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ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.62638/ZasMat1742

Zastita Materijala 67 ()
(2026)

Unveiling the use of invasive weed plant (*Chromolaena odorata*) based extracts towards protection of metals and alloys from corrosion -A review

ABSTRACT

The increasing demand for sustainable and environmentally benign corrosion inhibitors has stimulated growing interest in plant origin materials as alternatives to routine toxic synthetic chemicals. Chromolaena odorata (Siam weed), an invasive and abundantly available plant has emerged as a promising green corrosion inhibitor due to its rich phytochemical composition (flavonoids, phenolics, alkaloids, tannins, terpenoids, etc). This review initiative critically examines reported studies on the use of Chromolaena odorata based extracts for the protection of metals and alloys (mild steel, aluminium, stainless steel, copper, brass, etc) under diverse corrosive environments (acidic, saline, marine, oilfield, and microbiologically active conditions). The reviewed works employed gravimetric, electrochemical, surface analytical, and theoretical approaches to elucidate the inhibition performance and mechanisms. The overall inhibition efficiencies ranging from moderate to very high (34–99.8%) have been reported, predominantly governed by spontaneous physisorption pathway by adhering to Langmuir adsorption isotherm. The influence of extract concentration, temperature, medium composition, and extraction strategy on corrosion performance is systematically discussed in the article. Furthermore, emerging trends involving lignin, chlorophyll, nanocomposites, etc., derived from Chromolaena odorata are highlighted. This review segment underscores the plant's significant potential for sustainable corrosion prevention and outlines future research directions toward advanced formulations, mechanistic understanding, and industrial applicability.

***Key words**: Chromolaena odorata; plant extract; metals; alloys; corrosion; adsorption; inhibition*

INTRODUCTION

Chromolaena odorata (Siam weed) is also known as Jack in the Bush, has the binomial name as *Chromolaena odorata* (L.) R.M.King & H.Rob. It is a rapidly growing perennial shrub belonging to *Asteraceae* (sunflower) family, Figure 1. Basically this species belongs to the tropical and subtropical regions of America. It has been categorized under most aggressive invasive plant species, spreading across tropical Asia, Africa, and the Pacific regions. The plant typically grows as a multi-stemmed bush reaching moderate heights (2.5 to 3 meters), though it can climb up to 10 meters when supported by other vegetation.

The plant is hairy, glandular and the leaves give off a pungent, aromatic smell when crushed. The plant leaves are opposite, triangular to elliptical with serrated edges. The white to pale pink tubular flowers are in panicles of 10-35 flowers which are found at the ends of branches. The seeds are achenes and are somewhat hairy natured in existence.

Figure 1. Species: Chromolaena odorata [8]

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Paper received: 25.01.2026.
Paper corrected: 03.05.2026.
Paper accepted: 05.05.2026.

The seeds were mostly spread by the wind, but can also cling to fur, clothes and machinery, enabling for long-distance dispersal. The plant can regenerate from the roots and under favorable conditions the plant can grow more than 3 cm per day [1]. It is a major agricultural nuisance, since it forms dense thickets that will suppress the native biodiversity and increases forest fire risks [2-3]. It is highly valued in traditional medicine for its antibacterial, anti-inflammatory, and wound-healing properties [4-7].

1.1.Phytochemistry

Chromolaena odorata contains a wide spectrum of bioactive moleculeswhich account for its medicinal and corrosion inhibitory potential. Phytochemical investigations reveal the presence of flavonoids (such as quercetin, kaempferol, and flavone derivatives), phenolic compounds, tannins, alkaloids, saponins, terpenoids, steroids, and essential oils, **Figure 2**. The leaves are particularly abundant in polyphenols and flavonoids, which possess multiple hydroxyl groups and π-electron systems, enabling strong interaction with metal surfaces and biological targets. Additionally, compounds like chromomoric acid, eupolin, and other O and N-containing constituents contribute to antioxidant, antimicrobial, and metal-chelating properties. Such a diverse phytochemical pool underpins the plant's wide application in traditional medicine and supports its growing relevance as an eco-friendly corrosion inhibitor [9-11].

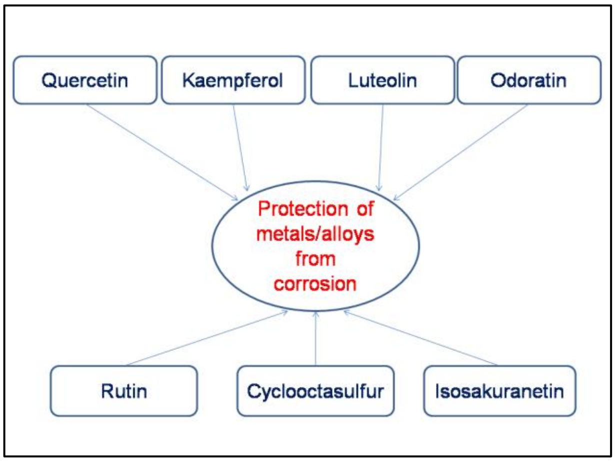

Figure 2. List of major biomolecules of Chromolaena odorata, which collectively contribute towards corrosion inhibition.

1.2. Importance of plant extracts

Plant extracts have emerged as potential and viable green corrosion inhibitors due to their rich composition of naturally occurring organic compounds such as alkaloids, flavonoids, tannins, phenolics, terpenoids, and amino acids. These phytochemicals contain heteroatoms (O, N, S) and π-electron systems that enable strong adsorption onto metal surfaces, forming protective films that suppress both anodic and cathodic corrosion reactions. Plantbased inhibitors are attractive alternatives to conventional synthetic inhibitors because they are biodegradable, renewable, cost-effective, and environmentally benign, making them suitable for sustainable corrosion control in acidic, neutral, and saline environments. Numerous studies have demonstrated their high inhibition efficiencies for metals like steel, aluminum, and copper, often comparable to commercial inhibitors. Moreover, their effectiveness can be enhanced through extraction optimization, concentration control, and synergistic combinations, reinforcing plant extracts as practical candidates for eco-friendly corrosion mitigation [12-15]. Considering the global shift towards green chemistry, and economic benefits, applicability of this invasive weed to inhibit corrosion by replacing toxic synthetic inhibitors (chromates) was a welcome choice. Various search terms were used to collectthe articles from major scientific repositories. Upon so, 24 research articles were disclosed till date regarding the utilization of *Chromolaena odorata* based extracts as inhibitors of corrosion metals or alloys. All these articles were critically examined in the review article for the materials used, executed methodology and the work outcome.

1.3. Literature review

To safeguard aluminium and its alloy

In a disclosure, aluminium specimens were exposed to 2.0 M hydrochloride solution containing varied concentrations of *Chromolaena odorata* leaf extract as corrosion inhibitor. Under the context, corrosion inhibition efficiency was evaluated using gasometric and thermometric techniques at 30°C and 60°C. The adsorption behavior was analyzed using kinetic and thermodynamic parameters and fitted to Langmuir adsorption isotherm.The plant based extract had exhibited good inhibition efficiency through physisorption, which increased upon rise in extract concentration but decreased with an increase in medium temperature. Under the context, maximum inhibition efficiency (97%) was attained for 0.5 g/Litre of inhibitor concentration at 30^{o}C [16]. In another venture, aluminium specimens, *Chromolaena odorata* leaf extract, 1.0 M hydrochloric acid, and 0.5 M sodium hydroxide solutions were used to evaluate the corrosion inhibition behavior. The prepared aluminium specimens were immersed in acidic and alkaline solutions containing different concentrations of leaf extract (as inhibitor). The rate of corrosion and inhibition efficiency was determined using the weight-loss method over fixed exposure times. The extract used had significantly reduced aluminium corrosion in both acidic and alkaline media. Moreover, the inhibition efficiency was found to enhance with an increase in extract concentration. The maximum inhibition efficiency of 34% in HCl and 33.8% in NaOH solution was recorded for the extract input of 25 mL/Litre in the medium [17]. In a work, aluminium alloy specimens, 2.0 M hydrochloric acid solution, and leaf extract were employed for corrosion studies. The prepared specimens were dipped into control medium and to the mediums having varied concentrations of inhibitor at RT for 20-30 min. The gasometric strategy (measuring the volume of evolved hydrogen gas) was executed to measure the corrosion inhibition impact. The highest inhibition efficiency (44%, approx.) was observed in the medium having the inhibitor concentration of 0.16 M for an exposure time of around 20 min at 30^{o}C and the rate of corrosion had decreased with an increase in inhibitor concentration. The interaction mechanism occurring between the phytochemicals (of extract) and the metal surface was well described by the Freundlich adsorption isotherm [18]. In a venture, prepared aluminium specimens were exposed to hydrochloric acid solutions of varying concentrations (0.01–0.1 M). For the studies, methanolic leaf extracts of *Chromolaena odorata* and *Hevea brasiliensis* were used as green corrosion inhibitors.The aluminium specimens were polished, cleaned, dried, weighed, and immersed in acidic media with and without plant extracts. The corrosion inhibition behavior was evaluated using the weight-loss method over fixed time intervals. Meanwhile FT-IR spectroscopy was employed to identify the major functional groups in the extracts which are responsible for corrosion prevention. According to results, both type of plant extracts had significantly reduced aluminium corrosion in acidic phases. Interestingly, *Chromolaena odorata* based extract had showed higher inhibition efficiency (62%) compared to *Hevea brasiliensis* based extract (57%) for an inhibitor input of 1.0 g/Litre at 30^{o}C. Meanwhile, the inhibition efficiency had increased with the rise in the concentration of inhibitor in the medium. It was hinted that, tannins, alkaloids, nitrogen bases, carbohydrates and proteins along with some hydrolysis products present in the phytochemicals rich pool of extract had collectively contributed to inhibit corrosion [19]. In another disclosure, aluminium specimens were used in 2.0 M hydrochloric acid solution to estimate corrosion in the absence and presence of extract. The phytochemicals rich leaf extract of *Chromolaena odorata* was used as inhibitor in different concentrations and the corrosion rate was measured by weight-loss method. The inhibition efficiency had increased with rise in concentration of extract in the medium and the maximum efficiency (99%) was recorded for 5% (v/v) of extract input at 30^{o}C. The adsorption of phytochemicals on the aluminum surface had followed the Langmuir isotherm, thus suggesting monolayer adsorption pathway behind the inhibition. This eventually led to the formation of a protective film that lowers the interaction of metal with the corrosive medium to retard corrosion. The findings in this work had showed enough promise to use the extract in corrosion-prone petroleum sector and marine utilities [20].

To safeguard mild steel

In an illustration, mild steel specimens, 0.5 M sulfuric acid, and ethanolic leaf extract of *Chromolaena odorata* were used for corrosion inhibition studies. The corrosion inhibition was determined by gravimetric method over a wide range of temperature (30-60°C). The adsorption behavior of introduced extract with metal surface was analyzed by thermodynamic parameters and Langmuir adsorption isotherm. The extract employed had displayed superior inhibition efficiency (up to 95%) through physisorption even at low extract concentrations (5% v/v) at 30^{o}C. As expected, the inhibition efficiency was increased with rise inhibitor concentration but decreased with an increase in temperature. It was hinted that, phytochemicals present in the extract (essential oils, steroids, tri-terpenes, flavonoids, chalcones, flavones, etc) had collectively supported for the superior inhibition efficiency [21].

In another demonstration, mild steel specimens, 2.0 M sulphuric acid and *Chromolaena odorata* leaf extract were used for corrosion inhibition studies.The corrosion inhibition efficiency was estimated by gasometric method at 60°C for 60 min under different mediums having varied concentrations of inhibitor (60, 100, 140 cm^3). The adsorption behavior was analyzed using Temkin isotherm, supported by regression analysis and optical micrograph studies.The extract employed had displayed highest inhibition efficiency (99%) and lowest corrosion rate at a high inhibitor concentration (140 cm^3). The rate of corrosion of mild steel had decreased as the inhibitor concentration was increased. The higher inhibition efficiency can be attributed to superior adsorption of phytochemicals onto the metal surface, thus imparting improved surface morphology at higher concentrations of inhibitor [22]. In a venture, mild steel specimens, 1.0 M hydrochloric acid solution, and lignin extracted from *Chromolaena odorata* stems were used for corrosion inhibition estimation. Accordingly, corrosion inhibition was evaluated by weight-loss method over a wide range of temperature (30–70°C) with varied lignin concentrations (500–5000 mg/Litre). The adsorption and thermodynamic parameters were analyzed using Langmuir isotherm, while FT-IR and SEM techniques were used for the metal surface characterization.The plant origin lignin had exhibited high corrosion inhibition efficiency (92.39%) at a concentration of 4000 mg/Litre at 30°C. The inhibition mechanism was estimated to be spontaneous and predominantly occured through physisorption. It was confirmed by thermodynamic data and surface morphology studies, hence substantiates the inhibitive role of lignin [23].

In a work, mild steel specimens were used in 1.0 M hydrochloric acid medium under with and without the presence of inhibitor to perform corrosion studies. For the work, methanolic leaf extract of *Chromolaena odorata* was used as corrosion inhibitor. The corrosion inhibition efficiency was evaluated by weight-loss measurements, electrochemical techniques (potentiodynamic polarization and electrochemical impedance spectroscopy), and surface analyses (SEM and EDX). The adsorption behavior was analyzed using the Langmuir adsorption isotherm, and theoretical studies were conducted using density functional theory (DFT) and molecular dynamics (MD) simulations. The inhibition efficiency had increased with an increase in inhibitor concentration in the medium but had decreased upon the rise in temperature. The extract behaved as a mixed-type inhibitor to support the formation of impermeable layer over the metal. The n-butanol fraction of the extract (1.0 g/Litre) had exhibited the highest corrosion inhibition efficiency (92%) due to the presence of constituents like n-hexadecanoic acid and *trans*-13-octadecenoic acid (by GC-MS) [24]. In another demonstration, mild steel specimens were used in 1.0 M hydrochloric acid mediums having (with or without) different concentrations of inhibitor. A titanium-based nanocomposite derived from the methanolic leaf extract of *Chromolaena odorata* was synthesized and explored as corrosion inhibitor. The titanium-based nanocomposite was characterized by FT-IR, XRD, SEM-EDX, HRTEM, and BET surface area analysis to confirm its chemical structure, crystallinity, morphology, size, and porosity. The corrosion inhibition performance was evaluated using weight-loss measurements and electrochemical methods. Meanwhile, adsorption behavior was analyzed using Langmuir isotherm, and surface morphology. The nanocomposite had showed excellent corrosion inhibition efficiency (92.39%) than the crude methanolic extract (84.77%) at an optimum inhibitor concentration of 1.0 g/Litre at 30^{o}C. As expected, inhibition efficiency had increased with rise in inhibitor concentration but decreased as temperature was increased. It was observed that, inhibition had occurred through physisorption to form a protective layer which had enhanced the charge transfer resistance and protected the metal from corrosion. Additionally, thermodynamic analysis indicated that, dissolution of metal either in the presence or absence of nanaocomposite was endothermic and orderly [25]. In a research work, mild steel specimens were used in 1.0 M hydrochloric acid solution medium under the presence and absence of extract. Ethanolic leaf extract of *Chromolaena odorata* was employed as the inhibitor at different concentrations. The corrosion inhibition rate was evaluated using weight-loss measurements and electrochemical techniques (potentiodynamic polarization and linear polarization resistance). The effects of inhibitor concentration, temperature, and immersion time were studied. Meanwhile, response surface methodology (RSM) was employed to optimize the inhibition efficiency and the surface characterization of mild steel was carried out using SEM and FTIR. The extract (700 mg/Litre) used was very productive to retard the corrosion of mild steel with high inhibition efficiency (83.33%) at 30^{o}C. The extract acted as a mixed-type inhibitor to impart a protective adsorbed film on the steel surface due to effective complexation between phytochemicals and metal ions [26].

In another disclosure, mild steel specimens were used as the test material in 1.0 M sodium chloride solution as the corrosive medium. For the studies, lignin extracted from plant stem of *Chromolaenaodorata* was employed as corrosion inhibitor. The corrosion inhibition feasibility was determined by weight-loss measurements, potentiodynamic polarization studies, and surface analysis (SEM). The adsorption behavior was analyzed using Langmuir adsorption isotherms, and FT-IR was used to identify the functional groups in lignin (hydroxyl, carbonyl and aromatic rings) which are responsible for the corrosion inhibition. The lignin extract (3000 mg/Litre) had provided an excellent corrosion inhibition efficiency (99.83%) for mild steel in sodium chloride solution at 30°C. achieving a maximum inhibition efficiency of about 99.8% at optimal concentration. The inhibition had occurred mainly through spontaneous and exothermic based physisorption to form an impermeable protective film on the surface of mild steel, as confirmed by electrochemical studies and SEM analysis [27]. In some ventures, mild steel specimens were dipped in enriched artificial seawater medium inoculated with *Pseudomonas aeruginosa* to impart biocorrosion. Ethanolic leaf extract of *Chromolaena odorata* was used as the biocorrosion inhibitor in the medium for 7 and 14 day trials under stagnant conditions. The impact of medium (with and without inhibitor) over the metal surface was studied. Moreover, infinite focus microscopy (IFM) was used for the 3-D analysis of metal surface and GC–MS was used to identify the phytochemicals present in the extract. The added inhibitor had effectively inhibited biofilm-associated pitting corrosion of mild steel in synthetic seawater medium. The obtained inhibition was attributed to antibiofilm activity imparted by the presence of phytochemicals (antibacterials) like germacrene D, caryophyllene, and cadinene [28-30].

In another illustration, Kirinyuh leaves (*Chromolaena odorata* L.) were used as the raw material to extract chlorophyll *a* and the same was used as corrosion inhibitor of mild steel (SAE/AISI Grade 1022). The extracted chlorophyll *a* (using solvents) was characterized for purity and structure using UV-Vis absorption and Fourier Transform Infrared (FTIR) spectroscopy. Weight loss analysis and microscopic surface analysis were conducted to determine the inhibition efficiency of chlorophyll *a* on mild steel specimens immersed in a 3% brine solution and seawater for 7 days. As per the results, moderate inhibition efficiency (60%) was achieved in 3% brine solution and a higher efficiency (77.89%) was observed in seawater in the presence of chlorophyll *a* (400 ppm). These findings indicate that the isolated chlorophyll a has conjugated double bonds and functional groups having of nitrogen, and oxygen, which are very much supportive for complexation with metal ions leading to superior adsorption (by protective film formation) over the metal surface [31]. In an illustration, mild steel specimens were employed as the test material in 1.0 M hydrochloric acid and 0.5 M sulphuric acid solutions under with and without inhibitor circumstances. Ethanolic leaf extract of *Chromolaena odorata* was used as corrosion inhibitor in different concentrations in the provided medium.The inhibition performance of the extract (25 mg, 600 mg and 1200 mg/Litre) was evaluated using the weight-loss method at 30-55°C for an immersion period of 3 h. Expectedly, the inhibition efficiency of the extract had increased with rise in extract concentration and decreased as the temperature was increased. Noticeably, better inhibition efficiency was obtained for 0.5 M sulphuric acid medium (86%, approx.) than the other one (67%, approx.) even under higher concentrations (1.2 g/ Litre of the extract at 30ºC [32]. In another venture, mild steel specimens were used in 1.5 M sulfuric acid solution to investigate the corrosion rate under the absence or presence of extract at different concentrations (2-10 g/Litre). The experiments were conducted at a wide range of temperature (25-55°C) for 6 h exposure time. It was observed that, enhancing the concentration of extract in the medium had led to superior inhibition but an opposite impact was seen with regard to rise in temperature. The adsorption consequences were analyzed by Langmuir, Temkin and Freundlich adsorption isotherms. Based on thermodynamic details, the adsorption of extract was found to be endothermic in nature, spontaneous and occurred through physisorption pathway (according to Gibbs' free energy values). As per the results, 10 g/Litre input of extract in to the medium gave the best corrosion inhibition efficiency (98.82%) at 25°C [33].

In a work, mild steel specimens were used in phosphoric acid medium for corrosion studies to estimate the impact of extract. The leaf origin extract of *Chromolaena odorata* was prepared and characterized to estimate active phytochemicals both qualitatively and quantitatively. Box–Behnken design (a response surface optimization technique) was used to determine the impact of different parameters like temperature (30-60°C), inhibitor concentration (0.2-0.8 g/Litre), and immersion time (3-12 days). The corrosion behavior was assessed by weight-loss measurements and the surface changes on mild steel were examined by SEM and FT-IR patterns. Upon intense process optimization studies it was noted that, 7.5 days of immersion at 45°C with 0.5 g/Litre of inhibitor in the medium was found ideal to retard corrosion with better efficiency (86.42%) [34]. In another illustration, ethanolic and aqueous leaf extracts of *Chromolaena odorata* were used as green corrosion inhibitors to manage microbiologically induced corrosion (MIC) of buried metals. More importantly, loamy-clay soil, and produced water were utilized to simulate natural corrosion imposing situations in buried conditions. The mild steel specimens were preconditioned with extracts and buried in simulating soil with (ethanolic/aqueous extract) and without inhibitor. The corrosion rate was estimated by weight-loss method at 14 and 28 days. As per the results, both the types had showed moderate corrosion inhibition efficiencies (53% for the aqueous extract and 50% for the ethanolic extract) on 28th day with

25.0 g/Litre of inhibitor input. Thus the extracts of *Chromolaena odorata* could be opted as a commercially feasible option to protect metals / alloys from corrosion in industries (oil, gas, and water utilities) [35].

To safeguard stainless steel

In another illustration, super austenitic stainless steel (UNSS31254, alloy), CO_2-saturated acidizing oilfield condition, and plant leaf derived inhibitors like *Chromolaena odorata* and *Tridax procumbens*(as extracts) were used to enumerate corrosion inhibition features. The corrosion inhibition was estimatedby electrochemical techniques (Tafel polarization), in a simulated acidizing oilfield condition at 40°C. Meanwhile, inhibition efficiency and adsorption behavior were determined from corrosion current densities and adsorption isotherm analysis. Based on the results, both plant extracts used had significantly reduced corrosion of UNSS31254 with good efficiency (99%, approx.) even at low dosages of inhibitors (100 ppm). More importantly, inhibition had occurred through effective adsorption by monolayer formation of extracts on the metal surface and followed theLangmuir adsorption isotherm [36]. In a venture, ASTM A36 steel specimens were employed for corrosion studies in natural seawater medium under the presence and absence of inhibitor for 7 days. The leaves of *Chromolaena odorata* are rich in phytochemicals like alkaloids, saponins, flavonoids, phenols, and tannins. These phytochemicals were extracted to methanollayer and used as the inhibitor in different concentrations (100-500 ppm). The corrosion rate was determined byweight-loss method, while optical microscopy was used for surface analysis. The optimum inhibitor concentration was established to be 400 ppm, which had resulted in highest inhibition efficiency (87.44%) at 30ºC. The inhibition had occurred due to the efficient adsorption of phytochemicals to form an impermeable protective film on the surface of metal [37]. Another study explored the use of blended leaf extracts isolated from *Ageratum houstonianum* and *Chromolaena odorata* as corrosion inhibitor of reinforcing steel embedded in concrete composites. Methanolic leaf extract of both variants were prepared and characterized by spectroscopic assistance (FT-IR and UV-visible) to establish the active functional groups. Additionally, phytochemical screening was also performed to ensure the presence of various biomolecules in the extract mixture. A few blends of concrete were prepared having different concentrations (500-2000 ppm) of the extract mixture. The corrosion behavior of steel reinforcement was monitored by half-cell potential measurement with the help of the ASTM C876-22b standard. Additionally, surface analysis (optical imaging, SEM/EDX) was executed to determine the morphology of metal surface. As per results, extract mixture had significantly reduced the corrosion (by synergistic effect) in the test specimens with good efficiency (89.5%) for 1000 ppm of extract input at 25ºC. The extract mixture forms a compact protective adsorption layer on the steel surface to retard the corrosion of embedded metal [38].

To safeguard low-carbon steel

Another initiative had evaluated the corrosion inhibition performance of low-carbon steel in aggressive carbonic acid mediums. Such types of mediums are quite common in slurry pots (oil and gas applications). Methanolic leaf extracts of *Chromolaena odorata* and *Tithonia diversifolia* were used in different concentrations as eco-friendly corrosion inhibitors. The rate of corrosion was assessed by weight-loss estimation method and electrochemical testing. Meanwhile, surface characterization techniques (SEM and EDS) were employed to examine the protective layer formed over the metal. Both the types of extracts were found efficient to retard corrosion with an optimum input of inhibitor (0.5 g/Litre) into the respective medium. Accordingly, highest inhibition efficiency (83.33%) was recorded for *Tithonia diversifolia* and marginally low efficiency (80.95%) was obtained for *Chromolaena odorata* under ambient conditions. As per FT-IR pattern, there are numerous hydroxyl groups and unsaturated bonds in the extracts. These functional group bearing molecules (phytochemicals) had significantly influenced the inhibition mechanism to form a firm protective film on the metal surface [39].

To safeguard copper and its alloy

In another venture, copper specimens were used in 0.5 M sulfuric acid medium under the presence and absence of extracts as inhibitor. Methanolic leaf extracts of *Chromolaena odorata* and *Newbouldia laevis* were employed as green corrosion inhibitors at different concentrations (100–1000 mg/Litre) at different temperatures (30, 40 and 50°C). The corrosion inhibition rate was established using weight-loss measurements and electrochemical impedance spectroscopy (EIS). Additionally, adsorption behavior was analyzed using Langmuir (better fitting) and Temkin isotherms, while SEM and XRD patterns were used to study the metal surface. Both the type of plant extracts (1000 mg/Litre) had significantly reduced copper corrosion (*Chromolaena odorata* provided an efficiency of 65.38% for 1.0 g/Litre of extract concentration at 30º*C*) in acidic medium, with inhibition efficiency increasing with rise in inhibitor concentration and decreasing with increase in temperature. The inhibition had occurred through physisorption pathway and it was found to be spontaneous and exothermic in nature [40]. In an illustration, brass specimens were used in 0.5 M sulfuric acid medium to study corrosion rate under the presence and absence of extract. Methanolic leaf extract of *Chromolaena odorata* was employed as corrosion inhibitor at different concentrations (100–1000 mg/ Litre). The corrosion inhibition feasibility was examined using the weight-loss method at different temperatures, supported by EIS to establish the electrochemical behavior. The adsorption features were analyzed by Langmuir and Temkin adsorption isotherms, while SEM and XRDpatterns were used to determine the crystalline nature and film formation on the alloy surface. The extract used was very effective (77.42% of efficiency) to provide good inhibition efficiency at 1000 mg/Litre of extract input in to the medium at 30ºC. Meanwhile, inhibition mechanism was predominantly physical adsorption, spontaneous and exothermic. The Langmuir isotherm was found to be best fit, thus confirming the extract as an efficient alloy corrosion inhibitor [41].

1.4. Summary

Mild steel, stainless steel, low-carbon steel, aluminium, aluminium alloy, copper, brass, and copper are the metals/alloys being safeguarded from corrosion in the past ventures using the extract obtained from the plant part of *Chromolaena odorata*, **Figure 3**.

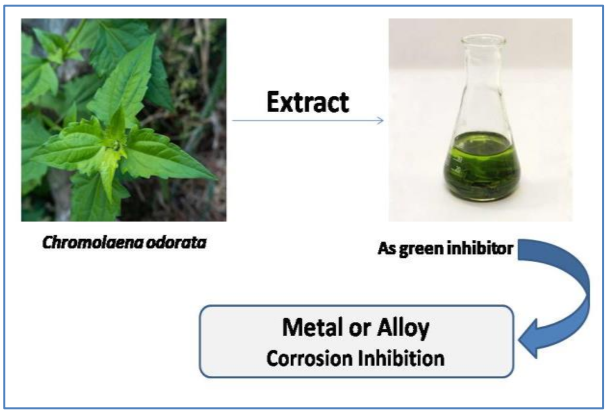

Figure 3.Overall theme of the review initiative

Under the context, various corrosive mediums were also imposed for the studies like hydrochloric acid, sulphuric acid, carbonic acid, phosphoric acid, sodium chloride, seawater, and microbiologically activated soil, Table 1.

Table 1. Outline details of past disclosures regarding safeguarding metals/alloys from corrosion by the use of Chromolaena odorata based extracts

Entry	Specimen/s	Imposed medium/environment	References
1.	Aluminium	2.0 M hydrochloric acid 1.0 M hydrochloric acid & 0.5 M sodium hydroxide solution (0.01-0.1 M) hydrochloric acid	[16], [20] [17] [19]
2.	Aluminium alloy	2.0 M hydrochloric acid	[18]
3.	Mild steel	0.5 M sulfuric acid 2.0 M sulfuric acid 1.0 M hydrochloric acid 1.0 M sodium chloride Artificial seawater 1.0 M hydrochloric acid & 0.5 M sulfuric acid 1.5 M sulfuric acid Phosphoric acid Burial soil condition type	[21] [22] [23], [24], [25], [26] [27] [28-30], [31] [32] [33] [34] [35]
4.	Stainless steel	CO_2-saturated acidizing oilfield type Natural seawater Concrete composites	[36] [37] [38]
5.	Low-carbon steel	Carbonic acid	[39]
6.	Copper	0.5 M sufuric acid	[40]
7.	Brass	0.5 M sulfuric acid	[41]

A wide range of corrosion inhibition efficiencies (34-99.8%) were achieved across ventures, which substantiates the impact of extract as good inhibitor, Table 2. Inhibitor concentration and the solvent used for the extraction were found to be very much influential to achieve higher inhibition efficiency rather than the nature of metal / alloy alone. For example, for aluminium (5% v/v of extract gave 99% of inhibition efficiency), for mild steel (10 g/Litre of extract gave 98.82% of inhibition efficiency), and low efficiencies were observed for the specimens subjected to low concentrations of extract. The solvent (alocohols) based extracts expectedly gave higher inhibition efficiencies (62-95%) than aqueous extracts (50-53%). Meanwhile, the use of isolated biomolecules (lignin, chlorophyll, nanocomposites, etc) gave very high efficiency (92–99.8%). The solvents (methanol/ethanol) had extracted more polyphenols and π-electron-rich compounds from the plant parts and hence contributed towards better efficiencies. Alongside these, nature of metal/alloy, corrosive environment and temperature would also contribute reasonably well for the final outcome. With regard to adsorption behavior, physisorption has been the pathway fitting mostly to Langmuir isotherm (uniform monolayer adsorption) in majority of ventures.In one of the context, aluminium alloy was used and the adsorption followed Freundlich isotherm. Alluminium surface is not chemically uniform due to the presence of inter-metallic phases, grain boundaries, inclusions, defects, etc. The presence of these features would create sites with varying adsorption energies. Hence, phytochemicals based inhibitor do not adsorb uniformly on the surface leading to Freundlich isotherm (uneven, multi-energy adsorption) driven adsorption consequences (stacking of molecules and Interactions between adsorbed species). In most circumstances, solvent/aqueous extract of *Chromolaena odorata* was employed for the corrosion studies. Meanwhile, lignin was extracted from *Chromolaena odorata* in a venture and chlorophyll *a* in another case and used for intended studies with good results. With regard to observed trends, inhibition efficiency increased with extract concentration decreased with rise in temperature. Similar trends were observed in other plant extract based past initiatives as well [42-44].

Table 2.Outline details type of specimens, optimum inhibitor concentration, optimum temperature and maximum inhibition efficiency achieved in past disclosures. (NA= Not Applicable)

References	Specimen/s	Optimum inhibitor concentration	Optimum temperature (ºC)	Maximum inhibition efficiency (%)
[16]	Aluminium	0.5 g/Litre	30	97
[17]	Aluminium	25 mL/Litre	30	34.45
[18]	Aluminium alloy	0.16 M	30	44 (approx.)
[19]	Aluminium	1.0 g/Litre	30	62
[20]	Aluminium	5% v/v	30	99
[21]	Mild steel	5% v/v	30	95
[22]	Mild steel	140 cm3	60	99
[23]	Mild steel	4.0 g/Litre	30	92.39
[24]	Mild steel	1.0 g/Litre	30	92
[25]	Mild steel	1.0 g/Litre	30	92.39
[26]	Mild steel	700 mg/Litre	30	83.33
[27]	Mild steel	3.0 g/Litre	30	99.83
[28-30]	Mild steel	5-10% v/v	25-28	NA
[31]	Mild steel	400 ppm (Chlorophyll a)	30	77.89
[32]	Mild steel	1.2 g/Litre	30	86 (approx.)
[33]	Mild steel	10.0 g/Litre	25	98.82
[34]	Mild steel	0.5 g/Litre	45	86.42
[35]	Mild steel	25.0 g/Litre	30	53
[36]	Stainless steel	100 ppm	40	90 (approx.)
[37]	Stainless steel	400 ppm	30	87.44
[38]	Stainless steel	1000 ppm	25	89.5
[39]	Low-carbon steel	0.5 g/Litre	25-30	80.95
[40]	Copper	1.0 g/Litre	30	65.38
[41]	Copper	1.0 g/Litre	30	77.42

1.5. Future directives

Very limited ventures are available around the abundantly available plant species *Chromolaena odorata* based extracts to retard corrosion. Hence, there will be numerous opportunities up-next to use the plant based extract in an improvised way for the corrosion prevention. In this regard, nanocomposite inhibitors (combination of extract with graphene oxide, titanium dioxide, zinc oxide, etc), polymer supported inhibitors (embedding the extract with polyaniline, polypyrrole, polyacetylene, etc), and encapsulation strategies (extract with liposomes, microcapsules, etc., for the slow release) can be explored and the commercially viable weed species (*Chromolaena odorata*) can be well utilized. Additionally, pilot scale trials (on pipelines, cooling systems, and storage tanks), field trials (in diverse sectors like petrochemical, marine, and construction) and commercialization aspects can also be explored.

CONCLUSION

Chromolaena odorata based extracts have been well demonstrated as an effective, eco-friendly corrosion inhibitors for various metals and alloys in acidic, saline, and microbiologically active environments. The inhibition performance can be attributed to the adsorption of phytochemical constituents on metal surfaces (via physisorption), forming protective films that follow predominantly Langmuir adsorption behavior. The experimental and theoretical studies had established the fact that, inhibition efficiency increases with rise in extract concentration and decreases with increase in temperature. The recent advancements involving nanocomposites, and targeted phytochemical fractions further enhance the protective efficiency and stability of extract based inhibitor. In overall, *Chromolaena odorata* based extracts provides a sustainable and costeffective abundant resource for corrosion prevention, with significant potential for future large scale industrial applications.

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IZVOD

OTKRIVANJEUPOTREBEEKSTRAKATA NA BAZIINVAZIVNEBILJKEKOROVA (*CHLOMOLAENAODORATA)* U CILJUZAŠTITEMETALA I LEGURA OD KOROZIJE–PREGLED

Rastuća potražnja za održivim i ekološki prihvatljivim inhibitorima korozije podstakla je sve veće interesovanje za materijale biljnog porekla kao alternative rutinskim toksičnim sintetičkim hemikalijama. Chromolaenaodorata (sijamski korov), invazivna i obilno dostupna biljka, pojavila se kao obećavajući zeleni inhibitor korozije zbog svog bogatog fitohemijskog sastava (flavonoidi, fenoli, alkaloidi, tanini, terpenoidi itd.). Ova inicijativa za pregled kritički ispituje objavljene studije o upotrebi ekstrakata na bazi Chromolaenaodorata za zaštitu metala i legura (meki čelik, aluminijum, nerđajući čelik, bakar, mesing itd.) u različitim korozivnim sredinama (kiseli, slani, morski, naftni i mikrobiološki aktivni uslovi). Pregledani radovi koristili su gravimetrijske, elektrohemijske, površinske analitičke i teorijske pristupe kako bi se razjasnile performanse i mehanizmi inhibicije. Prijavljena je ukupna efikasnost inhibicije u rasponu od umerene do veoma visoke (34–99,8%), pretežno određena putem spontane fizisorpcije pridržavanjem Langmirove adsorpcione izoterme. U članku se sistematski razmatra uticaj koncentracije ekstrakta, temperature, sastava medijuma i strategije ekstrakcije na performanse korozije. Pored toga, istaknuti su novi trendovi koji uključuju lignin, hlorofil, nanokompozite itd. dobijene iz Chromolaenaodorata. Ovaj pregledni segment ističe značajan potencijal biljke za održivu prevenciju korozije i ocrtava buduće pravce istraživanja ka naprednim formulacijama, mehanističkom razumevanju i industrijskoj primenljivosti.

Ključne reči: *Chromolaenaodorata; biljni ekstrakt; metali; legure; korozija; adsorpcija; inhibicija*

Pregledni rad
Radprimljen: 25.01.2026.
Radkorigovan:03.05.2026.
Rad prihvaćen:05.05.2026.

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