



Effect of gamma-irradiation of yam peel powder (*Dioscorea rotundata* L. Poir) on metal corrosion protection in sulphuric acid environment

 **Okomah, Yvette Esama**^{1,2,6+}
Oguzie, Emeka Emmanuel³
Emereibeole, Enos Ihediohamma¹
Ejiogu Chibuzor Christopher¹
Nwanonenyi, Simeon Chukwudozie⁵
Nwachukwu, Joseph Ikechukwu¹
Harcourt, Basene Iyenebowa⁴
Anyanwu, Chukwuma Egbule⁴
Ime, James⁴
Ogunsola, Ayobami Anthony⁴
Egwuogu, Chioma⁴
Barnabas, Henry⁴
Ukpe, Aniefiok Emem¹

¹Department of Environmental Management, Federal University of Technology Owerri, Owerri, Nigeria.

^{1,2,6}Email: yette4u@yahoo.com

¹Email: Emeribole-enos.emereibeole@futo.edu.ng

¹Email: chris.ejiogu@futo.edu.ng

¹Email: Joseph.nwachukwu@futo.edu.ng

¹Email: ani.ukpeh@gmail.com

²Centre for Nuclear Energy Studies and Training, Nigeria Atomic Energy Commission, Federal University of Technology Owerri, Owerri, Nigeria.

²Email: yette4u@yahoo.com

³Department of Chemistry, Federal University of Technology Owerri, Owerri, Nigeria.

³Email: emeka.oguzie@futo.edu.ng

⁴Nuclear Technology Centre, Nigeria Atomic Energy Commission, Sheda, Abuja, Nigeria.

⁴Email: bharcourtwhyte@yahoo.com

⁴Email: chuksebubechi12@gmail.com

⁴Email: jamesfam2002@yahoo.com

⁴Email: ayobamase@gmail.com

⁴Email: chommyegwu@yahoo.com

⁴Email: henrylingweb@gmail.com

⁴Department of Polymer Engineering, Federal University of Technology Owerri, Owerri, Nigeria.

⁴Email: simeonnwanonenyi@gmail.com

⁵Department of Energy and Applied Chemistry, Usmanu Danfodiyo University Sokoto, Nigeria.



(+ Corresponding author)

ABSTRACT

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The study assessed the influence of gamma irradiation at different temperatures and concentrations on the anticorrosion properties of yam peel. A mild steel surface was exposed to 0.5M H₂SO₄ at room temperature for five days. The highest inhibitor efficiency, exhibited by gamma-irradiated yam peel powder at 24 hours, was 98.76% at a concentration of 1.2 g/L, while the lowest at 120 hours was 40.03% at 0.2 g/L of Inh 2. The results revealed that increasing the inhibitor concentration from 0.2 g/L to 1.2 g/L enhanced inhibition efficiency. The highest efficiency was observed at 40°C, reaching 81.87% at 1.2 g/L of Inh 2, whereas the lowest was at 70°C, with 54.19% at 0.2 g/L of Inh 1. Inh 2 is irradiated yam peel powder, while Inh 1 is unirradiated yam peel powder. The efficiency depended on temperature, concentration, and time, with gamma-irradiated yam peel powder showing near-excellent inhibition efficiency compared to unirradiated yam peel powder, based on weight loss results. Surface analysis indicated that protection offered by gamma-irradiated yam peel powder was due to the extension of adsorbed molecules on the mild steel surface. The relationship between temperature and inhibition efficiency supported physical adsorption, and adsorption studies followed a Langmuir isotherm.

Contribution/Originality: The study assessed the anticorrosion property of the gamma irradiated yam peel at different variables of temperature, concentration and time. By using waste-yam peel, this study contributes to existing literature on waste conversion and sustainable chemical industries.

1. INTRODUCTION

Corrosion of metals and alloys has done a lot of damage to human lives, environments and economy. It's indeed a menace that needs to be controlled at minimal cost to increase return on investments (Akinbulumo, Odejobi, & Odekanle, 2020). The alloys and metals are unique materials due to their refined state; they are used because of their essential attributes such as physical, chemical and mechanical properties (Dakeshwar & Fahmida, 2015). Although the corrosion of metals and their alloys in various environments is inevitable, it can be controlled or regulated through the use of some effective and practicable control measures. For instance, the use of corrosion inhibitors has been reported to be a viable strategy in protecting the surface of metallic tools, equipment or components from deteriorating in an aggressive service environment (Ezeugo, Onukwuli, Ikebudu, Ezechukwu, & Nwaeto, 2019; Iroha & Nnanna, 2019; Nwanonyeni, Obasi, & Chidiebere, 2018; Zhang, Li, Gao, & Zhou, 2023). The use of corrosion inhibitors from some inorganic materials or substances has the potential to be effective inhibitors due to the presence of some functional groups within the chemical structures, but these materials are not cost-effective and equally not environmentally friendly. Hence, the increase in ecological awareness and economic challenges has pushed researchers in the field of corrosion science to look for alternative or substitute materials that are pocket-friendly, efficient, safe, accessible, and non-toxic green corrosion inhibitors. The basic objective of corrosion inhibitor research is to gain insight into the mechanisms by which materials added to a fluid in an aggressive environment retard the metal-corroding reaction (Oguzie, Li, Wang, & Wang, 2011).

Food security is a challenge that faces third-world countries due to crude cultivation methods, diseases, and field pests attacking food crops during growth, along with poor processing and storage facilities. Yam production is seasonal, making storage vital for year-round availability for food, industrial use, and future planting. In developing countries, poor farmers and many rely heavily on corm crops as their main sources of food, nutrition, and cash income. Consequently, yams become heavily utilized resources (Scott, Rosegrant, & Ringler, 2000), facing post-harvest losses that can range from 25% to 60% (Afoakwa & Sefa-Dedeh, 2001).

Yams possess high contents of starch, moisture, dry matter, potassium, iron, calcium, and nicotinic acid, with low levels of saturated fat, sodium, and vitamin A. However, the species *Dioscorea rotundata* L. Poir, a type of yam corm, is rich in calories, crude fiber, proteins, and has relatively high moisture content (Food and Agriculture Organization (FAO), 1998). The high moisture content makes the species susceptible to microbial rot during storage and sprouting, causing food insecurity and environmental hazards (Passam, 1977; Tortoe, Dowuona, & Dziedzoave, 2015).

To maximize the benefits of food crop preservation by irradiation, gamma-irradiated yam peel powder was subjected to an anti-corrosion test on mild steel induced in an acidic solution. Yam peel powder is non-toxic, cheap, safe to handle, and readily available. It contains chemical constituents that can potentially act as corrosion protection materials for metals exposed to harsh environments. Since most synthetic corrosion inhibitors are toxic, and recent negative environmental implications provide sufficient motivation for evaluating natural products as potential alternatives. To the best of our knowledge, there has been no previous report on the use of gamma-irradiated yam peel powder as a corrosion inhibitor for metals in aggressive environments. This study contributes to converting agricultural wastes into more useful materials and protecting the environment from toxic corrosion inhibitors.

Metallic corrosion varies in alloys and metals, as they are prone to undergo corrosion or deterioration in different environmental conditions, and this reaction process takes different forms, such as;

- i. Galvanic corrosion

This form of corrosion occurs when two different metals in electrical circuits are immersed in an electrolytic system. The metallic structures that are used for construction in a seawater environment manifest or witness this

form of corrosion, and this result set up what's referred to as a galvanic couple. In galvanic corrosion, a metal component is anode while the other is cathode with lesser corrosion occurring in that region and this is the science behind this type of corrosion (Hou et al., 2017).

ii. Crevice corrosion

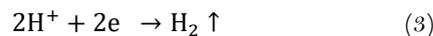
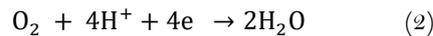
This is a type of localized corrosion normally caused by chemistry inside the vicinity of the crevice. This ion occurs when a very small solution settles under gaskets, fastener heads, washers, lap joints, disbanded coatings, and then the situation progresses when the following conditions exist: inhibitor depletes or loses its concentration, oxygen level depletes in the crevice, emergence of acidic conditions due to a shift in pH level, and an upsurge in the number of aggressive species present in the crevice.

Metal corrosion can be caused by different factors like the nature of alloys and metals, presence of moisture or water, temperature, conditions of the service environment, etc., and their mechanisms such as micro-organisms, temperature, water/moisture, nature of metal, electrolytic systems, etc.

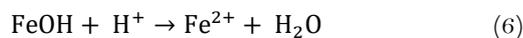
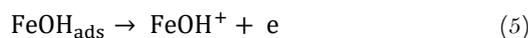
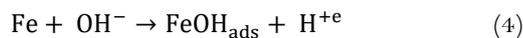
Corrosion is mainly induced by chemical and electrochemical processes. Chemical corrosion takes place in dry gases and nonconductive liquids where there is no current/electron flow. The main effect of chemical corrosion is an oxide layer as a result of oxidation in the air (McCafferty, 2010). Electrochemical corrosion occurs in solution, involving metallic materials and electrolytes due to different potentials on the surface of the corroded metal and redox reactions. One part of the metal acts as an anode, where the metal oxidizes and becomes an ion.



The other part is cathode, where depolarization takes place, mainly reduction of oxygen and hydrogen cation (Hou et al., 2017; Stewart, Wang, & Nguyen, 2012).



Mild steel has been used for various industrial purposes, and its use is driven by its availability, ease of fabrication, affordability, and good mechanical properties. Because it is readily available, it is commonly used with a high potential for corrosion. One major challenge is corrosion caused by acid attack. This situation is common during cleaning or transportation of chemicals like acids. The actual mechanism of iron and steel corrosion is complex, involving chemistry and electrochemistry, as iron will corrode only in the presence of both H_2O and O_2 , forming iron oxide. This corrosion occurs through two separate reactions in an acidic environment: anodic and cathodic reactions. The anodic reaction in acid corrodent solution leads to iron dissolution, which has been reported to proceed according to the mechanism below.



As a consequence of these reactions, there is weight depreciation since the products of iron corrosion are very soluble; they get dissolved in the solution in which the iron is immersed. In acid solutions without restraint, electrons react with hydrogen ions to form hydrogen gas in the corrodent that gets attached to the metal surface (Umoren, Eduok, Solomon, & Udoh, 2016). This reaction is the cathode reaction.



For steel in contact with water, the cathodic reaction proceeds as seen below.



And the rest below: Oxidation corrosion, Uniform corrosion, Concentration cell corrosion, Intergranular corrosion, Pitting corrosion, Erosion corrosion.

Corrosion control can be achieved through effective methods, and some of these means are discussed below.

(a) Metal isolation from corrosive media

This is the isolation of metal from corrosive media typically involves a combination of material selection, design considerations, and coatings to minimize corrosion and extend the lifespan of metal components (Umoren et al., 2016). Here are some strategies commonly executed, which industries can use to isolate metals from corrosive media and prolong the service life of their structures and equipment: Material selection, Cathodic protection, Passivation, Design considerations, Designing components, Protective coatings, Controlled environment, Monitoring, and maintenance.

(b) By use of corrosion inhibitors

The corrosion inhibitors used for controlling metal corrosion in various media originate from different sources, such as organic and inorganic sources. Faced with the dangers associated with many inorganic inhibitors to human health, the environment, and the economy, researchers have explored alternative sources of organic inhibitors that do not negatively affect human health. Previous research has investigated the use of various parts of plants, which have been reported to yield positive results (Abiola & James, 2010). Over the years, studies have shown that components of plants are rich in natural biochemical compounds, which can be successfully extracted through simple, low-cost processes. These compounds are environmentally acceptable, biodegradable, freely accessible, and renewable. Alkaloids, organic nitrogen bases, and carbohydrates have been identified as major inhibiting compounds, often coupled with proteins and products of their acid hydrolysis. Research continues into natural extracts capable of withstanding high temperatures without degrading. The economic benefits of natural extracts as inhibitors are well established. Common types of corrosion inhibitors include anodic inhibitors, passivation inhibitors, cathodic inhibitors, film-forming inhibitors, mixed inhibitors, volatile corrosion inhibitors (VCI), and green inhibitors. With growing environmental concerns, there is increasing interest in environmentally friendly or "green" corrosion inhibitors derived from natural sources. These inhibitors often utilize plant extracts, biopolymers, or other sustainable materials to provide corrosion protection without harmful environmental impacts.

Corrosion inhibitors can be applied in various industries such as oil and gas, chemical processing, marine, automotive, aerospace, and infrastructure. Regular monitoring and maintenance are necessary to ensure the effectiveness of corrosion inhibition over time. However, it's essential to select the appropriate inhibitor based on the specific corrosive environment and the type of metal being protected.

1.1. Green Inhibitory Potentials of Yam Peel

Yam peel is the back of the yam that is either dark or brownish in color, covering and protecting the yam's inner part (or tissue), which is white or yellow in color depending on the type of yam. It may be regarded as a waste part of yam, but in some cases, it is used as animal feed (Lawal, Akueche, Anjorin, Anyanwu, & Adesanmi, 2011). It is biodegradable material and contains some chemical constituents because it is organic material. It is believed that yam peel has the potential to serve as an anti-corrosion material for metal surfaces exposed to some aggressive environments due to the presence of organic chemical constituents within its chemical structure. On that note, the use of yam peel as a corrosion inhibitor for metals in acidic media may be seen as converting waste to wealth.

Research on various green (or organic) inhibitors for metal protection has been conducted, as these corrosion inhibitors are typically derived from plant extracts (leaves, roots, fruits, flowers, seeds, bark), polymers, dyes, drugs, etc. The focus is on environmentally friendly materials used to prevent corrosion.

i. Plant extracts/organic inhibitor

The plant extracts are mainly obtained from plant leaves, barks, seeds, fruits, and roots, comprising mixtures of organic compounds. Several compounds from plant sources have been employed as corrosion inhibitors for metals in harsh service environments due to the availability of molecules such as nitrogen, oxygen, or sulfur, with conjugated systems in their chemical structures. These inhibitive species usually function via adsorption of molecules on the metal surface, creating a barrier to prevent corrosion attack (Channouf, Souissi, & Bellakhal, 2015; Harek, Bentiss, Traisnel, & Lagrenée, 2014; Kissi, Bouklah, Hammouti, & Benkaddour, 2006; Tang et al., 2010). The adsorption bond strength is dependent on the composition of the metal and corrodent, inhibitor structure and concentration, as well

as temperature. Despite the broad spectrum of organic compounds, the final choice of the appropriate inhibitor for a particular application is restricted by several factors. One is increased environmental awareness and the need to promote environmentally friendly processes. Another factor is the vast variety of possible corrosion systems coupled with the specificity of action of most acid inhibitors, which often necessitates the use of combinations of additives to provide the multiple services required for effective corrosion inhibition. In addition, plant products are low-cost, readily available, and renewable sources of materials. Some typical examples of plant materials used as inhibitor include the following; Ginkgo leaf extract (Qiang, Zhang, Tan, & Chen, 2018) Lawsonia extract (El-Etre, Abdallah, & El-Tantawy, 2005); leaf extracts of *Occimum viridis*, *Telferia occidentalis*; *Azadirachta indica* *Hibiscus sabdariffa* (Molina-Ocampo, Valladares-Cisneros, & Gonzalez-Rodriguez, 2015) seed extract of *Garcinia kola delonix regia* extract (Abiola, Oforka, Ebenso, & Nwinuka, 2007; Ebenso, 2003) natural honey (El-Etre & Abdallah, 2000), Guar gum. *opuntia* extract (Hou et al., 2017), *Sida acuta* leaf and stem extract (Umoren et al., 2016) *Baphia nitida* leaves extract.

ii. Polymeric materials

Natural polymers are effective materials for metal corrosion inhibition due to their functional groups in chemical structures. Examples include gum arabic (Verma & Quraishi, 2021), polymer and polyvinylpyrrolidone (Nwanonenyi et al., 2018), polyvinyl acetate (Nwanonenyi, Ogbobe, Madufor, & Oguzie, 2016), henna and rosemary extract (Pourriahi, Nasr-Esfahani, & Motalebi, 2014), polyethylene glycol (Hou et al., 2017), honey, and *Rosmarinus officinalis* L. (Yee, 2004). Other examples are polyacrylic acid, polyvinylpyrrolidone, and polyacrylamide.

iii. Dye as corrosion inhibitors

Some examples of dye reported in some scientific literature as potential corrosion inhibitor include the following: *Ocimum basilicum*; indigo dye (Oguzie, Unaegbu, Ogukwe, Okolue, & Onuchukwu, 2004); Safranin-O (SO), thymol blue and Fluorescein – Na (Oguzie et al., 2004); Methylene blue. The use of Pigments and resins was examined. delved into the use of Sunset Yellow (SS), Amaranth (AM), Allura Red (AR), Tartrazine (TZ), and Fast Green (FG) dyes as corrosion inhibitors for mild steel metal in 0.5 M Hydrochloric acid environment (Hou et al., 2017). The possibility of using some organic dyes namely, safranin –o (SO), thymol blue (TB) and Fluorescein–Na (F-Na) as corrosion inhibitors of mild steel corrosion in sulphuric acid had been examined (Onen, Maitera, Joseph, & Ebenso, 2011). Gasometric technique was used in each of the studies, which revealed that the compounds act as corrosion retarders in acidic environments. It also shows that an upward increase in the concentration of SO and TB resulted in an IE% increment. The capacity of Methylene Blue (MB) dye to inhibit corrosion of aluminum in HCl electrolytic solution was analyzed using gravimetric techniques at 303 and 333 K. The researchers involved in this study revealed that MB acts as an inhibitor in acidic environments. They reported that the inhibition efficiency depends on the concentration of the acid and that of MB.

iv. Drugs

The typical examples of drugs used as corrosion inhibitors include the following; torsemide and furosemide drugs (Kumar & Karthikeyan, 2013); 2- Mercaptobenzothiazole 8-hydroxyquinoline and benzothiazole (Balaskas, Curioni, & Thompson, 2015); 2- Mercaptobenzothiazole and 2-aminobenzothiazole compounds (Vernack, Costa, Tingaut, & Marcus, 2020); 3-benzoylmethyl benzimidazolium hexafluoroantimonate compound (Hou et al., 2017).

2. MATERIALS AND METHODS

2.1. Materials Preparation

Metal sheet was sourced from the local market in Owerri Metropolis, Imo State, Nigeria. The yam corms and peels were obtained from two different species of yam (*Dioscorea rotundata* L. *Poir*), namely Ogini and Fakasa corms, sourced from the local yam market in Gwagwalada, Abuja, Nigeria, and identified at the Department of Agricultural Research, Nigeria Atomic Energy Commission, Abuja. The yam corms were investigated for food security after irradiation, and the yam corm peel was used for corrosion inhibition studies. The different yam samples were peeled,

washed, dried, and then finely powdered for physicochemical analysis, with the peels used for corrosion inhibition analysis.

The mild steel sheet was mechanically press-cut into coupons with dimensions of 2.5 x 2.5 x 0.5 cm. Prior to use, the coupons were polished using various grades (600, 1000, and 1200) of silicon carbide paper, cleaned thoroughly with double distilled water, degreased in 100% ethanol, dried with acetone, and kept in moisture-free desiccators for corrosion studies. Two different species of yam (*Dioscorea rotundata*), namely Ogini and Fakasa corms and peels, were used for the research.

They were obtained from the local yam market located at Gwagwalada, Abuja, Nigeria, and identified in the Department of Agricultural Research at the Nigeria Atomic Energy Commission, Abuja. The selected yams were arranged, and some were gamma irradiated at the Gamma Irradiation Facility (GIF) Sheda, Abuja, leaving some as controls. These samples were kept in a clean, moisture- and dust-free environment for physicochemical analysis and storability studies to be carried out over one year. Later, in another study, the irradiated and non-irradiated yam samples were washed with distilled water, peeled, dried, and ground into powdered form in the physicochemical laboratory.

The fine product obtained from the yam corms was used for physicochemical analysis in another study, while the peel was used for this corrosion study. The corrodent, sulfuric acid, was used for the corrosion studies, and a blank acid solution of 0.5 M H₂SO₄ was prepared by diluting concentrated acid with distilled water using the serial dilution principle. Additionally, the inhibited system was prepared by diluting 0.1 to 1.2 g of irradiated yam peel powder in one liter (1 L) of 0.5 M H₂SO₄ solution via shaking.

2.2. Experimental Method

In this section, the experimental techniques used for the research are discussed.

The experimental technique that was used for the evaluation of samples produced includes the following;

2.3. Gamma-Irradiation Process

The gamma-irradiation technique was employed to evaluate the effect of gamma-irradiation on yam corms' storability behavior and its impact on yam peels' corrosion-inhibitive behavior on mild steel coupons for corrosion studies. The process employed is described in Okomah, Nwanonenyi, Madufor, and Oguzie (2025).

2.4. Gamma-Irradiation Facility

Gamma irradiation of yam corms in the Gamma Irradiation Facility with cobalt-60 source located at Nigeria Atomic Energy Commission, Sheda, Abuja, as shown in Figure 1, was used for the irradiation. The facility is a multipurpose semi-commercial plant designed as a research and experimentation facility as well as for industrial purposes. It mainly consists of Co-60 radioactive sources with a total activity of about 5.5×10^{15} Bq (≈ 170 kCi) (Lawal et al., 2011).

Uniform irradiation and accurate computer-controlled irradiation dosage are ensured in all modes of operation. For my previous study that generated the irradiated yam peels used for this study, the irradiation was carried out in the stationary mode with the possibility of varying dose rates (0.05–5 kGy per hour) depending on the location and distance from the source. The prepared yam corms were subjected to gamma irradiation for 2 hours, while a portion was not irradiated (serving as the control) for the yam peel powder to be used in this study.



Figure 1. Pictorial representation of the radiation facility showing (a) Where the gamma irradiation processing of food and industrial products are executed and their finished products, (b) Entrance to the enclosed source, (c) Housing unit where loading of the basket is done to pass through the source, and (d) Perfect 150 Gy yam corms on the measurement scale 9 months after Irradiation in the facility.

2.5. Measurement of Absorbed Dose

Absorbed dose was measured with Bruker e-scan alanine dosimetry reader system, which provides a reliable means of measuring the absorbed dose based on the generation of specific stable radicals in crystalline alanine by ionizing radiation was used to measure the absorbed dose in the yam corms and peels. Figure 2 represents irradiated yam peel powder for corrosion inhibitor.



Figure 2. The yam peel powder sample for corrosion inhibition analyses.

2.6. Weight Loss Measurement

The weight loss measurement evolution method was employed for the assessment of corrosion behavior of the carbon steel surface induced in a solution of 0.5 M H₂SO₄ and yam peel powder as an inhibitor used for these corrosion studies. The standard G-31 method according to ASTM (2004) and Royani, Sulaiman, and Rahim (2019) was used. In performing the experiment, the prepared weighed metal samples were immersed in the corrosive medium with and without inhibitors for a specified immersion period of 24, 48, 72, 96, and 120 hours, respectively, at room temperature. Additionally, the experiment was repeated as the metal samples were placed in a round-bottom flask (which was partially immersed in water in a thermostatic water bath at different temperatures (40, 50, 60, and 70°C)) for a specific immersion period of 5 hours, as described elsewhere (Cruz, Pandiyan, & Garcia-Ochoa, 2005). The metal sample was retrieved from the electrolytic solution after the stipulated time interval, immersed in NaOH-Zinc oxide dust to quench further corrosion processes, cleaned with distilled water, dried in an oven after acetone, and reweighed. This experimental run or process was done in triplicate, and the average result was recorded. The following corrosion parameters of interest include weight loss, corrosion rate, corrosion inhibition efficiency, and degree of surface coverage.

(a) Weight loss

This is the amount of material lost or deteriorated as a result of the interaction of the metal sample with the surrounding electrolytic system. Mathematically, it is obtained from the expression stated below.

$$\text{Weight loss, WL(g)} = (W_i - W_f) \quad (9)$$

Where W_i and W_f represents initial weight of metal sample before immersion and final weight of metal sample after immersion.

(b) Corrosion rate

Corrosion rate refers to the rate or speed at which a material undergoes corrosion over a given duration. A lower corrosion rate suggests slower corrosion and less material degradation, while a higher corrosion rate indicates more rapid corrosion and higher material loss.

Mathematically, it is obtained from the expression stated below.

$$\text{Corrosion rate, CR (mm/yr)} = \left[\frac{87600 \Delta W}{ADt} \right] \quad (10)$$

Where: ΔW = weight loss (g), D = density of coupon (g/cm³) A = surface area of coupon (cm²) and t = time of exposure of the metal sample (h)

(c) Inhibition efficiency, IE (%) and degree of surface coverage (θ).

Inhibition efficiency will be the effectiveness of a corrosion inhibitor in reducing or preventing the corrosion rate of a metal material in a given environment. Higher inhibition efficiency indicates a more effective inhibitor in reducing corrosion and the degree of surface coverage refers to the extent to which a surface is shielded by a corrosion inhibitor or a coating as a protective layer.

Mathematically, these parameters are obtained from the expressions stated below.

$$\text{Inhibition efficiency, IE (\%)} = \left[\frac{W_i - W_f}{W_i} \right] \times 100 \quad (11)$$

$$\text{Degree of surface coverage (\theta)} = \left[\frac{W_i - W_f}{W_i} \right] \quad (12)$$

(d) Surface morphology examination.

The surface characteristics of metal samples exposed to test solutions within a 24-hour interval were monitored and carefully analyzed with a scanning electron microscope, SEM (Rhenom Prox model).

2.7. Experimental Design Matrix

The Central composite design (CCD) of response surface method (RSM) found in (Minitab Inc, 2013) was used to develop a design matrix for the experimental runs. Three independent variables, including dose, storage period and variety was tested for food storability in another work I described (Okomah et al., 2025). Dependent parameters tested include decay, drying, sprouting and acidity. Results from previous works (Gbabo, Gana, & Aremu, 2012; Hassan, Osman, & Babiker, 2011) were used to establish the high and low points of the CCD for each factor as shown in Table 1. The design matrix after experimental runs for food security using the gamma-irradiation process.

Table 1. Design summary for irradiation and storage.

Low	Constraint	High
40<	Dosage (Gy)	<180
1<	Storage (Mts)	<12
1<	Variety	< 2

After the treatment, the corms were analyzed to determine the effects of the doses of gamma irradiation on acidity and on some nutritional parameters of yam. Then the treated corms were stored for a period of twelve months to monitor the effects of irradiation and dosage on the sprouting vigour, decaying, drying and nutritional composition of the yams as capture in another work of mine (Okomah et al., 2025), while the powdered peels are use as corrosion inhibitors in this work.

2.8. Statistical Analysis

The effect of gamma irradiation on yam samples was subjected to statistical analysis. All analyses were performed in triplicates. Means were separated according to Duncan’s multiple range analysis ($P \leq 0.05$), with the help of SPSS 16.0 software. Results were expressed as means \pm standard deviation. Statistical significance was established using analysis of variance (ANOVA) models to estimate the effect of gamma irradiation on the nutritional and biochemical composition of Ogini and Fakasa yam cormels.

3. RESULTS AND DISCUSSION

Gamma-irradiation effect on yam corms and yam peel powder on corrosion rate and inhibition efficiency.

3.1. Effect of Gamma-Irradiation Dose on Yam Corm and Peels Samples

The gamma irradiation dose on different yam corm samples is presented in Table 2 and 3, respectively.

Table 2. Dose reading of 30 Ogini yam corm samples.

Sample	Required Dose (Gy)	Actual Dose (Gy)
S ₁	40	38
S ₂	80	79
S ₃	120	122
S ₄	150	155
S ₅	180	183

Table 3. Dose Reading of 30 Fakasa yam corm Samples.

Sample	Required Dose (Gy)	Actual Dose (Gy)
S ₁	40	38
S ₂	80	81
S ₃	120	123
S ₄	150	153
S ₅	180	184

The effect of gamma-irradiation dose on yam corm for food security and preservation was analysed for decay, drying, sprouting, nutritional value, physicochemical value and acidity using processes recorded elsewhere (Okomah et al., 2025).

3.2. Corrosion Measurement Via Weight Loss Analysis

Comprises of weight loss, Corrosion rate and Inhibitor Efficiency are presented in the Tables 4 - 7.

(i) Weight loss

The Weight Loss results of irradiated (WL_1) and un-irradiated yam peel powder (WL_2) on mild steel in 0.5 M H_2SO_4 at room temperature at varying time and varying temperature as shown in Tables 4 and 5.

Table 4. Weight loss results of irradiated (WL_1) and non-irradiated yam peel (WL_2) on mild steel in 0.5 M H_2SO_4 at room temperature and varying time.

Sample	Conc. (g/L)	Weight loss (g)				
		24 h	48 h	72 h	96 h	120 h
Un- irradiated yam peel	Blank	3.8311	2.4339	1.4654	2.3138	3.8676
	0.2	3.7074	2.1731	1.2051	1.4568	1.6659
	0.4	2.1074	2.0231	1.1951	1.4368	1.6359
	0.6	1.8126	1.0209	1.1881	1.401	1.602
	0.8	1.7517	1.8039	1.1722	1.3205	1.4305
	1.2	1.6417	2.4339	1.4422	1.0605	1.0605
Irradiated yam peel	Blank	3.8311	2.4339	1.4654	2.3138	3.8676
	0.2	3.1364	2.8951	1.5623	1.4792	1.6985
	0.4	2.1365	2.8652	1.2622	1.579	1.628
	0.6	1.6239	2.7914	0.9458	1.6446	1.7851
	0.8	1.5545	2.6593	0.9201	1.5442	2.6263
	1.2	1.4545	2.5493	0.8201	1.4342	2.7363

Table 5. Temperature effect on weight loss results of irradiated (WL₁) and non- irradiated yam peel powder (WL₂) on mild steel in 0.5 M H₂SO₄ for 5 h at varying temperatures.

Sample	Conc. (g/L)	40 °C			50 °C			60 °C			70 °C		
		W _i (g)	W _r (g)	WL(g)	W _i (g)	W _r (g)	WL(g)	W _i (g)	W _r (g)	WL(g)	W _i (g)	W _r (g)	WL(g)
Un-irradiated yam peel	Blank	4.6439	3.9393	0.5011	4.5194	3.7905	0.7289	4.5148	3.7037	0.8111	4.3742	3.4239	0.9503
	0.2	4.5409	4.0465	0.4944	4.3831	3.7165	0.6666	4.258	3.5573	0.7007	4.5958	3.714	0.8818
	0.4	4.4415	3.9979	0.4736	4.3583	3.7342	0.6841	4.5061	3.7764	0.6197	4.5069	3.3684	0.1963
	0.6	4.3415	3.9379	0.4036	4.3383	3.7542	0.5841	4.4961	3.9764	0.5197	4.4869	3.2884	0.1963
	0.8	4.4415	4.0379	0.3636	4.4483	3.8442	0.5241	4.4861	3.9764	0.5197	4.4869	3.2884	0.1963
	1.2	4.4678	4.1516	0.3162	4.5532	3.9043	0.4519	4.47	3.8467	0.6243	4.5672	3.1887	1.3785
Irradiated yam peel	Blank	4.4404	3.9393	0.5011	4.5194	3.7905	0.7889	4.5148	3.7037	0.8111	4.3742	3.4239	0.9503
	0.2	4.8605	4.4845	0.376	4.3911	3.6285	0.9626	4.5173	3.6019	0.9154	4.6244	3.5384	0.786
	0.4	4.7405	4.3445	0.356	4.5611	3.7285	0.8426	4.4273	3.6001	0.8254	4.5344	3.6584	0.771
	0.6	4.5749	4.2282	0.3467	4.65	3.8398	0.8192	4.3766	3.5915	0.7812	4.4822	3.8609	0.6213
	0.8	4.4071	4.1282	0.2687	4.7394	3.9734	0.5674	4.3869	3.7405	0.6964	4.5701	3.9755	0.6446
	1.2	4.307	4.0383	0.2687	4.8398	4.0734	0.2774	4.4569	3.8505	0.6064	4.7601	4.0755	0.6846

3.3. Weight loss

The initial weight of metal sample before immersion minus the final weight of the metal sample after immersion gives the weight loss, as shown in Tables 4 and 5.

After 5 days of immersion at intervals of 24-120 hours at room temperature, inh1 represents unirradiated yam peel powder, while inh2 represents irradiated yam peel powder as inhibitors at five different concentrations: 0.2, 0.4, 0.6, 0.8, and 1.2 g/L, with the blank serving as control. The highest weight loss occurs at the blank with an extension of time, reaching 3.8676 g at 120 hours. The lowest weight loss is at 24 hours with 1.5299 g at 1.2 g/L concentration of inh2. It is lowest in the irradiated yam peel corms powder.

For the temperature, the experiment was carried out at a constant period of 5 hours, at varied temperatures ranging from 40 to 70 °C, where the weight loss is highest at the blank at the highest temperature, which is 70 °C, at 0.9503 g, and lowest at 40 °C, at 1.2 g/L concentration of Inh 2, at 0.2687 g. It is lowest in the irradiated yam peel corms powder.

(ii) Corrosion rate Cr

Corrosion rate (Cr) and inhibition efficiency (%) of Irradiated and un-Irradiated yam on mild steel in 0.5 M H₂SO₄ for various immersion periods at room temperature Tables 4 - 7.

(iii) Inhibition efficiency, IE (%) and degree of surface coverage (θ)

There are calculated and presented in Tables 6 and 7.

Table 6. Corrosion rate and inhibition efficiency of irradiated and un-irradiated yam on mild steel in 0.5 M H₂SO₄ for various time at room temperature.

Sample	Conc. (g/L)	Corrosion rate, CR (mm/yr)					Inhibition efficiency (%)				
		24 h	48 h	72 h	96 h	120 h	24 h	48 h	72 h	96 h	120 h
Un-irradiated yam peel	Blank	0.1456	0.1088	0.0659	0.0431	0.0266	—	—	—	—	—
	0.2	0.1409	0.1074	0.0583	0.0375	0.0254	86.2	71.16	60.69	53.08	40.03
	0.4	0.1401	0.1054	0.0564	0.0355	0.0252	86.51	74.12	63.62	55.03	41.04
	0.6	0.1399	0.1036	0.0432	0.0306	0.0251	86.2	75.31	64.09	54.76	42.98
	0.8	0.1292	0.1016	0.0421	0.0296	0.0245	87.21	76.32	69.08	57.73	49.92
	1.2	0.1228	0.0946	0.0401	0.0287	0.0241	89.73	78.17	76.17	64.3	54.07
Irradiated yam peel	Blank	0.1406	0.0548	0.0399	0.033	0.0306	—	—	—	—	—
	0.2	0.0926	0.0486	0.0375	0.0271	0.0247	91.43	84.4	77.6	61.87	56.6
	0.4	0.0826	0.048	0.0371	0.0253	0.0241	92.43	85.4	77.84	62.87	56.92
	0.6	0.061	0.0479	0.0361	0.0261	0.0237	95.43	86.61	77.99	65.19	55.41
	0.8	0.0597	0.0461	0.0358	0.0287	0.0227	97.74	88.92	78.94	71.62	68.12
	1.2	0.0567	0.0451	0.0353	0.0297	0.0214	98.76	89.97	79.64	79.6	69.01

Table 7. Corrosion rate and Inhibition efficiency of irradiated and un-Irradiated yam on mild steel in 0.5 M H₂SO₄ for 5 h at varying temperatures.

Sample	Conc. (g/L)	Corrosion rate, CR (mm/yr)				Inhibition efficiency (%)			
		40 °C	50 °C	60 °C	70 °C	40 °C	50 °C	60 °C	70 °C
Un-irradiated yam peel	Blank	0.0223	0.024	0.0241	0.0259	—	—	—	—
	0.2	0.022	0.0208	0.0232	0.0243	76.61	72.4	65.91	54.19
	0.4	0.021	0.0206	0.0221	0.0233	76.69	72.54	65.61	54.18
	0.6	0.018	0.0194	0.0222	0.0232	78.73	74.76	67.17	56.17
	0.8	0.015	0.019	0.022	0.0235	78.74	74.75	67.19	56.13
	1.2	0.0141	0.015	0.018	0.0265	79.75	75.73	69.87	59.08
Irradiated yam peel	Blank	0.0223	0.024	0.0241	0.0259	—	—	—	—
	0.2	0.0167	0.012	0.0224	0.0237	77.31	75.31	66.19	56.19
	0.4	0.0157	0.014	0.0214	0.0217	78.31	75.5	66.18	56.18
	0.6	0.0154	0.0158	0.0204	0.0208	79.17	75.97	68.17	62.17
	0.8	0.013	0.0164	0.0141	0.02	81.17	76.17	72.08	64.08
	1.2	0.012	0.0174	0.0161	0.0198	81.87	76.87	74.08	66.08

3.4. Corrosion Rate

Mathematically, it is obtained from Equation 3.

This formula is used to calculate Tables 4 and 5.

After 5 days of immersion at intervals of 24-120 hours at room temperature, the inh1 represents unirradiated yam peel powder, while inh2 represents irradiated yam peel powder as inhibitors at five different concentrations: 0.2, 0.4, 0.6, 0.8, and 1.2 g/L, with the blank serving as control. The weight loss is highest at the blank with time extension, at 0.1456 g at 24 hours, and lowest at 120 hours at 1.2 g/L concentration of inh2, with 0.0226 g. It is lowest in the irradiated yam peel corms powder. The experiment was carried out at constant period of 5 hours, at varied temperature ranging from 40 – 70 °C where the weight lost is highest at blank at the highest temperature, which is 70 °C as it is 0.0259 g and lowest at 40 °C at 1.2 concentration of Inh 2 at 0.0120g, and it is lowest in the irradiated yam peel corms powder. The corrosion rates decrease with exposure time (Liu, Li, Zhao, & Zhang, 2014).

3.5. Inhibition Efficiency, IE (%) and Degree of Surface Coverage (θ)

There are calculated and presented in Tables 6 and 7.

After 5 days of immersion at intervals of 24-120 hours at room temperatures, the inh1 represents unirradiated yam peel powder, while inh2 represents irradiated yam peel powder as inhibitors at five different concentrations: 0.2, 0.4, 0.6, 0.8, and 1.2 g/L, with the blank serving as a control. The highest inhibitor efficiency at 24 hours at the highest concentration of 1.2 g/L is 98.76%, while the lowest at 120 hours at 0.2 g/L concentration of inh2 is 40.03%. The lowest efficiency is observed in the irradiated yam peel corms powder. Results revealed that increasing the inhibitor concentration from 0.2 g/L to 1.2 g/L increased inhibition efficiency, with 1.2 g/L achieving the highest efficiency at a constant immersion period of 5 hours within temperature ranges of 40–70°C. The highest inhibition efficiency at 40°C is 81.87% at 1.2 g/L of inh2, while the lowest at 70°C is 54.19% at 0.2 g/L of inh1. The lowest efficiency overall is in all yam peel corms powders.

As the temperature rises, so does the rate of weight loss of the metal. This means that when the temperature rose, the solubility of the metals increased. This result is explained by the basic rule governing the rate of chemical reaction, which states that the rate of chemical reaction increases as the temperature rises. An increase in temperature also stimulates the creation of activated molecules, which can double in number with a 10°C increase in temperature, resulting in a faster response rate. This is due to the reactant molecules gaining more energy and being able to break through the energy barrier faster (Ita & Offiong, 1997; James, Oforka, Abiola, & Ita, 2007).

The thickening of the passive film on the alloy surface could explain the decrease in corrosion rate of carbon steel over time. According to research, compounds containing the functional groups -NH₂, -N=N, -C=N, -S-CH₃, -C=S, -N-H, -CO, -CNS, -CHO inhibit metal corrosion (Morad & El-Dean, 2006; Ngobiri, Oguzie, Oforka, & Akaranta, 2019).

3.6. Temperature Effect on Corrosion Studies

Temperature increases the solubility of protective coatings on metals, increasing the metal's vulnerability to corrosion (Okafor et al., 2008). As the temperature rises, the solubility of oxygen gas drops. As a result, at greater temperatures, oxygen concentration is projected to be higher. At a higher oxygen concentration, the metal corrodes faster. This explains why, as the temperature rises, the solid protective coating becomes increasingly dissolving. Furthermore, when the concentration of the plant extract increased, the inhibitor's (yam peel) inhibitory efficacy increased, but as the temperature climbed, it reduced. Lastly, it's vital to note that explaining the adsorption mechanism of natural product extracts is difficult (Bouhlal et al., 2020).

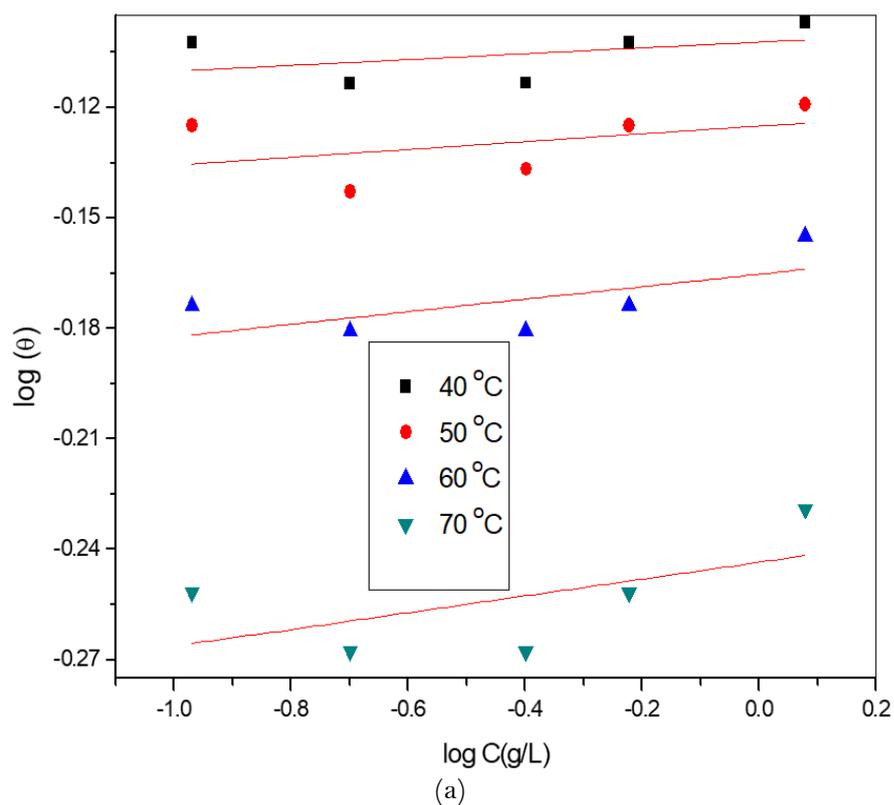
3.7. Adsorption Studies

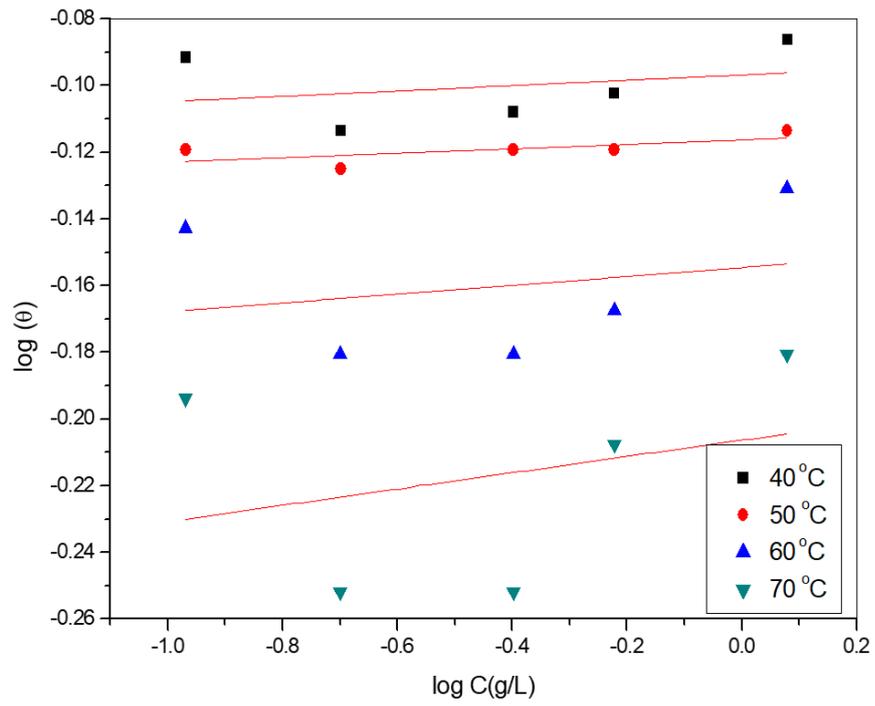
Information on the mode of adsorption of the inhibitor on the surface of the metal and the prediction of whether the adsorbed metal surface is homogeneous or heterogeneous is provided by these adsorption studies (Obot & Obi-

Egbedi, 2010). The protective thin complex film that safeguards the metal surface by adsorption is formed by the interaction between the inhibitive species and charge on the metal surface. Therefore, interaction can occur through chemical, physical, or a combination of both interactions, depending on the available inhibitive species within the structure of the inhibitor molecule (Obot & Obi-Egbedi, 2010). To evaluate the mode of adsorption inhibition for the inhibited systems (yam peel powder inhibitor on steel surface, the degree of surface coverage (θ) standards gotten from the weight lose measurements (as shown in Table 8) were fitted to Temkin isotherm and Frumkin adsorption isotherms (Murthy & Vijayaragavan, 2014; Roland, Smith, Khan, & Lee, 2016) respectively. The Frumkin isotherm assumes unit coverage at a specific inhibitor concentration and that the metal surface has heterogeneous adsorption sites, thus indicating the significance of lateral interactions and accounting for the active surface on the metal where adsorption inhibition occurs (Roland et al., 2016). Therefore, the adsorption inhibition followed the Langmuir isotherm model because values of the coefficient of linear correlation (R^2) obtained for all temperatures were closer to unity, as shown in Table 9. Adsorption isotherm plots were done for all the isotherms studied. The Langmuir adsorption for 1 liter of 0.5 M H_2SO_4 is shown in Figure 3. The calculated values of adsorption isotherm parameters obtained from all the isotherms studied are presented in Table 9. The adsorption equilibrium constant was observed to decrease as temperature increases, thus suggesting that the inhibitor performed better at low temperature and adsorbed physically onto the steel surface.

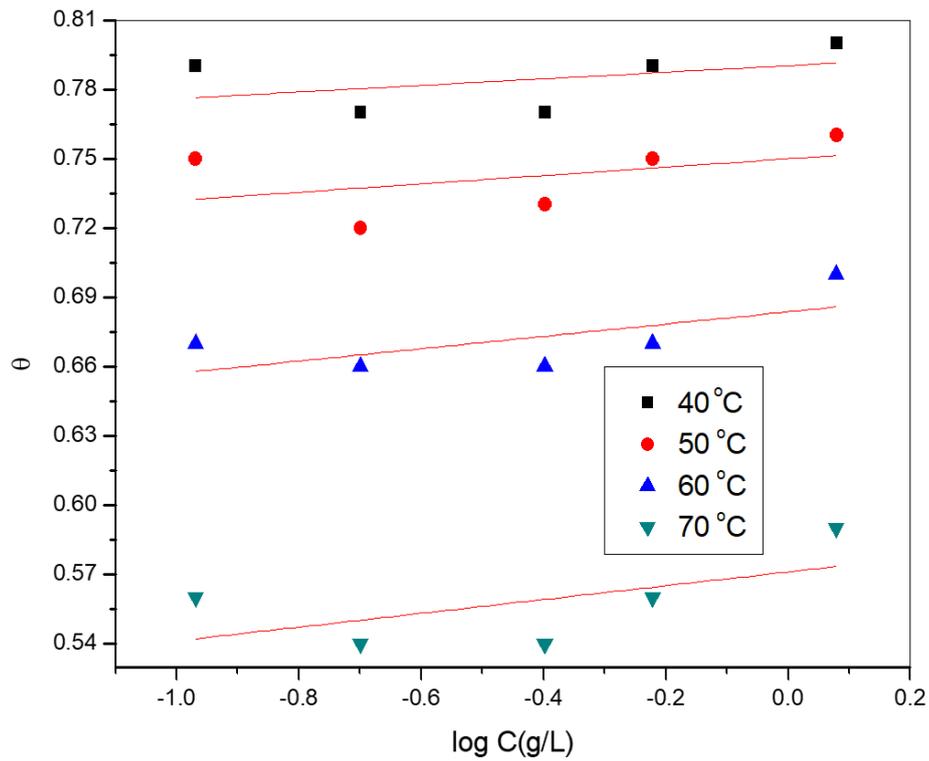
3.8. Adsorption Results

The plots for the adsorption isotherms are presented below.





(b)
Figure 3. Plot of $\log \theta$ against $\log C$ for Freundlich isotherm of mild steel in 0.5 M H_2SO_4 acid solution in the (a) Presence of un-irradiated and (b) Irradiated yam peel powder respectively at different temperatures.



(a)

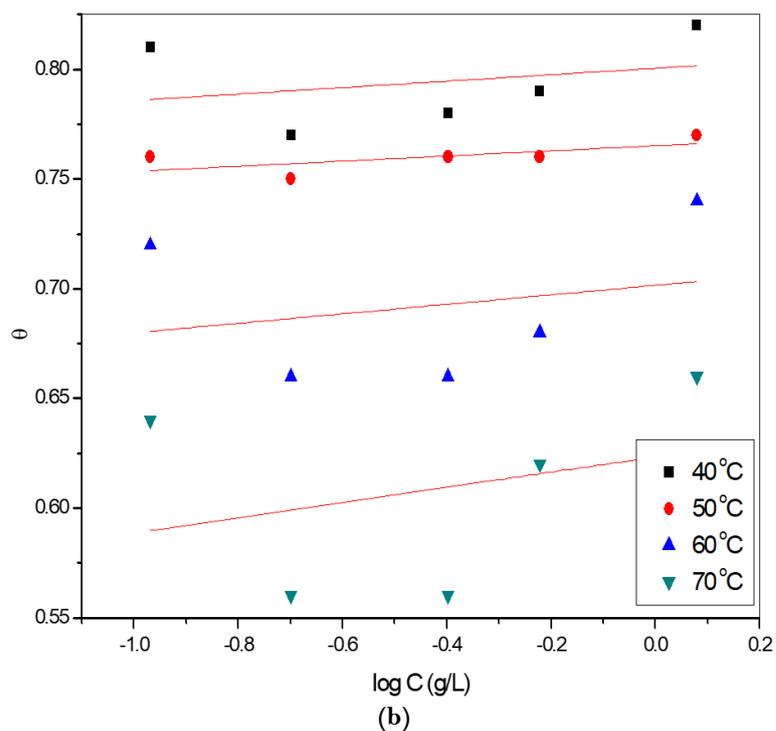
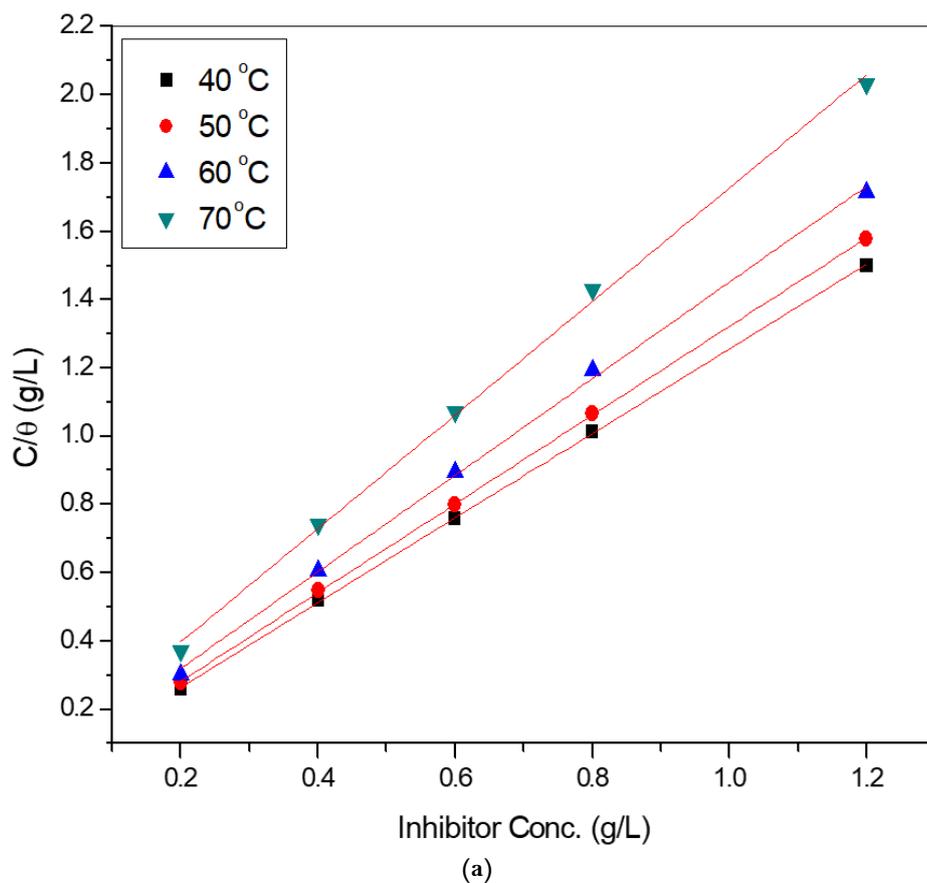
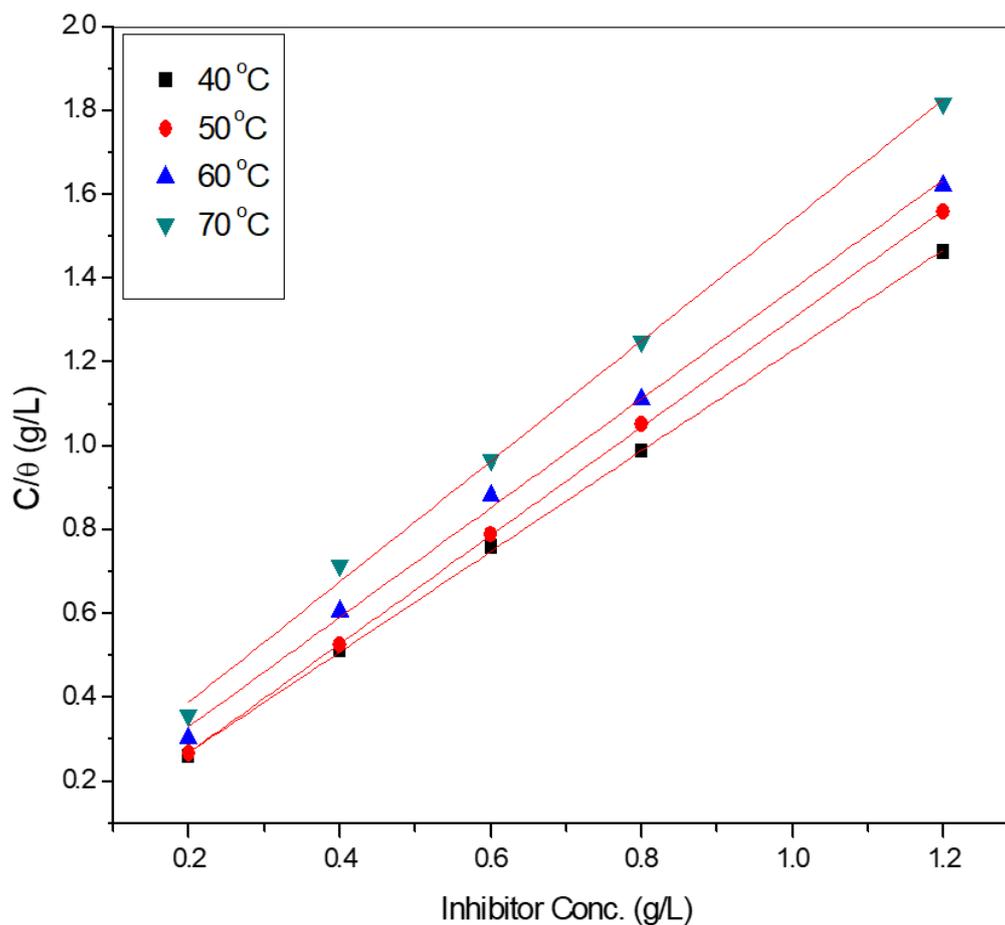


Figure 4. Plot of θ against $\log C$ for Temkin isotherm of mild steel in 0.5 M H_2SO_4 acid solution in the (a) Presence of un-irradiated and (b) Irradiated yam peel powder respectively at different temperature.





(b)

Figure 5. Plot of (C/θ) against C for Langmuir isotherm of mild steel in $0.5\text{ M H}_2\text{SO}_4$ acid solution in the (a) Presence of un-irradiated and (b) Irradiated yam peel powder respectively at different temperatures.

Table 8. Adsorption parameters for the inhibitive materials on mild steel in $0.5\text{ M H}_2\text{SO}_4$ acid solution at different temperatures for Langmuir and Frumkin adsorption isotherms.

System	Temp. (°C)	Freundlich isotherm				Temkin isotherm				Langmuir isotherm			
		Slope	I	R ²	K _{ads}	Slope	I	R ²	K _{ads}	Slope	I	R ²	K _{ads}
Un-irradiated yam peel	40	0.008	-0.102	-0.081	0.903	0.014	0.79	-0.084	2.203	1.238	0.018	1	55.556
	50	0.011	-0.125	-0.068	0.882	0.018	0.75	-0.064	2.117	1.299	0.023	1	43.478
	60	0.017	-0.165	0.247	0.848	0.027	0.684	0.251	1.982	1.413	0.038	0.998	26.316
	70	0.023	-0.244	0.13	0.783	0.03	0.571	0.138	1.77	1.482	0.065	0.998	15.385
Irradiated yam peel	40	0.008	-0.097	-0.223	0.908	0.015	0.8	-0.222	2.226	1.199	0.017	1	58.824
	50	0.007	-0.116	0.273	0.89	0.012	0.765	0.273	2.149	1.294	0.021	1	47.619
	60	0.013	-0.155	-0.257	0.856	0.022	0.702	-0.254	2.018	1.304	0.03	0.997	33.333
	70	0.024	-0.206	-0.213	0.814	0.035	0.623	-0.207	1.865	1.437	0.047	0.997	21.276

Note: I = Intercept.

(ii) Thermodynamics results

The results of thermodynamics considerations involve the followings: (i) Energy of activation and heat of adsorption.

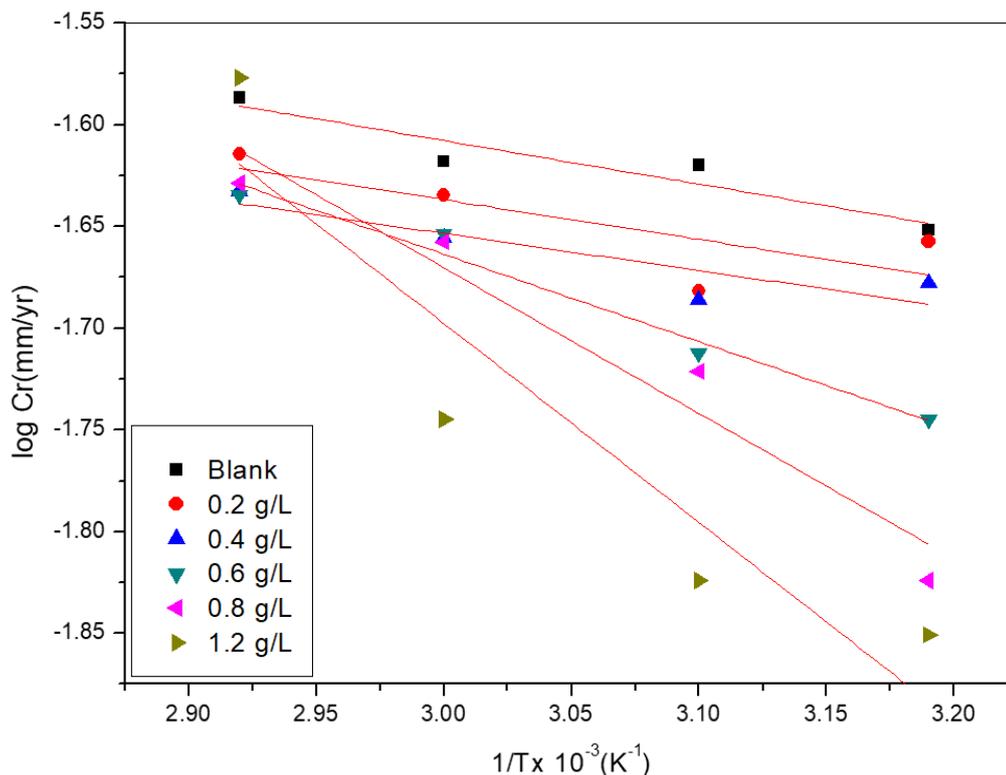


Figure 6. log CR against t / T for mild steel in 0.5 M H_2SO_4 acid solution and presence of un-irradiated yam peel powder at different temperatures.

Table 9. Calculated energy of activation and heat of adsorption for mild steel in 0.5 M H_2SO_4 acid solution and presence of irradiated yam peel powder.

System	Conc.	Energy of activation (KJ/mol)	Heat of adsorption (KJ/mol)
Un-irradiated yam peel powder	0.5 M H_2SO_4	4.0934	—
	0.2 g/L	5.7353	-3.223
	0.4 g/L	6.4851	-4.776
	0.6 g/L	8.2363	-5.445
	0.8 g/L	13.7068	-7.125
	1.2 g/L	18.7424	-9.089
Irradiated yam peel powder	0.5 M H_2SO_4	4.0934	—
	0.2 g/L	7.456	-5.067
	0.4 g/L	8.678	-7.801
	0.6 g/L	10.124	-9.024
	0.8 g/L	20.345	-10.123
	1.2 g/L	22.023	-12.456

4. ADSORPTION STUDIES RESULT DISCUSSIONS

The results from Figures 3, 4, 5 and 6, respectively and Table 8 revealed that adsorption of both un-irradiated and irradiated yam peel powder onto the surface of mild steel followed Langmuir adsorption isotherm due to close of their co-efficient linear regression to unity compared to other adsorption isotherms. Also, it is deduced from the results of adsorption isotherm that inhibited materials adsorbed onto the mild steel surface through mono layer adsorption to cover the corrosive sites or regions on the metal surface.

4.1. Thermodynamics and Kinetic Considerations Results

Figure 6 presents the plot of log CR against $(1/T)$ and results extract from the plot are shown in Table 4. Values of E_a were obtained from the slope of the plot using the expression: $-E_a = \text{Slope} \times 2.303R$. It is observed that values of E_a for the inhibited systems are greater compared to the blank 0.5 M H_2SO_4 acid solution. This confirmed that the

protection of mild steel immersed in 0.5 M H₂SO₄ acid solution offered by the inhibited systems occurred through physical adsorption on the mild steel surface. In addition, the mode of adsorption process observed based on the variations in E_a as a result of an increase in concentration of the inhibited system could be described as an activation-controlled process.

The values of heat of adsorption obtained as shown in Table 9 are below – 40 kJ/mol in all cases. This suggests that the inhibitive materials resisted corrosion activities of sulphate ions on mild steel immersed in 0.5 M H₂SO₄ acid solution to a certain degree by physical adsorption. Also, the variations in the values of heat of adsorption were reliant on the concentration of inhibitive materials and functional groups present within the material

The economic value of yams cannot be overemphasized, as it transcends beyond food consumption. Yam corms contain a steroid saponin compound called diosgenin, which can be extracted and used as a base for drugs such as cortisone and hormonal drugs.

The results indicate that radiation processing preserved the quality of yam corms through sprout and decay inhibition, reduction of weight loss, and preservation of macronutrients such as protein, fiber, lipids, and carbohydrate contents. Gamma irradiation could be a viable method for post-harvest management of yam corms.

5. SURFACE ANALYSES

Figure 7 presents scanning electron micrograph images of mild steel coupons in 0.5 M H₂SO₄ in the absence and presence of an inhibitor. Comparing the surface analyses of mild steel coupons under different immersion conditions (raw coupon (a), blank (b), and inhibited system (c)) for 10 hours demonstrated that gamma-irradiated yam peel powder slowed the rate of material deterioration. It formed a protective shield that adsorbed on the metal surface, preventing much direct attack from the corrosive sulfate ions.

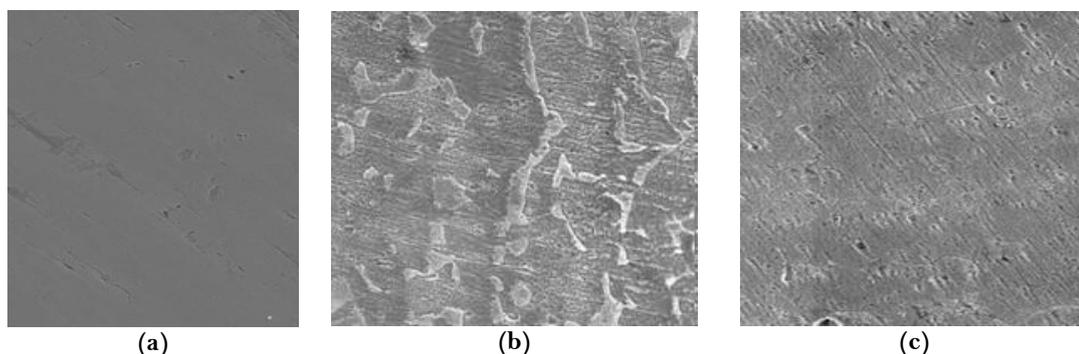


Figure 7. Surface analyses of mild steel coupons in different immersion conditions (Raw coupon (a), blank (b) and inhibited system(c)) for 10 h.

6. CONCLUSION

The results show that irradiated yam corm peel powder is a better inhibitor than unirradiated yam corm peel powder in 0.5 M H₂SO₄ solution. Gamma-irradiated yam peel powder offered the highest and lowest efficiencies of 93.17% and 74.34% at 24 and 120 hours, respectively, under room temperature. However, at varied temperatures, the highest inhibition efficiency was observed at 40°C, reaching 81.87% at a concentration of 1.2 g/L of Inh 2, while the lowest was at 70°C, with 54.19% efficiency at 0.2 g/L of Inh 1. The irradiated yam peel powder demonstrated a 99.00% efficiency compared to 90.00% for unirradiated yam peel powder. Yam corm peel powder exhibited some anticorrosion characteristics for protecting mild steel in 0.5 M H₂SO₄ environment, considering its potency when freshly prepared, stored, treated by gamma irradiation, and stored for one year. When employed at the proper concentration, plant peel powder functions as an effective green inhibitor on mild steel in acidic medium and can slow down the corrosion rate. Impedance data provided evidence of protection via adsorption, while surface analyses confirmed that the protection offered by gamma-irradiated yam peel powder was due to adsorption. The adsorption process followed the Langmuir

adsorption isotherm, indicating probable monolayer formation. The Gibbs free energy values suggested physical adsorption. The polarization curve confirmed gamma-irradiated yam peel powder as a mixed-type inhibitor, balancing corrosion activities at anodic and cathodic sites on the metal surface. Despite increasing concentration, the efficiency of gamma-irradiated yam peel powder declined under temperature studies, indicating a temperature-dependent effect and a physical adsorption process. A steady increase in weight loss was observed as temperature rose, indicating faster metal dissolution at higher temperatures. Consequently, yam corm peel powder is regarded as a good corrosion inhibitor, as it significantly reduces the corrosion rate. Gamma irradiation could be a viable method for post-harvest management of yam corms and food crop sustainability, aligning with SDG 1; Zero Hunger, and SDG 7; Innovation, as gamma irradiation application is new in Nigeria.

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Competing Interests: The authors declare that they have no competing interests.

Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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