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Leucaena leucocephala (Ipil-Ipil) Bark as a Natural Rust Remover for Mild Steel

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Abstract

This study investigated the effectiveness of Leucaena leucocephala (ipil-ipil) bark extract as a natural rust remover for mild steel, addressing the growing need for eco-friendly alternatives to hazardous chemical rust removers. Grounded in phytochemical interaction theory, the study focused on the ability of tannins, polyphenols, and organic acids to react with iron oxides and facilitate corrosion removal. A quantitative true experimental design was employed, using rusted mild steel plates as experimental units. Rust was induced using a 10% NaCl solution, and treatments included Leucaena leucocephala bark extract, a commercial rust remover, and distilled water as control. Data were collected through mass analysis, ISO 8501-1 surface cleanliness ratings, and photographic documentation, with statistical analysis conducted using mean, One-Way ANOVA, and Tukey HSD tests. Results revealed that Leucaena leucocephala bark extract achieved the highest effectiveness (83.33%, Sa 2½), outperforming the commercial rust remover (55.56%, Sa 2), while distilled water showed no effectiveness (0%). Statistical analysis confirmed significant differences among treatments ($F = 30.5$, $p = 0.000718173$), establishing the natural extract as significantly more effective. The findings demonstrate that treatment type significantly influences rust removal performance and validate the bark extract as a viable, cost-effective, and environmentally friendly alternative. The study recommends further investigation into concentration optimization, broader metal applications, and formulation improvements. This study supports SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production) by promoting sustainable material maintenance and eco-friendly alternatives to chemical products. Its sustainability impact lies in reducing environmental and health risks associated with chemical rust removers while advancing green chemistry solutions that are accessible to local communities.

Keywords: Corrosion, Leucaena Leucocephala, Mild Steel, Phytochemicals, Rust Removal, Sustainable Materials, Tannins

1. Introduction

Metals, particularly iron-based alloys such as mild steel, are essential in modern infrastructure due to their mechanical strength, ductility, and cost-effectiveness. However, their susceptibility to corrosion significantly reduces durability, structural integrity, and safety. Conventional rust removal methods rely on chemical agents that pose environmental and health risks, prompting interest in eco-friendly alternatives. Plant-based extracts containing bioactive compounds, especially tannins and organic acids, have demonstrated potential in rust removal and corrosion control. Among these, Leucaena leucocephala (ipil-ipil) contains phytochemicals capable of interacting with iron oxides. Despite its chemical potential, limited research exists on the use of its bark extract as a rust remover for mild steel. This study investigates its effectiveness as a natural, sustainable alternative to commercial rust removers.

1.1 Background on Mild Steel Corrosion and Leucaena leucocephala Bark as Natural Rust Remover

Metals are widely used in industrial and technological applications due to properties such as conductivity, malleability, and durability. Iron, a primary component of steel, is highly reactive and prone to rusting, necessitating alloying processes to improve performance (Li et al., 2021). Mild steel, containing approximately 0.15%–0.20% carbon, is extensively used in construction and manufacturing due to its strength and affordability (Li et al., 2021). Despite these advantages, mild steel is highly susceptible to corrosion, a chemical process involving reactions with oxygen and moisture that form iron oxides and weaken structural integrity (Darmokoesoemo et al., 2018). Corrosion can reduce steel yield strength by up to 37.5%, increasing the risk of failure (Li et al., 2021). Rust formation, driven by oxidation, produces a flaky layer that progressively degrades metal surfaces and poses safety risks (Tamura, 2008). Environmental conditions such as humidity and rainfall accelerate corrosion. High-moisture environments facilitate oxygen dissolution in water films on metal surfaces, promoting rust formation (Willsey et al., 2020). Traditional rust removers containing strong acids are effective but hazardous to both materials and human health (Muhsin, 2020). These limitations have led to the exploration of plant-based alternatives containing phytochemicals such as tannins, which can interact with iron oxides and reduce corrosion (Yahya et al., 2008; Shirmohammadli et al., 2018; Sesia et al., 2024).

1.2 Phytochemical-Based Rust Removal on Mild Steel: Themes from Related Literature

Mild steel's susceptibility to corrosion is attributed to its composition and exposure to environmental factors such as moisture, oxygen, acids, and salts (Salgado et al., 2019). Corrosion is an electrochemical process involving oxidation and reduction reactions that degrade metal surfaces and increase maintenance costs (Salgado et al., 2019). Environmental variables such as pH, temperature, and ionic content significantly influence corrosion rates (Chuka, & Sinebe, 2023; Pant et al., 2023). Plant-based rust removal has emerged as a sustainable alternative to chemical treatments. Phytochemicals such as oxalic acid, flavonoids, and tannins can dissolve or loosen rust and inhibit further corrosion (Zulfiqar et al., 2024). Studies demonstrate the effectiveness of various plant extracts, including guava leaves, taro leaves, water spinach, tamarind, and passion fruit, in removing rust through chemical interactions with iron oxides (Dador et al., 2024; Ezeamaku et al., 2023; Suprianti et al., 2022; Sari et al., 2022; Aguma et al., 2025; Long et al., 2019; Yuanita et al., 2019). These studies consistently show that plant-derived compounds adsorb onto metal surfaces, weaken rust adhesion, and convert iron oxides into soluble compounds, highlighting their potential as eco-friendly rust removers.

1.3 Environmental Conditions Influencing Mild Steel Corrosion in Local and Global Contexts

Corrosion is a global issue affecting infrastructure durability, safety, and economic costs. In humid and tropical regions, such as the Philippines, environmental conditions significantly accelerate rust formation due to high rainfall and moisture levels (Willsey et al., 2020). These conditions increase the demand for effective and accessible rust control methods. Globally, industries rely on chemical rust removers, but concerns about environmental impact and human safety have driven the search for sustainable alternatives. Locally available plant resources, such as Leucaena leucocephala, offer potential solutions due to their abundance and phytochemical composition (Willsey et al., 2020). The use of such resources aligns with growing global efforts to reduce reliance on hazardous chemicals and promote eco-friendly technologies.

1.4 Phytochemical Interaction Theory in Leucaena leucocephala Bark for Rust Removal

This study is grounded in the chemical interaction between plant-derived phytochemicals and iron oxides. Tannins and polyphenols can bind with iron ions, forming stable complexes that loosen rust and inhibit further corrosion (Yahya et al., 2008; Shirmohammadli et al., 2018). Organic acids such as oxalic acid dissolve rust by forming water-soluble compounds, facilitating removal (Zulfiqar et al., 2024). The conceptual framework follows an Input–Process–Output model, where Leucaena leucocephala bark extract is applied to rusted mild steel, and its effectiveness is evaluated based on observable rust removal. The interaction of phytochemicals with iron oxides underlies the expected outcome of reduced corrosion and improved metal condition. Studies confirm that compounds in Leucaena leucocephala can adsorb onto metal surfaces and disrupt rust formation (Muthukrishnan et al., 2013; Salim et al., 2019; Salim, Asik, and Sarjadi, 2021; Ikhmal et al., 2019).

1.5 Research Gap on Leucaena leucocephala Bark Extract for Mild Steel Rust Removal

Although numerous studies have explored plant-based rust removers, most focus on leaves, seeds, or fruit extracts. Research on Leucaena leucocephala has primarily examined its corrosion inhibition properties rather than its direct application as a rust remover, particularly using bark extract (Muthukrishnan et al., 2013). There is limited investigation into the effectiveness of Leucaena leucocephala bark extract on mild steel surfaces, despite its rich tannin and polyphenol content. This gap highlights the need for experimental evaluation of its rust removal efficiency and comparison with commercial products. The study aims to address this gap by assessing its potential as a natural, cost-effective, and environmentally friendly alternative.

1.6 Sustainable Development Goals Relevant to Natural Rust Removal Using Leucaena leucocephala

This study aligns with several Sustainable Development Goals. It supports SDG 9 – Industry, Innovation and Infrastructure by promoting improved material durability and innovative corrosion control methods. It contributes to SDG 12 – Responsible Consumption and Production through the use of biodegradable, plant-based alternatives to chemical rust removers. Additionally, it aligns with SDG 8 – Decent Work and Economic Growth by enabling cost-effective solutions for households and small businesses, and SDG 13 – Climate Action by reducing reliance on environmentally harmful chemicals.

1.7 Multidisciplinary Sustainability Contributions of Leucaena leucocephala Bark-Based Rust Removal

The study contributes to socio-economic sustainability by providing affordable rust removal solutions for households, farmers, and small enterprises. It supports environmental sustainability by reducing chemical pollution and promoting biodegradable alternatives. From a technological perspective, it advances innovation in green chemistry and materials science through the application of plant-based corrosion treatments. It also contributes to community sustainability by utilizing locally available resources, potentially generating additional income opportunities and encouraging sustainable practices. Overall, the research integrates environmental, economic, and technological dimensions, supporting sustainable development through the adoption of eco-friendly and locally sourced rust removal methods.

2. Material and methods

2.1 Research Design

This study utilized a quantitative research design focused on measuring variables and determining relationships through objective data collection and statistical analysis (Ghanad, 2023). Specifically, a true experimental design was applied, allowing manipulation of independent variables under controlled conditions to observe their effects on rust removal effectiveness (Zubair, 2023). The independent variable was the treatment applied to rusted mild steel plates, including Leucaena leucocephala bark extract, distilled water as the control, and a commercial rust remover. Rust was uniformly induced using a 10% NaCl solution to accelerate corrosion. The dependent variable was the effectiveness of rust removal, measured through changes in steel plate condition before and after treatment, including quantitative mass analysis and visual assessment using a rust coverage scale (ASTM International, 2019). The design ensured that observed effects were directly attributable to the treatments (Muthukrishnan et al., 2013).

2.2 Locale of the Study

The experimental procedures were conducted in the Science Laboratory of Saint Louis School of Pacdal, Baguio City. Rust evaluation was further assessed at the City Buildings and Architecture Office (CBAO), where qualified engineers evaluated the treated samples using standardized criteria. All activities were performed under institutional supervision and approved laboratory conditions.

2.3 Respondents of the Study

This study did not involve human respondents. Instead, the experimental units consisted of mild steel plate samples subjected to different treatment conditions.

2.4 Sample and Sampling Procedure

The samples consisted of ten mild steel plates measuring 6 inches by 6 inches with uniform thickness and low-carbon composition. The plates were cleaned, weighed, and then subjected to corrosion through immersion in a 10% NaCl solution for three weeks to ensure uniform rust formation. After rust induction, the plates were divided into three groups: those treated with Leucaena leucocephala bark extract, those treated with distilled water, and those treated with a commercial rust remover. Each group underwent identical treatment conditions to ensure comparability of results.

2.5 Research Instrument

The study employed structured observation and measurement tools to ensure accurate data collection. Structured observation allowed systematic monitoring of changes in the steel plates during treatment (Kumar, 2022). A digital weighing scale was used to measure plate mass before rusting, after corrosion, and after treatment. Visual assessment of rust removal was conducted using ISO 8501-1 surface cleanliness ratings, which provided standardized criteria for evaluating rust reduction (ASTM International, 2019). Photographic documentation supported visual comparisons of treated surfaces. Data were recorded using structured logs and notebooks to ensure consistency and reliability of results.

2.6 Data Gathering Procedure

The research process began with securing approval from school authorities and coordinating with laboratory personnel and external evaluators. Laboratory safety protocols were strictly followed throughout the experiment. The bark of Leucaena leucocephala was collected from Acupan, Benguet, verified by DENR-CAR, cleaned, air-dried, and processed into a fine paste. The extract was prepared using maceration in 70% ethanol at a 1:2 ratio to optimize extraction of bioactive compounds. The mixture was stored for seven days, filtered, and prepared for application. Steel plates were cleaned, weighed, and subjected to rust induction using a 10% NaCl solution for three weeks. After corrosion, plates were reweighed and assigned to treatment groups. Each plate received 150 mL of its designated solution daily for three consecutive days (Yu et al., 2022). Mass measurements and photographic documentation were conducted throughout the treatment period. Following treatment, the plates were evaluated by qualified engineers using ISO standards to assess rust removal effectiveness based on surface condition, uniformity, and remaining corrosion (ASTM International, 2019). All observations and measurements were systematically recorded.

2.7 Data Analysis Techniques

Descriptive statistics, particularly the mean, were used to determine the effectiveness of each treatment. Rust removal was evaluated using ISO 8501-1 surface cleanliness ratings, which were converted into numerical values and expressed as percentage effectiveness relative to the maximum rating (ASTM International, 2019). To determine statistical differences among treatments, a One-Way Analysis of Variance (ANOVA) was applied, comparing the effectiveness of Leucaena leucocephala bark extract, commercial rust remover, and distilled water (Montgomery, 2019; Field, 2018). A significance level of 0.05 was used to assess statistical significance. A Tukey Honestly Significant Difference (HSD) post-hoc test was conducted to identify specific differences between treatment groups, ensuring accurate pairwise comparisons while controlling for Type I error. This analysis provided a comprehensive evaluation of the comparative effectiveness of the treatments.

3. Results and Discussion

3.1 Effectiveness of Rust Removal Treatments

3.1.1 Effectiveness of Commercial Rust Remover Solution

The commercial rust remover solution obtained a mean score of 1.67, corresponding to an average ISO rating of Sa 2, with an effectiveness of 55.56%. This indicates that most visible rust and contaminants were removed, resulting in a moderately cleaned metal surface. This level of performance suggests that the commercial rust remover is moderately effective in improving the condition of mild steel. The Sa 2 rating reflects acceptable cleaning efficiency, demonstrating that even low-cost commercial products can reduce corrosion and restore surface quality for basic applications.

3.1.2 Effectiveness of Leucaena leucocephala Bark Extract Solution

The Leucaena leucocephala bark extract achieved a mean score of 2.5, corresponding to an ISO rating of Sa 2½, with an effectiveness of 83.33%. This result indicates that nearly all visible rust and contaminants were removed, leaving only slight traces on the metal surface. This high effectiveness can be attributed to the presence of bioactive compounds such as tannins and phenolic substances, which interact with iron oxides and facilitate rust removal. The findings support previous studies indicating that plant-based extracts with such compounds are effective in corrosion control. The high rating and effectiveness demonstrate the strong potential of Leucaena leucocephala bark extract as an environmentally friendly alternative to chemical rust removers.

3.1.3 Effectiveness of Distilled Water as Control

Distilled water produced a mean score of −1, corresponding to an ISO rating of Sa −1, with an effectiveness of 0%. This indicates that no improvement occurred, and the rust condition remained unchanged after treatment. The result confirms that distilled water is ineffective in removing rust due to the absence of active chemical components needed to dissolve or disrupt corrosion. This supports its role as a control treatment and highlights the necessity of using solutions containing reactive compounds to achieve effective rust removal.

3.2 Statistical Differences Among Treatments

3.2.1 One-Way ANOVA Results

The ANOVA results showed an F-value of 30.5, which is significantly higher than the critical value of 5.143, with a p-value of 0.000718173. The between-group variation was substantially larger than the within-group variation, indicating that differences in rust removal effectiveness were primarily due to the treatments rather than random error. These results confirm that there is a statistically significant difference among the three treatments. The large F-value and very low p-value indicate that the type of solution applied significantly influenced rust removal effectiveness, leading to the rejection of the null hypothesis.

3.2.2 Tukey Post-Hoc Test Results

The Tukey HSD test showed that all pairwise comparisons had mean differences greater than the HSD value of 2.3624, indicating that each comparison was statistically significant. The differences between Leucaena leucocephala and commercial solution, Leucaena leucocephala and distilled water, and commercial solution and distilled water were all significant. These findings indicate that Leucaena leucocephala bark extract is significantly more effective than both the commercial rust remover and distilled water, while the commercial rust remover is also significantly more effective than distilled water. This establishes a clear ranking of effectiveness, with the natural extract performing best, followed by the commercial solution, and distilled water showing no effectiveness.

4. Conclusion & Recommendations

This study determined the effectiveness of Ipil-Ipil (Leucaena leucocephala) bark extract as a natural rust remover for mild steel and compared it with a commercial rust remover and distilled water. The results showed that the commercial rust remover exhibited moderate effectiveness with an ISO 8501-1 rating of Sa 2 and 55.56% effectiveness, indicating removal of most visible rust with slight remaining stains. In contrast, the Ipil-Ipil bark extract demonstrated high effectiveness, achieving an ISO rating of Sa 2½ and 83.33% effectiveness, indicating that nearly all visible rust was removed. Statistical analysis using One-Way ANOVA confirmed a significant difference among treatments, with an F-value of 30.5 exceeding the critical value of 5.143 and a p-value of 0.000718173 lower than 0.05, leading to rejection of the null hypothesis. These findings confirm that treatment type significantly affects rust removal performance and that Ipil-Ipil bark extract is a viable and more effective natural alternative to the commercial rust remover tested.

Based on the findings, it is recommended that future research explore varying concentrations of Leucaena leucocephala bark extract to determine the most effective formulation for rust removal. Further studies should also evaluate its effectiveness on different types of metals and varying levels of corrosion to assess broader applicability. Additionally, improving the extract by reducing or removing its natural color through purification or chemical treatment is suggested to prevent staining or alteration of metal surfaces. Lastly, combining the bark extract with other natural substances may be investigated to enhance its rust removal performance.

The study is limited to the use of Leucaena leucocephala bark collected from a specific location and tested only on mild steel plates under controlled conditions. It focuses on visual and quantitative rust removal effectiveness without addressing toxicological or long-term material effects, and comparisons were restricted to a single low-cost commercial rust remover, which may limit the generalizability of the findings.

Compliance with ethical standards

This study was conducted in accordance with institutional guidelines and approved laboratory procedures. All experimental activities were performed under proper supervision within designated facilities, and necessary permissions were secured prior to data collection. Standard laboratory safety protocols were strictly followed throughout the research process. The study did not involve human participants, and all materials used were handled responsibly in line with established laboratory practices.

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