Exploring Corrosion Protection Potential of Sustainable and Green *Morus alba* 'Pendula' Fruit Extracts

Sara Shiri *

[a] *Department of Chemical Engineering, Faculty of Engineering, University of Garmsar, Garmsar, Iran*

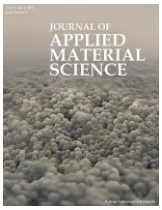
Editor's note: Plant extracts can provide new opportunities for developing next-generation sustainable corrosion protection systems. Shiri utilized Pendula fruit extracts as a novel resource for creating corrosion inhibition systems. The developed system was effective in preventing mild steel corrosion in a salty environment, indicating the potential of this green corrosion protection method for future sustainable applications.

doi: 10.22034/jams.2025.210139

How to cite: S. Shiri. *Journal of Applied Material Science*, **2025**, *1*, 210139.

JOURNAL OF
APPLIED
MATERIAL
SCIENCE
jams.hsu.ac.ir

Journal of Applied Material Science **2025**, *1*, 210139
How to cite: S. Shiri, *Journal of Applied Material Science*, **2025**, *1*, 210139.
Journal homepage: **jams.hsu.ac.ir**



Communication

Exploring Corrosion Protection Potential of Sustainable and Green Morus alba 'Pendula' Fruit Extracts

Sara Shiri *

Department of Chemical Engineering, Faculty of Engineering, University of Garmsar, Garmsar, Iran

Abstract

With climate change, corrosion is becoming more and more important. This phenomenon reduces the strength of metals and causes both huge damage and environmental pollution. It can be said that among all the methods to prevent corrosion, the use of chemical corrosion inhibitors is very common. But they cause environmental pollution because many of the raw materials used to prepare these inhibitors are toxic. On the other hand, many of them cause the release of heavy metals into the environment. Therefore, today, researchers are evaluating the use of plant extracts as a corrosion inhibitor. These inhibitors are known as green corrosion inhibitors (GCI). In this study, an attempt was made to evaluate the corrosion potential of the ethanolic extract of *Morus alba* 'Pendula' fruit on mild steel (MS) in salt solution. For this purpose, electrochemical impedance spectroscopy (EIS) testing was used. The evaluation results showed that this extract improves corrosion resistance and can be used and evaluated in protective coatings in the future.

Keywords: Green chemistry; Protection of metal; Inhibitory efficiencies.

1. Introduction

Corrosion can be considered a phenomenon that both causes environmental pollution and brings huge economic losses [1, 2]. Researchers consider this phenomenon to be a spontaneous process, although many factors play a role in it, such as temperature, humidity, and chemicals [3-5]. Destruction of metal structures due to corrosion always causes damage to many industries, such as construction and marine [6-8]. To prevent corrosion, chemical corrosion inhibitors have always been the priority, but their use has been very limited due to environmental issues and toxicity [9-11].

In the meantime, researchers have conducted a lot of research on the use of plant extracts to prevent corrosion [12]. Plant extracts are very popular due to their availability, cheapness, and non-toxicity [13-16]. Mulberry is a valuable plant that can be said to be used from almost all parts [17]. In many countries, such as Iran, Türkiye, and Greece, varieties of this plant are cultivated [18]. In traditional medicine, *Morus alba* 'Pendula' is used to treat fever, protect the liver, and reduce blood pressure [19]. Also, *Morus alba* 'Pendula' contains antimicrobial and antioxidant compounds [20]. In this study, the potential of *Morus alba* 'Pendula' fruit extract as a GCI has been evaluated.

* Corresponding author.
Email address: sarashiri.chem.eng@gmail.com (S. Shiri)

Received 09 May 2025
Revised 16 May 2025
Accepted 18 May 2025
Available online 19 May 2025

https://doi.org/10.22034/jams.2025.210139

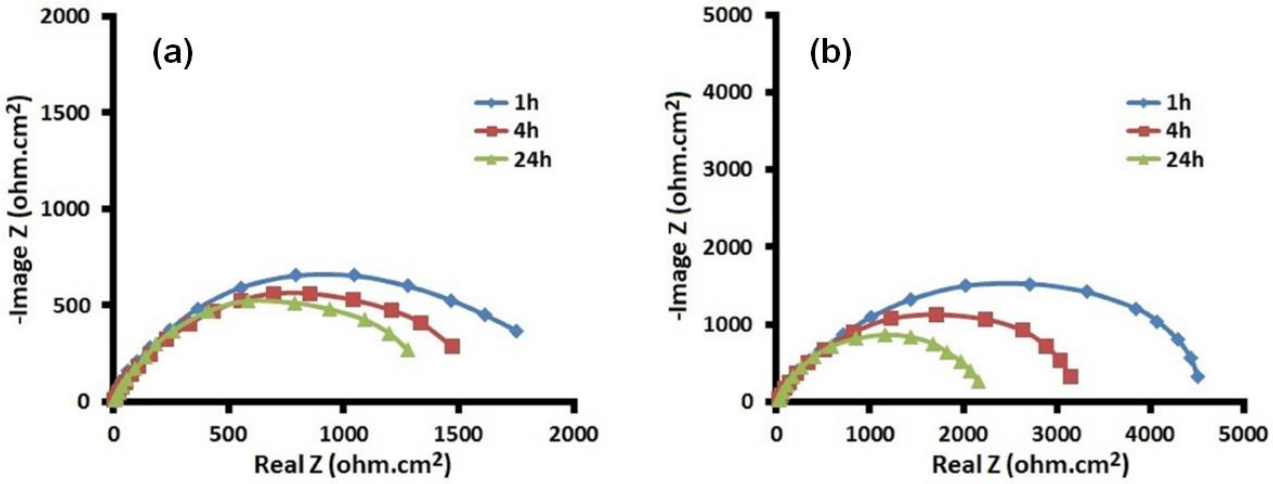


Figure 1. Nyquist plots at different immersion times.

2. Experimental

2.1. Materials

The sodium chloride (NaCl) and MS were obtained from Merck Company (Germany) and Iranian Mobarakeh Steel Company, respectively. Also, *Morus alba* 'Pendula' fruit was obtained from a local market (Ramsar city, a region in northern Iran).

2.2. Preparation of extract, MS substrate, and electrochemical tests

Potentiostat-galvanostat instrument (CorrTest CS350) was used for EIS test. Fruit extract was prepared as reported in the literature [1, 21]. Briefly, fruit extract was extracted with ethanol at 50°C for 20 min. The substrates were prepared as reported in the literature [6, 8]. For the tests, a 1×1 cm² area of the substrate was selected, and the rest of the surface was covered with a mixture of Beeswax melt and colophony resin. 100 ml of the extract was stirred in 1 liter of NaCl solution (3.5 wt.%) under magnetic stirring, and finally, the substrates were immersed in it. NaCl solution (3.5 wt.%) without extract was used as a reference solution. In this study, inhibition efficiency (η) was obtained using equation 1 [8].

$$\eta(\%) = 100\left(1 - \frac{R_{ct\ Without\ extract}}{R_{ct\ With\ extract}}\right) \quad (1)$$

3. Results and discussion

The results of the EIS test evaluation are reported in Figures 1 and 2 and Table 1. The degradation of MS without extract is observed by changing the diameter of the Nyquist plots in Figure 1a. In fact, the decrease in the diameter of the curves (indicating the charge transfer resistance (R_{ct})) with increasing immersion time indicates the penetration of corrosive species into the MS and its degradation [8]. It can be seen from Figure 1b that the presence of the extract has changed the degradation process of MS, and the R_{ct} value has increased. Typically,

Table 1. Electrochemical parameters obtained from EIS results

Samples	Time (h)	R_{ct}(a) (ohm.cm²)	R_s (ohm.cm²)	log |z| (ohm.cm²)	η (%)
Without extract	1	1751.27	7.1	1873.59	-
	4	1472.08	7.9	1493.46	-
	24	1279.19	7.4	1296.63	-
With extract	1	4506.79	15	4465.23	61
	4	3148.86	14	2795.36	47
	24	2158.76	13	1967.78	41

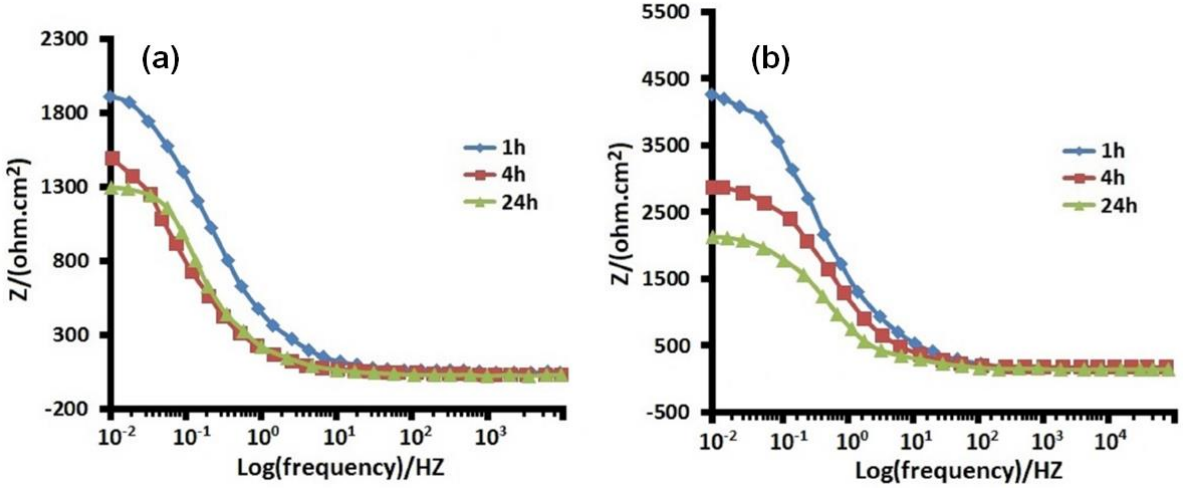


Figure 2. Bode plots at different immersion times.

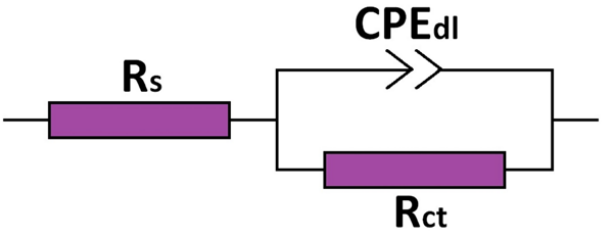


Figure 3. An equivalent circuit to describe the results. Also, Rs represents the solution resistance.

the absolute value of the impedance at low frequencies can be used to compare the inhibition in samples [6, 8]. Considering the R_{ct} value, it can be said that the sample containing the extract has greater resistance after 24h than the sample without the extract after 1h of immersion. The Bode plots (see Figure 2) show that this value decreases with the immersion time for MS without extract, but in the presence of extract, we observe an increase in this value. This behavior is probably related to the interactions between the functional groups in the extract and the MS surface, which cause the surface passivation.

Based on the results, the equivalent circuit that best matched the impedance results was selected (see Figure 3). The results in Table 1 show that the extract compounds were adsorbed on the mild steel surface. The mechanism of inhibition of an extract is directly related to the bioactive compounds present in it. This fruit contains flavonoids, polyphenols, lipids, sterols, and isoquercetin [22]. In the meantime, using a suitable solvent that can extract these compounds is very important. According to the literature, ethanol can extract these compounds [1], which have been used in this study. It can be said that the main compounds of this fruit are adsorbed on

Table 2. Corrosion inhibition performance of some plants

Plant	Substrate	Corrosive Medium	Maximum inhibition efficiency (%)	Reference
Date seed	Mild steel	NaCl	71	[8]
Matcha	Mild steel	NaCl	70	[20]
Zenthoxylum alatum	Mild steel	15% HCl	91	[25]
Argemone mexicana	Mild steel	1 M HCl	92.5	[26]
Ganoderma Lucidum	Mild steel	NaCl	98.26	[27]
Morus alba 'Pendula'	Mild steel	NaCl	61	This study

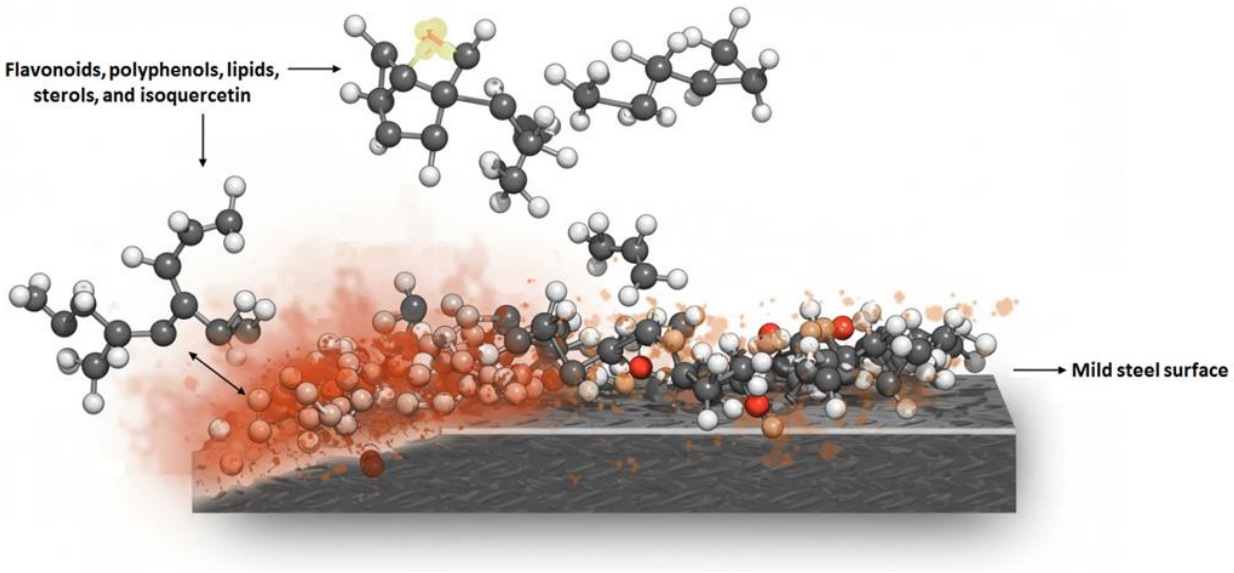


Figure 4. Adsorption of the main components of Morus alba 'Pendula' extract on the MS surface.

the MS surface (see Figure 4), which can be attributed to the π-electron transfer between oxygen atoms and aromatic rings of compounds with vacant *d*-orbitals of the MS surface [23]. In fact, these compounds can interact with the anodic dissolution products and block this region, and can form a protective layer on the surface [23, 24]. Table 2 reports a comparison between the results of this study and the results of several other studies.

4. Conclusions

In summary, a corrosion inhibitor was prepared using Morus alba 'Pendula' fruit extract. According to the results, it can be said that this extract can inhibit corrosion. Although the use of environmentally friendly corrosion inhibitors is very attractive, all their aspects, such as their effectiveness over time and temperature changes, should be evaluated in the future. However, it can be said that their non-toxicity and inexpensive encourage researchers to use them. Perhaps in the future, they can be introduced as a suitable alternative to chemical inhibitors.

Conflict of Interest

The authors declare no conflict of interest.

References

1. M. Sheydaei. The Use of Plant Extracts as Green Corrosion Inhibitors: A Review. *Surfaces*, **2024**, *7*, 380.
2. M. Lavanya, J. Ghosal, and P. Rao. A comprehensive review of corrosion inhibition of aluminium alloys by green inhibitors. *Canadian Metallurgical Quarterly*, **2023**, *63*, 119.
3. H.A. Al Salihi, et al. Exploring the Efficacy of Polysaccharides as Green Corrosion Inhibitors: A Comprehensive Review. *Starch - Stärke*, **2024**, *76*, 2300234.
4. A. Kadhim, et al. Corrosion inhibitors. A review. *International Journal of Corrosion and Scale Inhibition*, **2021**, *10*, 54.
5. B. R. Holla, et al. Plant extracts as green corrosion inhibitors for different kinds of steel: A review. *Heliyon*, **2024**, *10*, e33748.
6. M. Edraki, et al. Protective Nanocomposite Coating Based on Ginger Modified Clay and Polyurethane: Preparation, Characterization and Evaluation Anti-Corrosion and Mechanical Properties. *Polymer Science, Series B*, **2022**, *64*, 756.
7. K.D. Ralston and N. Birbilis. Effect of Grain Size on Corrosion: A Review. *Corrosion*, **2010**, *66*, 075005.
8. M. Edraki and M. Sheydaei. Investigation of date seed powder as green corrosion inhibitor for mild steel: A study of solution and coating phases. *Hybrid Advances*, **2024**, *6*, 100238.
9. N. Eliaz. Corrosion of Metallic Biomaterials: A Review. *Materials*, **2019**, *12*, 407.

10. M. Zunita and V.A. Rahmi. Advancement of Plant Extract/Ionic Liquid-Based Green Corrosion Inhibitor. *Chemistry Africa*, **2023**, *7*, 505.

11. Y. Li, et al. Exploring the potential of plant extracts as corrosion inhibitors: A comprehensive review. *Progress in Organic Coatings*, **2025**, *198*, 108915.

12. P. Singh and P.N. Dave. Sustainable technology for cultural heritage preservation: The role of green corrosion inhibitors. *Science of The Total Environment*, **2025**, *975*, 179301.

13. H. Thacker and V. Ram. Green corrosion inhibitors derived from plant extracts and drugs for mild steel in acid media: A review. *Results in Surfaces and Interfaces*, **2025**, *18*, 100364.

14. M. Sheydaei, et al. An overview of the use of plants, polymers and nanoparticles as antibacterial materials. *Chemical Review and Letters*, **2022**, *5*, 207.

15. M. Edraki, et al. Enhanced Mechanical, Anticorrosion, and Antimicrobial Properties of Epoxy Coating via Pine Pollen Modified Clay Incorporation. *Iranian Journal of Chemistry and Chemical Engineering*, **2023**, *42*, 2775.

16. M. Edraki, et al. Characterization and antimicrobial properties of Matcha green tea. *Chemical Review and Letters*, **2022**, *5*, 76.

17. M.S. Butt, et al. Morus alba L. nature's functional tonic. *Trends in Food Science & Technology*, **2008**, *19*, 505.

18. S. Ercisli. A short review of the fruit germplasm resources of Turkey. *Genetic Resources and Crop Evolution*, **2004**, *51*, 419.

19. J. Zhishen, T. Mengcheng, and W. Jianming. The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry*, **1999**, *64*, 555.

20. A. Gryn-Rynko, G. Bazylak, and D. Olszewska-Slonina. New potential phytotherapeutics obtained from white mulberry (Morus alba L.) leaves. *Biomedicine & Pharmacotherapy*, **2016**, *84*, 628.

21. N.O. Eddy, et al. A Brief Review on Fruit and Vegetable Extracts as Corrosion Inhibitors in Acidic Environments. *Molecules*, **2022**, *27*, 2991.

22. T. Katsube, et al. Antioxidant flavonol glycosides in mulberry (Morus alba L.) leaves isolated based on LDL antioxidant activity. *Food Chemistry*, **2006**, *97*, 25.

23. I.S. Cole and D. Marney. The science of pipe corrosion: A review of the literature on the corrosion of ferrous metals in soils. *Corrosion Science*, **2012**, *56*, 5.

24. A.J. Betts and L.H. Boulton. Crevice corrosion: review of mechanisms, modelling, and mitigation. *British Corrosion Journal*, **2013**, *28*, 279.

25. L.R. Chauhan and G. Gunasekaran. Corrosion inhibition of mild steel by plant extract in dilute HCl medium. *Corrosion Science*, **2007**, *49*, 1143.

26. G. ji, et al. Inhibitive Effect ofArgemone mexicanaPlant Extract on Acid Corrosion of Mild Steel. *Industrial & Engineering Chemistry Research*, **2011**, *50*, 11954.

27. M. Sheydaei, M. Edraki, and S. Javanbakht. Ganoderma Lucidum-Modified Clay Epoxy Coating: Investigation of Thermal, Mechanical, Anticorrosion, and Antimicrobial Properties. *Polymer Science, Series B*, **2024**, *65*, 991.