RJC

RASĀYAN J. Chem.
Vol. 17 | No. 4 |1709-1716| October - December | 2024
ISSN: 0974-1496 | e-ISSN: 0976-0083 | CODEN: RJCABP
http://www.rasayanjournal.com
http://www.rasayanjournal.co.in

UTILIZATION OF PURPLE SWEET POTATO LEAVES (*Ipomoea batatas L.*) AS IRON CORROSION INHIBITOR IN HYDROCHLORIC ACID MEDIUM

Sitti Rahmawati[1,✉], Tri Santoso[1], Muharrikah Rahmat[1], Purnama Ningsih[1], Afadil[1], Sitti Aminah[1], Siti Nuryanti[1] and Yassaroh[2]

[1]Departement of Mathematics and Natural Sciences Education, Faculty of Teacher Training and Education, Tadulako University, Jl. Soekarno Hatta Km 9 City of Palu, 94118, Central Sulawesi, Indonesia

[2]Research Center for Polymer Technology-National Research and Innovation Agency (BRIN), KST BJ. Habibie, Kawasan Puspiptek Building 460, Tangerang Selatan, 15314, Indonesia

✉Corresponding Author: sittirahmawati.q3a@gmail.com

ABSTRACT

The aim of this investigation is to assess the effectiveness of iron inhibition and the rate at which iron corrodes in HCl solution media using leaf from purple sweet potato (*Ipomoea batatas L.*) powder and extract. Immersing iron in a 3% HCl solution for 12 days while adding 9 grams of inhibitor produced the lowest corrosion rate and maximum inhibition efficiency. In these conditions, a concentrated extract of purple sweet potato leaves produced a corrosion rate of 0.3197 mg/cm^2.day and an inhibitory efficiency of 96.7191%. Then using an inhibitor of purple sweet potato leaf powder, the corrosion rate that occurs is 0.4585 mg/cm^2.day and inhibition efficiency of 95.2942%. The reaction rate of the corrosion inhibition process using purple sweet potato leaf extract and powder is a first-order reaction. The lowest reaction rate constant was for purple sweet potato powder, 0.0007 mg/day, and purple sweet potato extract, 0.0006 mg/day. These data indicate that concentrated extract and purple sweet potato leaf powder have good inhibition performance.

Keywords: Purple Sweet Potato Leaves, Iron Plate, Corrosion, Rate Reaction, Inhibition, Efficiency.

RASĀYAN *J. Chem.*, Vol. 17, No.4, 2024

INTRODUCTION

Central Sulawesi is among the regions that possess abundant natural resources in the tuber group such as purple sweet potato plants. According to Central Sulawesi Agricultural Statistics Agency (BPS) data for 2022, the total sweet potato harvest area is 1,533 ha with a total production of 16,650.21 tons. High production yields were achieved from the utilization of purple sweet potato roots, whereas the leaves were not optimally utilized. Phytochemical tests revealed that purple sweet potato leaves contain alkaloids, flavonoids, saponins, and tannins and have relatively higher antioxidant effectiveness. [1] Tannins provide antioxidants that are able to donate electrons to oxidant compounds so that the activity of oxidant compounds can be inhibited. These organic compounds can adhere to the metal surface, covering the active sites and thereby decreasing the corrosion rate.[2] The breakdown of metal due to a chemical reaction with water or air is known as corrosion. This affects businesses like gas and transportation, where large sums of money are spent to prevent corrosion or repair rusted components and is especially common in steel and ferrous materials. Utilizing corrosion inhibitors is the most practical and cost-effective method for protecting and preventing metal corrosion. [2] A material known as a corrosion inhibitor is one that, when introduced to an environment in a certain quantity, lessens the rate at which metals corrode in that environment. In general, both organic and inorganic chemicals are used to make corrosion inhibitors. While inorganic compound inhibitors are widely used, they are not environmentally friendly and are highly toxic. Therefore, it is necessary to replace them with non-toxic, biodegradable alternatives that are economically viable and capable of significantly reducing the corrosion rate. [3] Organic inhibitors obtained from natural materials, especially those with N, O, P, and S atoms with lone pairs of electrons, are useful inhibitors. Elements with lone electron pairs can act as ligands, forming complex compounds with metals. [4] Organic

http://doi.org/10.31788/RJC.2024.1748964
This work is licensed under a CC BY 4.0 license.

inhibitors come from plants so these inhibitors are economical and effective in reducing the corrosion rate. The presence of organic tannin components in purple sweet potato leaves indicates that the vegetable may have uses in the prevention of corrosion. Plant extracts have been shown in numerous tests to be beneficial at preventing corrosion, including jengkol peel (*Pithecellobium jiringa*) which contains polyphenolic compounds, tannins, and saponins have the potential to reduce the rate of corrosion for iron with the lowest corrosion rate of 0.0189 mg/cm^2. [2] Moringa leaves (*Moringa oleifera*) containing antioxidants effectively reduced the corrosion rate in seawater medium with an inhibition efficiency of 70.5%.[5] The Mangifera odorata Griff seed extract, materials containing nitrogen, oxygen, phosphorus, and sulfur atoms, as well as atoms with unshared electron pairs, considerably reduce the corrosion rate of mild steel. The value of the highest inhibition efficiency of 91.78% was obtained by weight loss and 94.55% by potentiodynamic polarization method at MOSE concentration of 8 g/L and the immersion temperature of 30ºC.[4] Guava leaf extract *(Psidum Guajava L)* which contains tannin effectively reduces the rate of corrosion on orthodontic wire with the highest effectiveness of 85.53%.[6] Papaya leaf extract *(Load Papaya L.)* containing tannins was also proven to be effective in reducing the corrosion rate with an inhibition efficiency value of 99.87%. [7] Based on these studies, the extracts of natural ingredients that can reduce the rate of corrosion are tannin and anthocyanin which are found in many parts of plants such as fruit, leaves, and roots. Purple sweet potato leaves, like other plant parts containing anthocyanins and tannins, can serve as corrosion inhibitors due to the presence of these compounds. In addition, based on literature searches, no research has been found on purple sweet potato leaf extract as a corrosion inhibitor. Previous studies only used extracts from purple sweet potatoes containing anthocyanins as corrosion inhibitors. Therefore, in this study, purple sweet potato leaf extract was used with two variations of inhibitor forms (powder and extract) as well as variations in the addition of various inhibitor concentration variations and time variations. This research employed the same methodology as the previous study conducted by Tambun in 2022, which solely focused on organic inhibitors, specifically the application of purple sweet potato foliage as a corrosion inhibitor for iron in hydrochloric acid solution.

EXPERIMENTAL

Material

The supplies included an iron plate that was 5 centimeters in length and 0.5 centimeters in diameter, as well as purple sweet potato leaf inhibitors in two forms: powder and concentrated extract. Other chemicals, namely distilled water, 3% HCl, 70% methanol, $FeCl_3$, silicon carbide gride type 80. The tools used are an oven, analytical balance, beaker, Buchner vacuum, evaporator, and desiccator.

Preparation of Test Sample (Iron Plate)

The exterior of the iron plate was smoothed using silicon carbide gride type 80. The iron plate was cleaned and washed using detergent and running water and then rinsed using distilled water. After 20 minutes of drying at 100°C in the oven, the iron plate is cooled for 10 minutes in a desiccator. The iron plate is then weighed to find out how much it weighed initially.

Making Purple Sweet Potato Leaf Inhibitor (Powder)

Purple sweet potato leaves are cleaned and washed under running water, then cut into smaller pieces. For six hours, purple sweet potato leaves were dried at 50°C in the oven. The dried purple sweet potato leaves are blended in a blender to get the purple sweet potato leaves coarse powder. Furthermore, sifting with a size of 40 mesh was carried out to obtain a fine powder of leaves of purple sweet potato roots.

Preparation of Inhibitory Extract from Leaves of Purple Sweet Potatoes

100 grams of powdered purple sweet potato leaves were measured, and then 500 mL of 70% methanol was added. The mixture was macerated for 72 hours (3 days). After maceration, the mixture was filtered using a Buchner vacuum, and the filtrate was evaporated at 50°C for 1 hour.

Qualitative Analysis of Tannin Compounds

Add 10 mL of distilled water to 10 grams of extract from purple sweet potato leaves, then heat the mixture until it boils. Furthermore, filtering was carried out, the filtered filtrate was dripped with 10 drops of 1% $FeCl_3$ solution. A color change to dark greenish-black occurs indicating the presence of tannins. [8]

The Iron Plate Submerged in Hydrochloric Acid Solution Exclusively
The iron plate's initial mass was determined, and then it was submerged in a 50 mL solution of 3% HCl. After 3, 6, 9, and 12 days of immersion, the iron plates were reweighed to obtain their final weights.

Dipping the Iron Plate in an HCl Solution Enhanced with Inhibitors
After measuring the iron plate's original mass, it was submerged in a 50 mL solution of 3% HCl. The following weights of purple sweet potato leaf extract and powder inhibitors were added: (1, 3, 5, 7, and 9) grams, respectively. The iron plate was soaked for 3, 6, 9, and 12 days. Afterward, it was taken out of the corrosive medium and dried for 20 minutes at 100°C in an oven. Finally, it was placed in a desiccator for 10 minutes. The final weight of the iron plate was then determined by weighing it.

Calculation of Corrosion Rate and Inhibitory Effectiveness
The corrosion rate and the efficiency of inhibition are determined through the following equations (1) and (2):
Corrosion reaction rate:

$$C_r = \frac{W_b - W_a}{At} \qquad (1)$$

Where:
W_b = Weight of the test object before soaking in the solution (mg)
W_a = Weight of the test object after being immersed in the solution (mg)
A = Total area of the test object (cm^2)
t = Immersion time (days)
Inhibition Efficiency:

$$\text{Inhibition Efficiency} = \left[1 - \frac{Cr_b}{Cr_a}\right] \times 100 \qquad (2)$$

Where :
Cr_b = Corrosion rate using inhibitor (mg/cm^2.day)
Cr_a = Corrosion rate without using inhibitors (mg/cm^2.day)

Determination of Reaction Order and Reaction Rate Constant
The integral method is used to determine the reaction order and reaction rate constant (Equations 3 and 4). The reaction order is obtained from an equation that gives a constant value of k to the increase in the value of t [9]

$$\text{Orde 1} \qquad k = \frac{(\ln[Wb] - \ln[Wa]}{t} \qquad (3)$$

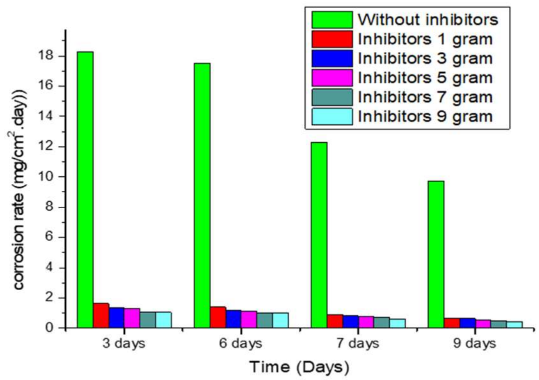
$$\text{Orde 2} \qquad k = \frac{1}{t}\left(\frac{1}{[Wa]} - \frac{1}{[Wb]}\right) \qquad (4)$$

Where :
Wb indicates the initial weight of the iron plate before immersion (measured in milligrams), while Wa represents the final weight of the iron plate after soaking (measured in milligrams). "t" refers to the duration of soaking (in days).

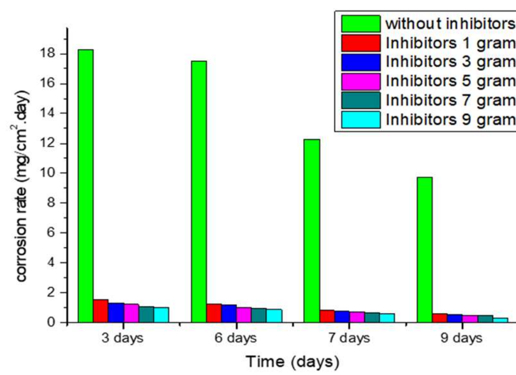
RESULTS AND DISCUSSION

Impact of Purple Sweet Potato Leaf Inhibitor Addition on 3% HCl Medium Corrosion Rate
The results showed that adding inhibitors made from purple sweet potato leaves significantly reduced the rate at which iron plates corroded, whether in powder or extract forms. As depicted in **Fig.-1(A)**, it's evident that with the powder inhibitor, the rate of corrosion experienced by iron plates is lower when compared to those without the inhibitor. For instance, over immersion periods of 3, 6, 9, and 12 days, the rate of corrosion experienced by iron plates without inhibitors was 18.2672 mg/cm^2 day, 17.5163 mg/cm^2 day, 12.2931 mg/cm^2 day, and 9.7439 mg/cm^2 day, respectively, whereas, with the addition of purple sweet potato leaf powder inhibitor, the rate of corrosion exhibited a significant decrease. Furthermore, With the increasing concentration of purple sweet potato leaf powder inhibitor rose, the rate of corrosion reduced. It took 12 days to reach the minimal corrosion rate of 0.4585 mg/cm^{2}day when 9 grams of powdered purple sweet potato leaf were added.
Figure-1(B) illustrates the impact of incorporating concentrated extract inhibitors from purple sweet potato leaves on the rate of corrosion exhibited by iron plates. When iron plates are submerged in hydrochloric

acid media and these inhibitors are added, the rate of corrosion is decreased in comparison to the case of untreated plates. The lowest corrosion rate observed for iron plates with the inclusion of concentrated extract derived from purple sweet potato leaves was recorded at 0.3197 mg/cm^2 day, achieved with the addition of 9 grams of extract during a 12-day soaking period.



(A)



(B)

Fig.-1: Iron Plate Corrosion Rate: Without Inhibitor and After Adding Extract Inhibitor (B) and Purple Sweet Potato Leaf Powder Inhibitor (A)

Observing Fig.-1(A) and Fig.-1(B), it's apparent that the corrosion rate experiences a notable reduction with the incorporation of the purple sweet potato leaf inhibitor. Furthermore, as the level of concentration of the inhibitor derived from purple sweet potato leaves rises, the corrosion rate tends to decrease. This occurrence may be attributed to the existence of tannin compounds found in purple sweet potato leaves, which feature OH- groups situated on the aromatic ring at the ortho position, facilitating the creation of chelates with iron. Ferrous tannins can be formed properly because tannins are hydrolyzed. When ions Fe^{3+} reacts with OH in the ortho position as shown in Fig.-2, a blue-black iron tannate complex solution will be formed. Tanat will stick to the iron surface which will prevent the corrosion process from occurring. [10]

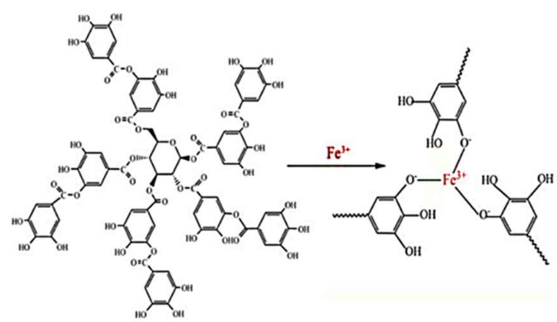
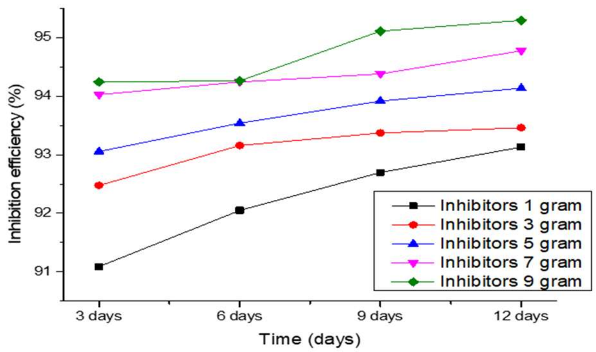


Fig.-2: Interaction of Tannins with Iron

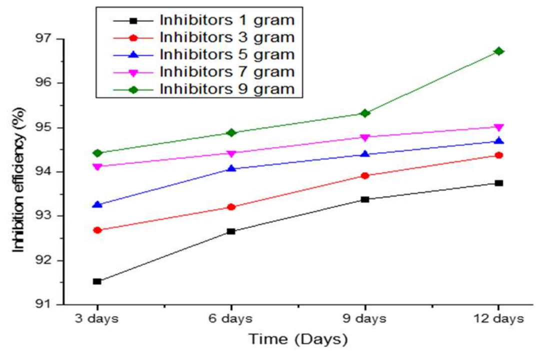
The rate of corrosion falls as the inhibitor's concentration rises. This results in more surface coverage because inhibitor molecules attach to the metal surface more frequently. [2] The research findings indicate that employing inhibitors in the form of the extract derived from purple sweet potato leaves yielded a lower corrosion rate compared to using inhibitors in the composition of the powder made from purple sweet potato leaves. This is due to differences in the surface area factor, where the extract possesses a larger surface area compared to the powder, resulting in greater adhesion of the extract, absorbing and reacting more easily to the iron. [11]

Effect of Addition of Purple Sweet Potato Leaf Inhibitor on Inhibition Efficiency in 3% HCl Medium

Figure-3(A) illustrates the inhibition efficiency, which is impacted by the concentration of inhibitors made from purple sweet potato leaf powder and the duration of immersion for the iron plate. It shows that higher inhibitor concentrations and longer immersion times result in higher efficiency in inhibition. The addition of 9 grams of inhibitor and a 12-day soaking period produced the maximum inhibition efficiency, at 95.2945%. In Fig.-3(B), the inhibition efficiency is influenced by the concentration of inhibitors derived from. The extract from purple sweet potato leaves and the duration of immersion for the iron plate is depicted. It demonstrates that greater inhibition efficacy is correlated with higher inhibitor concentrations. When 9 grams of inhibitor were added and the soaking period was extended to 12 days, the greatest inhibition efficiency of 96.719% was obtained.



(A)



(B)

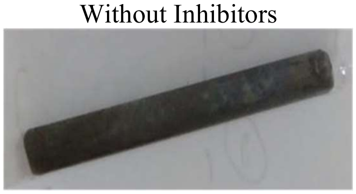
Fig.-3: The Efficiency of Iron Plate Inhibition in the Lack of Inhibitor and with the Introduction of Inhibitor Derived from Purple Sweet Potato Leaf Powder (A), as well as Extract Inhibitor (B)

Tannins act as inhibitors by converting oxidized iron into a tightly closed iron surface. Figure-2 which shows the structure of tannin compounds and their interactions with iron. The diagram indicates that the functional groups found in tannins facilitate the interaction of molecules with the iron surface, leading to the formation of a protective coating, in which the oxygen atom groups donate their free electron pairs to donate electrons to the metal Fe^{3+} [12]. The more powder and purple sweet potato leaf extract adsorbed, the greater the inhibition efficiency. When an inhibitor is added to an acidic environment, it sticks to the metal surface and forms a thin layer with several inhibitor molecules in it. Even though imperceptible without magnification, this layer effectively prevents environmental corrosion of the metal. Additionally, environmental factors may prompt the precipitation of the inhibitor, further safeguarding the surface from corrosion. [13] The effectiveness of organic compounds as inhibitors relies on their ability to adsorb onto surfaces. The adsorption mechanism of inhibitor compounds onto metal surfaces is accelerated when heteroatoms and μ electrons are present, as they have a substantial influence on it. [14] The results are consistent with the theory, showing that the inhibitor's concentration and the length of time the metal is exposed to the corrosive medium affect how effective the inhibition is. Higher inhibition efficiency results from longer metal-corrosive media contact times, and vice versa. Figure-4 illustrates an iron plate after immersion, both with and without the inclusion of inhibitors derived from concentrated extracts of purple sweet potato leaves, over a period of 12 days.

Without Inhibitors

Inhibitors 1 gram

Inhibitors 3 gram



Inhibitors 5 gram

Inhibitors 7gram

Inhibitors 9 gram

Fig.-4: Iron Plate After Soaking Without Inhibitor and Adding Inhibitor Purple Sweet Potato Leaf Extract with Soaking Time of 12 day

Determination of the Reaction Order and Reaction Rate Constant

The results of calculating the inhibition reaction rate constants for purple sweet potato leaf powder and extract for each time interval, the data is presented in Table-1 and 2.

Table-1: Reaction Rate Constant Values for First-Order Powder Inhibitors

No	Powder in HCl 3% (g)	Orde 1				
		K_1	K_2	K_3	K_4	The value of reaction rate constant (mg/day)
1	Non Inhibitors	0.0171	0.0186	0.0128	0.0101	0.0147
2	1	0.0015	0.0014	0.001	0.0006	0.0011
3	3	0.0013	0.0012	0.0008	0.0006	0.001
4	5	0.0012	0.0011	0.0008	0.0005	0.0009
5	7	0.001	0.001	0.0007	0.0005	0.0008
6	9	0.001	0.0009	0.0006	0.0004	0.0007

Table-2: Values of Reaction Rate Constants of Order 1 Extract Inhibitors

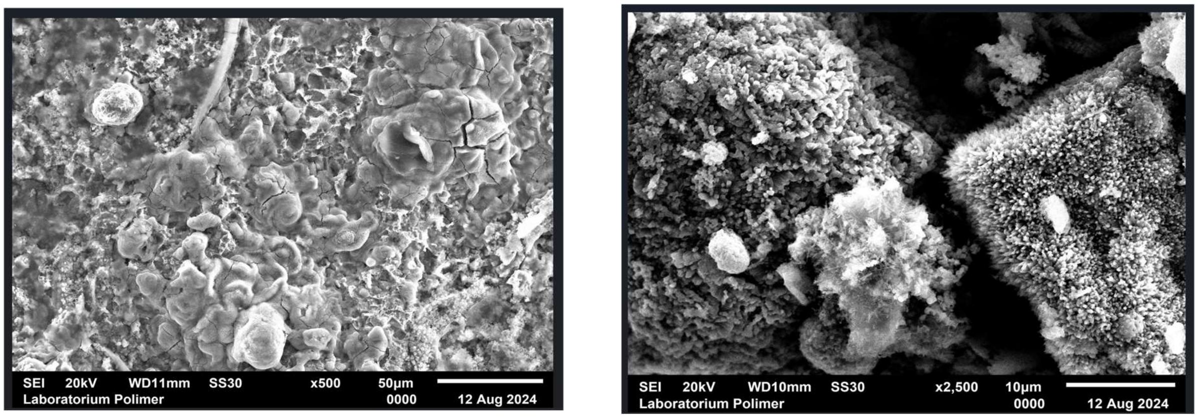
No	Extract in HCl 3% (g)	Orde 1				
		K_1	K_2	K_3	K_4	The value of reaction rate constant (mg/day)
1	Non Inhibitors	0.0171	0.0186	0.0128	0.0101	0.0147
2	1	0.0016	0.0012	0.0008	0.0006	0.0010
3	3	0.0012	0.0012	0.0007	0.0005	0.0009
4	5	0.0012	0.0010	0.0007	0.0005	0.0008
5	7	0.0010	0.0011	0.0006	0.0004	0.0008
6	9	0.0009	0.0008	0.0005	0.0003	0.0006

From the information presented in Table-1 and Table-2, it can be inferred that the reaction rate constant remains consistent according to the first-order formula 8. Thus, it can be concluded that the corrosion inhibition process utilizing both purple sweet potato leaf extract and powder follows a first-order reaction. The lowest reaction rate constant, namely 0.0007 mg/day, was obtained from the addition of 9 grams of purple sweet potato leaf powder inhibitor. Likewise, the incorporation of inhibitor extract from purple sweet potato showed that the lowest reaction rate constant value, namely 0.0006 mg/day, was obtained from the addition of 9 grams of extract inhibitor. The comparison of the two outcomes indicates that as the concentration of extract from purple sweet potatoes and powder increases, the reaction rate of the inhibition process with iron also increases. In a first-order reaction, the reaction rate is directly linked to the concentration of the reactant. If the concentration is increased twice, the reaction rate will be twice as fast as before. The obtained reaction rate constant value indicates the strength of adsorption between the extract from purple sweet potatoes/ powder inhibitor and the iron surface.

Surface Morphology Analysis Scanning Electron Microscope (SEM)

Testing using SEM (Scanning Electron Microscopy) aims to visualize the surface structure of the iron plate. Figure-6 shows the results of SEM testing of the iron plate surface before and after immersion in HCl solution, both with and without the addition of purple sweet potato leaf extract as a corrosion inhibitor.

Figure-6a shows the morphology of the iron plate surface without the addition of inhibitor after immersion for 12 days in 3% hydrochloric acid solution. The plate surface shows signs of corrosion, such as holes formed due to corrosive reactions. Figure 6b shows the surface of the iron plate with the addition of purple sweet potato leaf extract as an inhibitor. The surface of the plate looks smoother, with little or no holes, indicating that the inhibitor has succeeded in minimizing corrosion. The significant difference between the two images shows that the surface of the iron plate in HCl without the addition of inhibitor experiences more intensive corrosion, characterized by holes and damage to the surface. Conversely, the addition of purple sweet potato extract forms a protective layer on the surface of the iron plate that reduces corrosion. The mechanism of action of this inhibitor is the formation of a passive layer that protects the metal surface from attack by corrosive solutions. Organic inhibitors from purple sweet potato extract form an adsorption layer on the surface of the iron plate, which acts as a barrier to electrochemical reactions that cause corrosion so that the corrosion rate is significantly reduced. This process occurs through an adsorption mechanism, where inhibitor molecules attach to the metal surface and form a continuous film layer. This layer is hydrophobic, so it acts as a barrier that protects the metal surface from direct contact with corrosive electrolytes. Inhibitor molecules adsorbed on the metal surface create effective protection against corrosion attacks. This mechanism helps reduce corrosive reactions, lowers the corrosion rate, and maintains the integrity of the metal in an aggressive electrolyte environment. [2, 15]



(a) (b)

Fig.-6: SEM of Iron Plate Surface (a), After Soaking Without Inhibitor, (b) After Soaking with Purple Sweet Potato Leaf Extract Inhibitor

CONCLUSION

Based on the findings and discussions regarding the utilization of the application of sweet potatoes in purple color leaves (*Ipomoea batatas L.*) as an iron corrosion inhibitor in a hydrochloric acid medium, it can be inferred that incorporating purple sweet potato leaf powder inhibitor and concentrated extract into a 3% HCl solution effectively decreases the rate of corrosion for iron plates. The minimum rate of corrosion observed on the metal plate made of iron was 0.3197 mg/cm^2.day with the use of concentrated extract inhibitors of purple sweet potato leaves, and 0.4585 mg/cm^2.day with the application of purple sweet potato leaf powder inhibitor. This condition was achieved by adding 9 grams of inhibitor and 12 days of soaking time. The maximum inhibition effectiveness was obtained from the addition of 9 grams of the inhibitor derived from purple sweet potato leaf extract with a soaking time of 12 days, namely 96.719% and 95.2945% from the addition of 9 grams of inhibitor made from powder of purple sweet potato leaves with a soaking time of 12 days. The reaction rate of the corrosion inhibition process using purple sweet potato leaf extract and powder is a first-order reaction. The lowest reaction rate constant was for purple sweet potato powder, 0.0007 mg/day, and purple sweet potato extract, 0.0006 mg/day.

ACKNOWLEDGMENTS

The author appreciates the laboratory assistants from the Faculty of Education for their assistance in this research.

CONFLICT OF INTERESTS

There are no competing interests.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

Sitti Rahmawati http://orcid.org/0000-0002-7954-4822
Tri Santoso https://orcid.org/0000-0003-0959-3626
Muharrikah Rahmat https://orcid.org/0009-0009-3151-2432
Purnama Ningsih https://orcid.org/0000-0002-0082-7126
Afadil https://orcid.org/0000-0002-5145-4403
Sitti Aminah https://orcid.org/0000-0002-8738-2915
Siti Nuryanti https://orcid.org/0000-0002-5927-5274
Yassaroh https://orcid.org/0000-0002-9321-9479

Open Access: This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

REFERENCES

1. J. Manasathien, and P. Khanema, *Trends in Sciences,* **19(17)**, (2022), https://doi.org/10.48048/tis.2022.5766
2. R. Tambun, M.D. Fitri, R. Husna, and V. Alexander, *Rasayan Journal of Chemistry,* **15(2)**, 830(2022), http://dx.doi.org/10.31788/RJC.2022.1525965
3. R.O. Medupin, K. Ukoba, K.O. Yoro, and T.-C. Jen, *Materials Today Sustainability,* **22**, 100373 (2023), https://doi.org/10.1016/j.mtsust.2023.100373
4. Y. Stiadi, Rahmayeni, L. Rahmawati, M. Efdi, H. Aziz, and Emriadi, *Rasayan Journal of Chemistry* **13(1)**, 230(2020), http://dx.doi.org/10.31788/RJC.2020.1315325
5. F. Atan, R. Rosliza, and W.M. Wan Syahidah, *Journal of Physics: Conference Series,* **2266**, 012009(2022), http://dx.doi.org/10.1088/1742-6596/2266/1/012009
6. F.R. Sari, . N., and . I., *International Journal of Science and Healthcare Research,* **7(2)**, 166(2022), https://doi.org/10.52403/ijshr.20220425
7. D.E. Septiyani Arifin, D. Muliastri, R. Rudiana, and F.N.I. Sari, *Current Journal: International Journal Applied Technology Research,* **2(1)**, 21(2021), https://doi.org/10.35313/ijatr.v2i1.40
8. B. Hamzah, S. Rahmawati, W.S. Suwena, M.F. Hardani, and R. Hardani, *Rasayan Journal of Chemistry,* **13(4)**, 2243(2020), http://dx.doi.org/10.31788/RJC.2020.1345753
9. S. Rahmawati, and B. Bundjali, *Indonesian Journal of Chemistry,* **12(3)**, (2012), https://doi.org/10.22146/ijc.21345
10. J. Bolobajev, M. Trapido, and A. Goi, *Applied Catalysis B: Environmental,* **187**, 75(2016), http://dx.doi.org/10.1016/j.apcatb.2016.01.015
11. P. Suresh Kumar, L. Korving, K.J. Keesman, M.C.M. Van Loosdrecht, and G.J. Witkamp, *Chemical Engineering Journal,* **358**, 160(2019), https://doi.org/10.1016/j.cej.2018.09.202
12. F. Mukoningah, R.A. Fikroh, and S.S. Dewi, *EduChemia (Jurnal Kimia Dan Pendidikan*), **7(2)**, 236 (2022), http://dx.doi.org/10.30870/educhemia.v7i2.15063
13. A.M. Abdel-Karim, and A.M. El-Shamy, *Journal of Bio- and Tribo-Corrosion,* **8(2)**, 35(2022), https://doi.org/10.1007/s40735-022-00636-6
14. H.S. Gadow, A. Fawzy, M. Khairy, M.M.S. Sanad, and A. Toghan, *International Journal of Electrochemical Science,* **18(7)**, 100174(2023), https://doi.org/10.1016/j.ijoes.2023.100174
15. C. G., and A. F., “Corrosion Inhibitors – Principles, Mechanisms and Applications,” in *Developments in Corrosion Protection*, (InTech, 2014), http://dx.doi.org/10.5772/57255

[RJC- 8964/2024]