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Original Paper

The contribution of extracts from medicinal plants to the research of corrosion inhibition

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Abstract

The increasing interest in natural plants, fueled by the discovery of highly effective elements with diverse beneficial biological properties, underscores the quest for novel compounds from natural sources. This study focuses on exploring the anticorrosive potential of the aqueous extract from two specific plants within this broader context. In the initial phase, which centers on extraction methods, the hexane extract from Mullein, obtained through Soxhlet extraction, proves to be particularly promising, boasting the highest yield at 39 percent. Gravimetric test results affirm a commendable level of inhibitory efficiency. Notably, among the various extracts, EHM and EHC demonstrate significant anticorrosive activity, with the EmM extract displaying a notable level of efficiency. Finally, the gravimetric method is employed to characterize corrosion-inhibiting qualities, revealing that Mullein extracts obtained through diverse methods consistently exhibit the highest activity. This study contributes valuable insights into the potential of natural plant extracts as effective anticorrosive agents, with a specific emphasis on the significance of extraction methods in optimizing their inhibitory properties.

1. Introduction

Metals and alloys experience corrosion when their environments act chemically or electrochemically upon them **[1,2]** Mild steel is the steel that is used widely in the manufacturing and construction industries. The main problem is the use of mild steel industry is when dissolution in acidic media solution. Nature of very weak resistance to corrosion makes mild steel is easily to corrode. Among the areas that use mild steel are cleaning industrial, oil field, petrochemical processing, heat exchangers, tanks and other **[2-4]**. Significant ramifications arise in multiple domains, especially in the industrial sector: manufacturing halts, corrosion-prone component replacements, mishaps, and environmental hazards are commonplace, occasionally leading to severe financial fallout. These days, there are many different ways to prevent corrosion, including cathodic protection, applying metallic or polymeric coatings to surfaces, or adding corrosion inhibitors to alter the corrosive environment**[5]**. One novel method of preventing corrosion is the use of corrosion inhibitors. These are compounds that lessen or even stop the metal's reaction with its surroundings when added in small amounts to corrosive media. Currently, combining two or more of these defense strategies is popular**[6]**. Inhibitors are still frequently and unavoidably used to prevent metals from breaking down**[7]**. Throughout ancient times, plants have been alive. For both humans and other living things, like animals, she is a vital and crucial part of the biological cycle of life. It is true that of the roughly 500,000 plant species on Earth, 80,000 are known to have therapeutic benefits**[6]**. Traditional corrosion inhibitors, known for their harmful impact, are now subject to restrictions, mirroring a shift in environmental consciousness and regulatory standards. Consequently, there is a growing trend toward environmentally friendly corrosion inhibitors. Notably, those derived from natural products distinguish themselves by leveraging a diverse range of active elements capable of forming protective films on metal surfaces, thereby mitigating further corrosion. This underscores the increasing necessity for eco-friendly inhibitors. Green corrosion inhibitors, gaining traction due to both environmental concerns and economic considerations, present a viable solution to meet this demand. In this review article, we succinctly explore various corrosion prevention methods and shed light on green inhibitors, offering insights into their sources and effective application methods **[8,9]**.

Medicinal plants have long been used for healing, a practice influenced by ancient Greek, Roman, Indian, Chinese, and Arab-Muslim medicine. As part of a study on the use of plants in traditional medicine, an investigation was carried out nationwide, and 71 % of those surveyed reported using aromatic and medicinal plants for self-care**[10]**. Globally, there is still a growing number of medicinal forms made from plants or other plant materials **[11]**.
Conversely, in recent years, scientists have directed their attention not only toward plant biological activities but also toward the anti-corrosive properties of naturally occurring plant-based products **[12]**. With the increasing utilization of metals and alloys in everyday applications, corrosion has become a significant concern, posing potential irreversible and detrimental effects. Plant extracts stand out as promising environmentally friendly alternatives to conventional corrosion inhibitors **[13]**. The current work's goal is to study the inhibition efficiency of natural extract obtained from Caralluma and Mullein in an acidic medium using mild steel. Weight loss measurements have been used to determine the protection efficiency of this compound based on its behavior in 1.0 M HCl. Fig. 1 represents the plants of (a) Mullein and (b) Caralluma tuberculata.

In the study conducted by Muhammad Abdul Aziz et al **[14]**, the significance of medicinal plant species was assessed through use reports (URs). The findings indicated that certain plant species held notable importance within indigenous communities, with Caralluma tuberculate recording the highest URs. They revealed that Caralluma tuberculata plant demonstrated extensive traditional use against jaundice, dysentery, stomach pain, and high blood pressure. Additionally, it is valued as a vegetable, commanding a high price in local markets. Traditional practices in Pakistan involve using C. tuberculata in tea for managing diabetes, and in Quetta, Pakistan, chewing the fresh plant is a tradition for treating high blood pressure. The plant's applications extend globally, including blood purification in South Africa, Saudi Arabia, and Iran, as well as addressing digestive disorders and skin problems in various regions. Scientific validation supports its anti-malarial activity and ability to enhance joint mobility. This study contributes to the broader understanding of the diverse uses and significance of Caralluma tuberculata in traditional medicinal practices **[15]**.

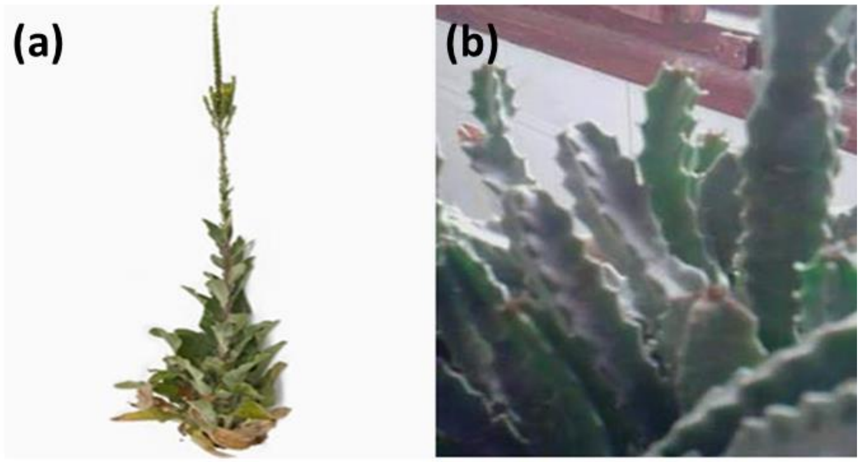

Fig.1. Plant of (a) Mullein and (b) Caralluma tuberculata

2. Experimantal details

The plant material utilized in this study comprised leaves from Mullein and Caralluma tuberculata. These leaves were harvested in March 2021 from the Beni Mellal-Khénifra region, near Khénifra. After air-drying at ambient temperature and being shielded from light, the leaves from each plant were finely powdered using a mortar (Fig. 2).

Fig. 2. Extraction of Mullein and Caralluma tuberculata leaves (a) Soxhlet Extraction (b) Maceration

Subsequently, two extraction methods, maceration and Soxhlet, were employed to extract the plant material **[16-18]**. Three solvents—water, methanol, and ethanol—were used in the extraction process. The yield of each extract was determined using the following formula **[18]**:

$$R_{extract}\ \% = (m_{extract} / m_{plant})\ x100$$

For electrochemical tests, a gravimetric approach was adopted. Mild steel served as the test substance, characterized as a fine-grained, narrowly-analyzed, non-alloyed steel with dimensions of 1.5 x 1.5 x 0.05 cm. The composition of the steel was expressed as the following percentage by weight (Table 1).

Table 1. Mild Steel Chemical Composition (% by Weight)

Element	Fe	Si	C	P	S	Mn	Al
Mass percentage	**99.21**	**0.38**	**0.21**	**0.09**	**0.05**	**0.05**	**0.01**

The steel sample underwent meticulous preparation before each measurement. It was manually polished using abrasive paper with varying grain sizes ranging from 200 to 1500. Subsequently, the sample was cleaned with distilled water and acetone and then dried.

Gravimetric experiments were conducted in glass flasks. An aggressive solution of 1 M hydrochloric acid (HCl) was prepared by diluting Analytical Grade 37% HCl with distilled water, and the inhibitor concentration was set at 1 g/L. Each specimen was initially weighed using an analytical balance and then immersed in HCl solutions, both with and without inhibitors. The immersion period lasted for 6 hours at a temperature of 303 K.

After the immersion period, the specimens underwent a thorough washing process before being reweighed. This rigorous procedure ensured accurate and reliable data collection for the gravimetric experiments.

3. Results and discussion

3.1. Yields of extraction from Mullein and Caralluma tuberculata using various techniques

The extraction yields, depicted in Fig. 3, exhibit a range of 13–39%. Specifically, the maceration extraction method demonstrated the highest yield for Mullein at 32%, with hexane extraction ranking second at 25%, and methanol extraction at 16%. Our findings highlight that water-diluted extracts tend to yield higher amounts of chemicals. This phenomenon can be attributed to water's high polarity, enabling it to extract a diverse range of molecules, including significant quantities of highly soluble non-phenolic substances like proteins and carbohydrates**.** In contrast, for Caralluma extracts, hexane extraction yielded the highest extraction rate at 39%. Water-extractable compounds displayed lower yields, ranging from 19% for maceration extraction to 13% for de-methanol extraction.

The results underscore the necessity to carefully select the extraction method and solvent system based on the plant under investigation. It is evident that active components vary, and their extraction efficiency depends on the chosen extraction solvent. Therefore, the selection of a suitable solvent system remains a pivotal step in optimizing the extraction process.

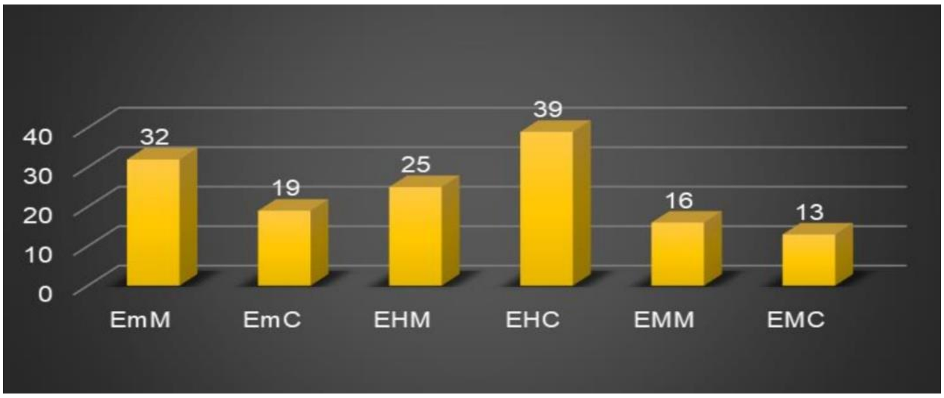

Fig. 3. Yields from the extraction of Mullein and Caralluma tuberculata using various extraction techniques. Hexane extract (EH), methanol extract (EM), and maceration extract (Em)

3.2. Plant extracts with anti-corrosive properties

A wide range of artificial organic and inorganic substances has traditionally served as corrosion inhibitors for metals, albeit with associated hazards and high costs. In response to these drawbacks, there is a growing inclination in current research toward the utilization of "green inhibitors." Natural substances are gaining prominence as eco-friendly corrosion inhibitors due to their non-toxic and biodegradable characteristics **[19].** The exploration of simple and cost-effective methods for extracting plant materials has become particularly significant, offering a sustainable source of chemical compounds that are inherently generated and environmentally friendly.

In the subsequent study, our focus was on examining the impact of an HCl acid solution on mild steel, both in the presence and absence of an aqueous extract from two specific plants. Electrochemical methods were chosen as the primary investigative tools **[20,21]**. By employing these electrochemical techniques, we aimed to gain insights into the corrosion behavior of mild steel in the presence of natural extracts, evaluating the effectiveness of these green inhibitors in mitigating corrosion. This research direction aligns with the broader shift towards sustainable and environmentally friendly practices in corrosion inhibition, emphasizing the potential of natural products in addressing corrosion challenges.

3.3. Gravimetric study

To assess the inhibition of metal corrosion in an electrolytic solution, one commonly employed method is mass loss measurements. This straightforward approach offers the advantage of simplicity and requires no specialized equipment. The inhibitory effectiveness (IE%) of the compounds is determined using the formula **[22,23]**:

$$IE\% = \left(1 - \frac{W}{W_{inh}}\right) \times 100$$

where W and W_{inh} represent the corrosion rate values in the presence and absence of the inhibitor, respectively.

The corrosion rate (W) is calculated using the formula **[24]**:

$$W = \frac{\Delta m}{S \times t}$$

Where Δm is the mass loss in mg, S is the exposed surface area in cm^2, and t is the immersion time in the solution in hours.

Table 2. Corrosion Rates and Inhibitory Efficiencies of Mullein and Caralluma tuberculata Extracts in Different Solvents

Plant	Solvent	Medium	W ($mg.cm^{-2}.h^{-1}$)	IE (%)
Mullein	Distilled Water	EmM	0.214	**76**
	Hexane	EHM	0.089	**90**
	Methanol	EMM	0.390	**56**
Caralluma tuberculata	Distilled Water	EHC	0.126	**86**
	Hexane	EmC	0.590	**34**
	Methanol	EMC	0.728	**19**

Table 2 represents a comprehensive overview of the gravimetric corrosion rates and inhibitory efficiencies of the studied compounds in 1M hydrochloric acid. The inhibitory efficacy is notably influenced by the chosen extraction technique, exemplified by the Mullein extract with an average efficiency of 76%, compared to the Caralluma extract at 34%. During soxhlet extraction in hexane, both Mullein and Caralluma extracts exhibit high inhibitory efficiencies, reaching 90% and 86%, respectively. This underscores hexane's industrial utility in plant oil extraction due to its remarkable lipid-affinity qualities. Conversely, the inhibitory efficiencies of extracts obtained through methanol extraction are less than 60%, indicating the solvent's selectivity in removing phenolic chemicals. Notably, extracts EHM and EHC from the two plants in hexane prove to be more potent and effective, underscoring the critical role of solvent selection in determining inhibitory efficiency.

4. Conclusion

In conclusion, this study explored the electrochemical characteristics of two plants, examining their potential as corrosion inhibitors. Natural bioactive compounds, such as lipids and polyphenols found in plants, have long been of interest for their potential health benefits. The aim of this work was to investigate the inhibitory effects of compounds derived from medicinal plant extracts on mild steel corrosion in 1M HCl media. The gravimetric analysis conducted in this study revealed a significant reduction in the corrosion rate upon the addition of the studied compounds. Notably, the inhibitory effectiveness reached a maximum of 90.14% with EHM, indicating its substantial capability to suppress mild steel corrosion. This result underscores the promising potential of these natural compounds as effective corrosion inhibitors. Furthermore, the findings emphasize the critical role of extraction techniques and solvent selection in obtaining active chemicals from each plant. As demonstrated in this research, the inhibitory effectiveness is not only influenced by the inherent properties of the compounds but also by the extraction process. The careful consideration of these factors is essential for harnessing the full potential of natural inhibitors. In essence, this study contributes valuable insights into the application of plant extracts as corrosion inhibitors and highlights the importance of understanding the extraction process for optimizing their inhibitory effectiveness. The observed decrease in corrosion rates suggests a practical avenue for the development of environmentally friendly corrosion protection strategies with potential implications for various industrial applications.

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