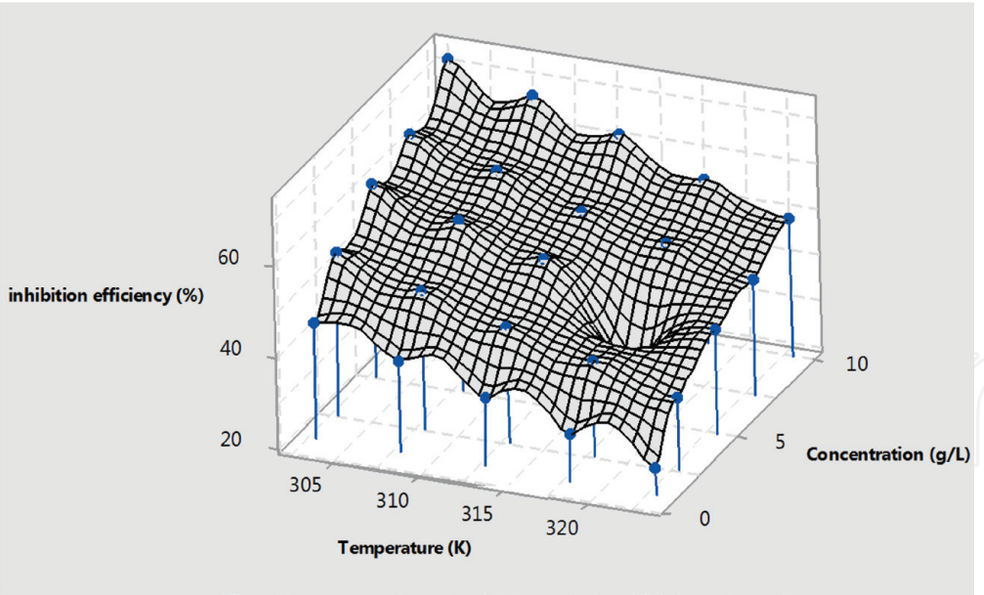

Figure 6.
Surface plot of inhibition efficiency (%) against concentration (g/L) and temperature (K) for gasometric method.

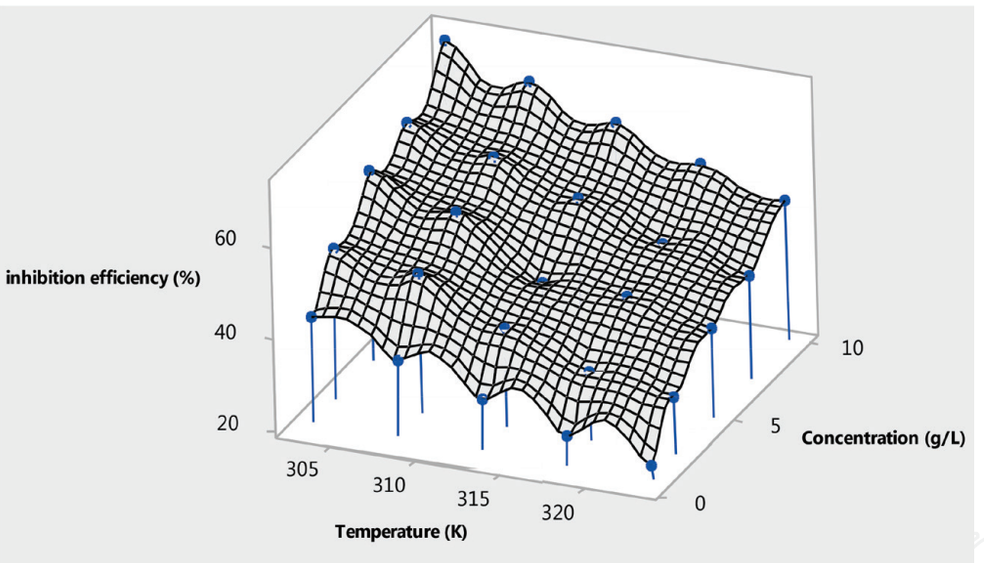

Figure 7.
Surface plot of inhibition efficiency (%) against concentration (g/L) and temperature (K) for thermometric method.

4. Conclusion

Statistical analysis using full factorial and the Regression Fit Model of MINITAB 17.0 was carried out to assess the effectiveness of *Musa paradisiaca* (banana) peel extract as a green corrosion inhibitor for mild steel in acidic medium. The effect of concentration of inhibitor and reaction temperature was investigated while the efficiency of corrosion inhibition was evaluated by gasometric and thermometric methods. The system's response (inhibition efficiency) showed a stochastic distribution with respect to the independent variables, with the highest corrosion inhibition efficiency being 72.03 and 71.56%, for gasometric and thermometric methods, respectively. This peak performance occurred when the concentration was 10 mol/L

and temperature 303 K. Furthermore, the ANOVA of the quadratic regression model for the corrosion inhibition showed the significant level of the model at 90.72 and 95.56% for gasometric and thermometric methods, respectively. The response surface as well as the contour plots indicated the extract from the agro-waste was most efficient at temperature below 307.5 K and at concentrations between 8 and 10 g/L. The least inhibitory effect was observed at temperatures above 318 K and at concentrations below 6 mol/L. Banana peel extract is one of those plant extracts that have shown to be promising in green corrosion inhibition.

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