Antioxidant and Anticorrosive Activities of the Plant Inula Viscosa L. from the Rif Region of Morocco

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Abstract: This work aims to highlight two activities of the abundant plant in the Rif region (northern Morocco), *Inula viscosa L.,* namely, antioxidant and anticorrosive activity. We prepared extracts using the Soxhlet extraction technique using four solvents to increase polaritywich are water , and ethanol , ethyl acetate , and diethyl ethe. . Phytochemical screening is done using the Folin-ciocalteau method and the.$AlCl_3$The results of this work have shown that our extracts are rich in secondary metabolites such as flavonoids and flavonols, whose plant inspired its antioxidant capacity evaluated in vitro by the DPPH and FRAP techniques. The aqueous extract tested as a corrosion inhibitor showed considerable ability to inhibit the corrosion of mild steel in 1M HCl acidic media.

Keywords: Medicinal Plants, Inula viscosa L., Extraction Methods, Phytochemical Screening, Antioxidant, Anticorrosive

I. Introduction:

In recent years, exploring natural resources for their potential therapeutic and industrial applications has garnered significant attention [1,2]. Among these resources, medicinal plants have been extensively studied for their diverse bioactive compounds and promising roles in various fields [3]. Inula viscosa L., a plant abundantly found in the Rif region of northern Morocco, has attracted particular interest due to its rich phytochemical composition and traditional medicinal uses. This plant species has been traditionally utilized for its purported therapeutic properties, prompting scientific investigation into its bioactive constituents and potential applications [4,5].

Extraction methods are pivotal in isolating and concentrating bioactive compounds from plant materials. In this study, the Soxhlet extraction technique was employed to prepare extracts from Inula viscosa L. Using four solvents (Diethyl Ether, Ethyl Acetate, Ethanol, and water) with increasing polarity the extraction process aimed to capture a broad spectrum of phytochemicals present in the plant. This methodological approach allows for the comprehensive extraction of diverse secondary metabolites, providing a holistic view of the plant's chemical profile [6].

Phytochemical screening serves as a crucial step in characterizing the chemical composition of plant extracts. In this research, the Folin-Ciocalteu method and AlCl3 assay were employed for phytochemical screening, enabling the identification of various secondary metabolites, including flavonoids and flavonols. Renowned for their antioxidant properties, these compounds hold significance for therapeutic and industrial purposes. Following this, the antioxidant capacity of the extracts was assessed in vitro using the DPPH and FRAP techniques, offering insights into their potential as natural antioxidant [7,8,9].

Moreover, the study explored the anticorrosive activity of the aqueous extract of Inula viscosa L. Specifically, its ability to inhibit corrosion of mild steel in acidic media (1M HCl) was assessed. The findings of this research not only contribute to understanding the bioactive constituents of Inula viscosa L. and shed light on its potential applications in antioxidant and anticorrosive formulations. This interdisciplinary approach underscores the importance of bridging traditional knowledge with scientific inquiry to harness medicinal plants' therapeutic and industrial potential.

II. Materials and methods:

2.1. Sampling and Preparation of the extracts

2.1.1 simples collect.

The leaves of *Inula viscosa L.* were collected in April 2023 at Al-Hoceima National Park (Rif) in northern Morocco. The fresh leaves were cut with a special chisel, packed in a polyethylene bag, and transported immediately to the laboratory.

2.1.2. Preparation of the extracts

A cartridge containing 20 g of vegetable powder was subjected to sequential extraction with four solvents arranged in increasing polarity: diethyl ether, ethyl acetate, ethanol, and water. Extraction was halted upon observation of colorless liquid surrounding the cartridge, indicating cessation of further extraction from the solid material. Following each extraction, the resultant solution was concentrated using a rotavapor until a solid residue was obtained, which was subsequently utilized for phytochemical analyses.

2.2. Phytochemical screening.

2.2.1. Content of phenol total

The phenolic compound of Chamaerops humilis extracts was determined ustilising the Folin-Ciocalteu reagent with gallic acid as the standard reference [10,11]. In this procedure, 200 µl of the extract was combined with 1 ml of Folin-Ciocalteu reagent (diluted 10-fold) in a test tube. The mixture was thoroughly mixed and allowed to stand in the dark at approximately 23°C for 5 minutes. Subsequently, we added 750 µl of a 7.5% sodium carbonate (Na2CO3). Following a 2-hour incubation period, the absorbance was measured at 760 nm using a UV-1800 Shimadzu spectrophotometer against a blank. A calibration curve was established using gallic acid as the standard, plotting absorbance against concentration. The resulting linear relationship was utilized as a standard curve to quantify the phenolic compounds of the samples, expressed in ($mg\ E_{AG}/g_{ext}$).

2.2.2. Total flavonoid content

Using the aluminum trichloride method [12], the total flavonoid content was assessed with quercetin as the standard reference. Each appropriately diluted extract (1 mg/mL) was aliquoted into 10 mL test tubes containing 1 mL of aluminum trichloride solution (2% in methanol) and a single drop of acetic acid. The resulting mixture was then allowed to incubate at room temperature for 40 minutes. Then, absorbance was measured at 415 nm against a blank consisting of 1 mL of methanol, 1 mL of aluminum trichloride (2%), and one drop of acetic acid. A series of quercetin-based standards (ranging from 5 to 100 µg/mL) were also prepared following the same procedure. The flavonoid content of the extracts was expressed in (mg EQ/gext).

2.2.3. Total flavonol content

Kosalec et al. [13] employed the method with slight modifications to evaluate the flavonol content in various extracts [34]. For this, test tubes were prepared by adding 1 mL of distilled water, 0.1 mL of AlCl3, 1 mL of sodium acetate solution (50 g/L), and 1 mL of the extract. The resulting mixture was thoroughly stirred and then incubated in the shade at room temperature for 90 minutes. Under identical conditions as described previously, the absorbance was measured at 440 nm. The flavanol content was quantified and expressed as milligrams of quercetin equivalent per gram of the plant's dry weight (mg EQ/gext).

2.3. Antioxidant activity:

2.3.1. Antiradical effect DPPH.

The DPPH (2,2-diphenyl-1-picrylhydrazyl) technique evaluates different substances' antioxidant or antiradical activity, including phenolic compounds. This approach uses an antioxidant chemical to decrease the stable free radical DPPH, resulting in a color change that spectrophotometry can measure. The extracts (10 mg) are diluted in 10 ml of methanol. To establish a constant concentration of DPPH radicals, a stock solution of DPPH (4 mg/100 ml) is prepared in methanol. The sample solution (1.5 mL) is with 1.5 mL of DPPH solution at different concentrations (50 g/mL to 500 g/mL). The mixture is left to incubate in the dark for 30 minutes at room temperature or regulated. Meanwhile, the antioxidant chemicals in the sample interact with DPPH radicals, causing the purple hue to fade. The absorbance of the mixture is measured by spectrophotometry (UV-1800 Shimadzu) at a specified wavelength (517 nm) after incubation [14].

This equation present the percent inhibition (I%) :

$$I\,\% = \frac{A_{cont} - A_{éch}}{A_{cont}} \times 100 \qquad (1)$$

Where A_cont: is the absorbance of the negative control (DPPH alone in methanol) and A_sam: is the absorbance of the sample or standard .

Percentages of recovery activity can be plotted as a function of sample concentrations to form a dose-response curve. The IC50 value, the sample concentration needed to remove 50% of DPPH radicals, can be calculated by the curve. Lower IC50 values suggest more significant antioxidant activity.

2.3.2. Antioxidant-reducing power

The reducing power of Iron, coming from to, in the extracts, the ions are assayed according to the method described by $Fe3{+}K3Fe(CN)6Fe2{+}$[15].
Briefly, 2.5 mL of phosphate buffer solution (0.2 M, pH 6.6) and 2.5 mL of 1% (m/V) Fe 〖(CN)〗_6 solution are added to 1 mL K_3 of each extract at different concentrations (ranging from 50 µg/mL to 500 µg/mL). The mixture is well stirred and then incubated in a water bath at 50°C for 30 minutes. Next, 2.5 mL of 10% trichloroacetic acid (TCA) is added to stop the reaction. The tubes are centrifuged at 3,000 rpm for 10 min, and then an aliquot (2.5 mL) of the collected supernatant is mixed with 2.5 mL of distilled water and 0.5 mL of a 0.1% ferric chloride solution.
The absorbance of the reaction medium was measured at 700 nm using a UV-VIS spectrophotometer, with a blank prepared by replacing the extract with distilled water. This step allowed the device to be calibrated. A solution of ascorbic acid (a standard antioxidant) is used as a positive control, and its absorbance was measured under the same conditions as the samples [16].

2.4. Anticorrosive activity

2.4.1. sample Used

Mild steel, commonly considered a building material in many industrial plants, is a recognized means to combat the phenomenon of corrosion. For such reasons, it was chosen to be a corrosion sample to be studied. The mild steel samples are prepared before each immersion in the solutions by polishing the surface with sandpaper of increasingly fine granulation (SiC 180, 220, 320, 400, 600, and 1200), then they are rinsed with distilled water, followed by acetone degreasing and finally drying under an airflow.

2.4.2. Solutions used.

- ***Corrosive Solution***

The electrolyte is an acidic solution of 1 M HCl, prepared by dilution from a commercial solution (Merck (Darmstadt, Germany)) of hydrochloric acid (d = 1.19 and 37%).

❖ ***Inhibitory Solutions***

Because of its result in terms of phenol content in general, this study was based on the aqueous extract of the plant inula viscosa L.

2.5. Gravimetry

Gravimetry quantifies the extent of corrosion on a metal surface by measuring the mass loss Δm = mi − mf of the metal as it corrosions over time. It is a direct and widely used technique for evaluating corrosion inhibition by protective methods. It is relatively simple to implement and does not require extensive equipment. To determine the rate of corrosion experimentally, the following procedure is carried out: mild steel plates in square form with well-defined surfaces (2 cm × 2 cm × 0.3 cm), whose initial masses (mi) are known, are immersed in the corrosive solution at given and constant temperatures for well-defined intervals of time. At the end of the experiment, the corrosion products are removed, and new mass weighings are performed (mf). The following relationship calculates the corrosion rate:

$$v_{Corr} = \frac{m_i - m_f}{\Delta t} \quad (2)$$

2.6. Electrochemical techniques

Electrochemical data, including Tafel bias and impedance parameters, were collected using the PGZ 100 with Volta master 4.0 software. Measurements occurred in a 100 mL three-electrode cell with a saturated calomel reference and graphite counter electrodes. Manual electrode polishing, followed by potentiodynamic polarization curve recording, was conducted for analysis.

III. Results and discussion:

3.1. Humidity level:

The moisture content of plant leaves was assessed using the 105°C method [17]. Fresh leaves were subjected to steaming for 1.5 hours. Three replicates were conducted, and the average value obtained was considered indicative of the moisture level. The following equation will allow us to calculate it.

$$R\% = \frac{m_{sec}}{m_{fresh}} \times 100 \quad (3)$$

With:

m_{sec}: Dry matter mass in g .
m_{Fresh}: Mass of the fresh plant sample in g.

The moisture content of Inula viscosa L. plant is approximately 68.78%, indicating that water comprises more than half of its weight. Factors such as soil condition, climate, plant age, and post-harvest shelf life can all impact moisture content values.

3.2. Extraction Yield

The following formula calculates the extraction yield:

$$\rho = \frac{m_{ext}}{m_{fraiche}} \times 100 \quad (4)$$

The extraction yields obtained by grinding the dry plant are shown in the following figure:

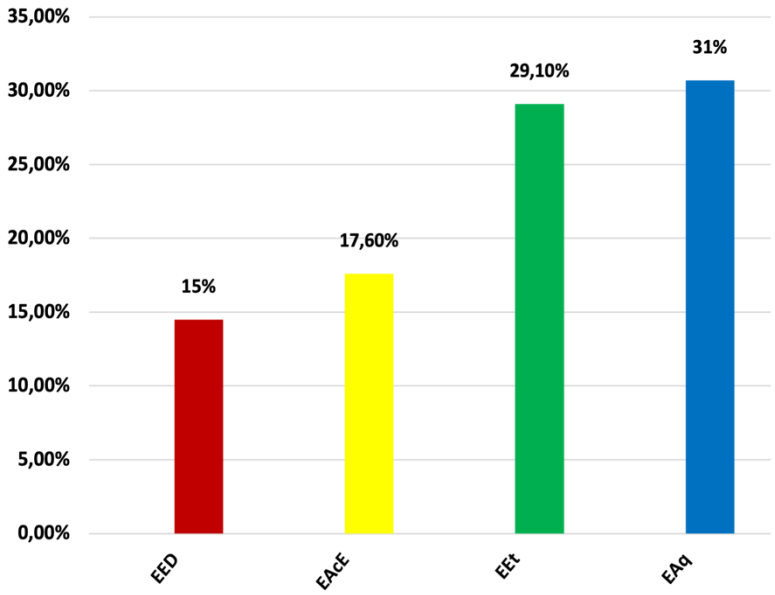

Fig. 1: extraction yield for Inula Viscosa L.

3.3. Phenolic Compound

Most antioxidant properties in plants are generally attributed to this family of compounds. This is why we chose to determine their Content in the four extracts of our plants.

Table 1. : Phenolic compound in Inula Viscosa L. plant in diffrents extracts

Plant	Extract	Total phenols [a]	Flavonoids[b]	Flavonols[c]
Inula Viscosa	Ether diéthylique	141,90 ± 2,15	60,06 ± 0,87	83,56 ± 1,23
	Acetate d'éthyle	44,91 ± 1,12	25,06 ± 1,15	21,83 ± 0,45
	Éthanol	64,48 ± 0,67	46,64 ± 0,76	27,98 ± 0,54
	Eau	153,56 ± 1,12	108,82 ± 1,65	60,34 ± 1,26

All values are averages ± SD: Standard Deviation; With (a) (mg GAE/g extracted) / (b) (mg EQ/g extracted) / (c) (mg EQ/g extracted)

In Table 1, the aqueous extract contained the largest amount (153.56 ± 1.12 mg EAG/gext) of phenolic compounds, followed by the order diethyl ether (141.90 ± 2.15 mg EAG/gext) > Ethanol (64.48 ± 0.67 mg EAG/gext) > Ethyl acetate (44.91 ± 1.12 mg EAG/gext).

The largest amount of flavonoids was also extracted by water (108.82 ± 1.65 mg EQ/gext), followed by diethyl ether (60.06 ± 0.87 mg EQ/gext) > Ethanol (46.64 ± 0.76 mg EQ/gext) > Ethyl Acetate (25.06 ± 1.15 mg EQ/gext).$AlCl_3$

In the case of flavonols, it is simply noticeable that this order is not respected this time. Diethyl ether extracts a large amount of flavonols (83.56 ± 1.23 mg EQ/gext), followed by water (60.34 ± 1.26 mg EQ/gext), > Ethanol (27.98 ± 0.54 mg EQ/gext) > Ethyl Acetate (21.83 ± 0.45 mg EQ/gext).

These results showed an expressive level of compounds tested. These metabolites play an essential role in human health. In addition, humans easily ingest flavonoids and exhibit important anti-inflammatory, anti-allergic, and anti-cancer activities [18,19,20].

3.4. Antioxidant Activity.

3.4.1. Trapping Effect of the DPPH Radical.

The antiradical activity of the different extracts *of Inula viscosa L.* and that of standard ascorbic acid have been illustrated in the following :

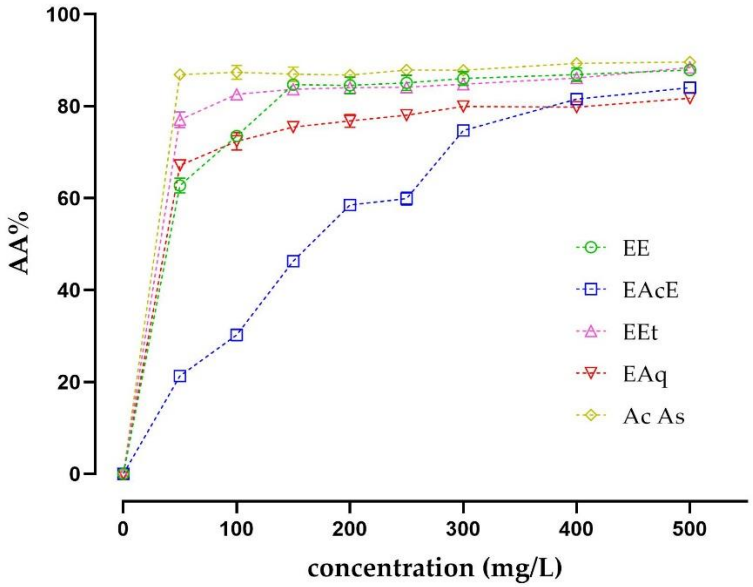

Fig. 2: Antiradical activity profiles of extracts and ascorbic acid

3.4.2. *Ferric Reducing Power (FRAP)*

The FRAP method includes the reduction of ions in the presence of an antioxidant via a donor hydrogen atom $Fe^{3+}Fe^{2+}$. The mechanism is known as an indicator of electron-donating activity, which is characteristic of the antioxidant action of polyphenols. The reducing power of the different extracts (50-500 µg/mL) of *Inula viscosa L.* is shown in Figure 3.

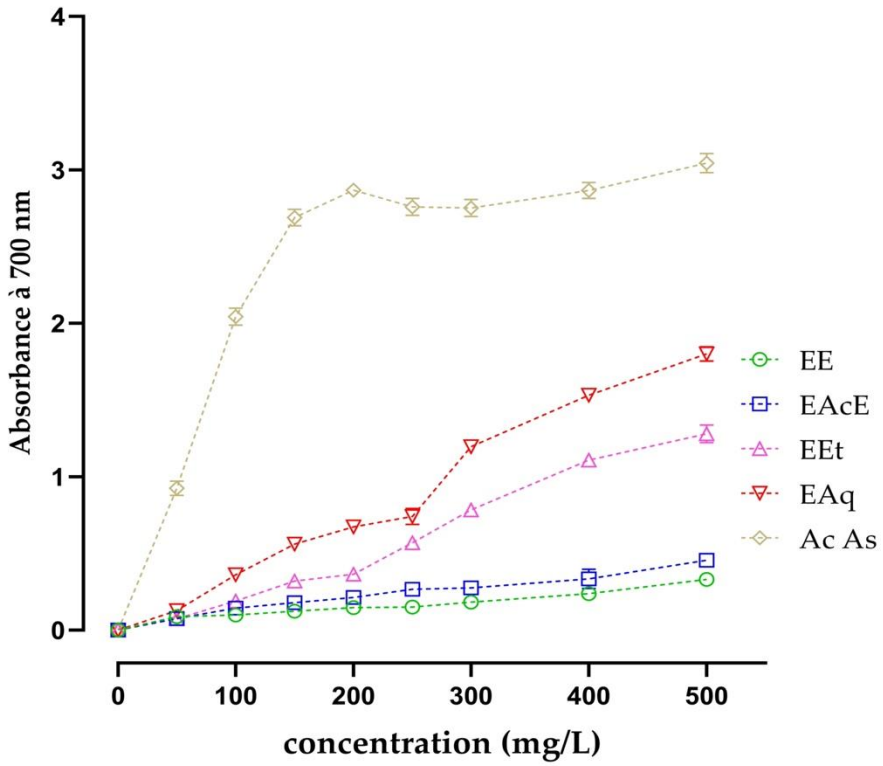

Fig. 3: Reducing Power Profiles (FRAP Test) of Crude Extracts and Ascorbic Acid

3.5. Anticorrosive activity

3.5.1. Weight Loss Measurements: Gravimetry.

Mass loss tests were performed in a 100mL beaker. We used a water bath to keep the electrolyte temperature at the desired temperature, which was 60 mL. The mild steel samples were rectangular, measuring 2 cm × 2 cm × 0.3 cm. Subsequently, these samples were immersed in a 1 M HCl solution for given durations of time, with and without the addition of different concentrations of inhibitors. The following relation gives it:

$$E_I(\%) = \frac{v_{corr} - v_{corr(inh)}}{v_{corr}} \times 100 \quad (5)$$

With and are the absent-absence and inhibitor-present velocities, respectively. $v_{corr} v_{corr(inh)}$

3.5.2. Effect of Immersion Time

To study the effect of immersion time on the rate of corrosion of steel in acidic environments in the presence and absence of inhibitory compounds at the 2g/L concentration, for which the inhibitory efficacy reaches maximum values for all three extracts, we measured these rates at time intervals varying from 30 min and 6 h. The following table shows the results achieved.

Table 2.: Influence of immersion time on corrosion rate and inhibitory efficiency for concentration 2 $g.L^{-1}$.

t (h)	HCl (1 M)		Aqueous extract of Inula Viscosa	
	v_{corr} $(mg.cm^{-2}.h^{-1})$	EI (%)	v_{corr} $(mg.cm^{-2}.h^{-1})$	EI (%)
0,5	1,964	-	0,761	61,25
1	1,611	-	0,484	69,96
2	1,397	-	0,333	76,16
3	1,268	Plant	Extract	Total phenols
Flavonoids	Flavonols	Inula Viscosa	Diethyl ether	141.90 ± 2.15
60.06 ± 0.87	83.56 ± 1.23	-	Ethyl acetate	44.91 ± 1.12
25.06 ± 1.15	21.83 ± 0.45	-	Ethanol	64.48 ± 0.67

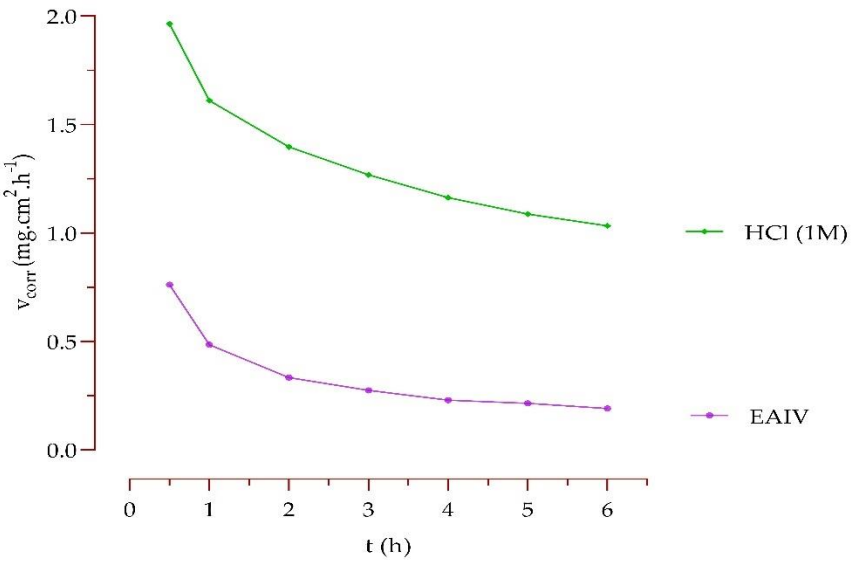

Fig. 4: Effect of Inhibitory Extracts on Corrosion Rate in Acidic Medium Over Time

Figure 4 shows that at each moment, the corrosion rate is more remarkable in an acidic medium alone than in the presence of inhibitory extracts. The addition of the latter increases the corrosion resistance in this medium. We also notice that this speed takes similar values after about 4 hours of immersion.

3.5.3. Effect of concentration

Rectangular mild steel plates, serving as samples, are immersed in 1M HCl solution with and without various concentrations of our extracts for 6 hours. Before each test, samples are polished, rinsed with distilled water, degreased with acetone, dried, and weighed. Mass loss tests are carried out at 35 ± 1°C for different inhibitor concentrations. The inhibitory efficacy value represents the average of three tests conducted under identical conditions for each concentration. The outcomes of this experiment are summarized in Table 3, and the relationship between corrosion rate variation and inhibitory efficiency is depicted in Figure 5.

Table 3. Effect of Concentration of Inhibitors on Corrosion Rate and Inhibitory Efficiency in 1M HCl

Inhibitors	Conc (g/L)	v_{corr} $(mg.cm^{-2}.h^{-1})$	EI (%)	θ
HCl 1M	0	1,003	-	-
Aqueous extract of inula viscosa L	0,125	0,701	30,10	0,3010
	0,25	0,469	53,24	0,5324
	0,5	0,313	68,79	0,6879
	1	0,191	80,96	0,8096
	1,5	0,178	82,25	0,8225
	2	0,161	83,95	0,8395

From the results obtained, we can see that the corrosion rate decreases progressively with the increased concentration of the extracted inhibitors. This means that the addition of these inhibitors delays the corrosion process of the steel, while the inhibitory efficacy increases with increasing concentration of these inhibitors.

The two extracts, EACH and EAMV, were found to be suitable inhibitors of corrosion in the medium studied. From the concentration of 0.25 g/L, their inhibitory efficiencies are comparable and vary in the vicinity of 84%, while the EAIV represents this value only at the concentration of 2 g/L

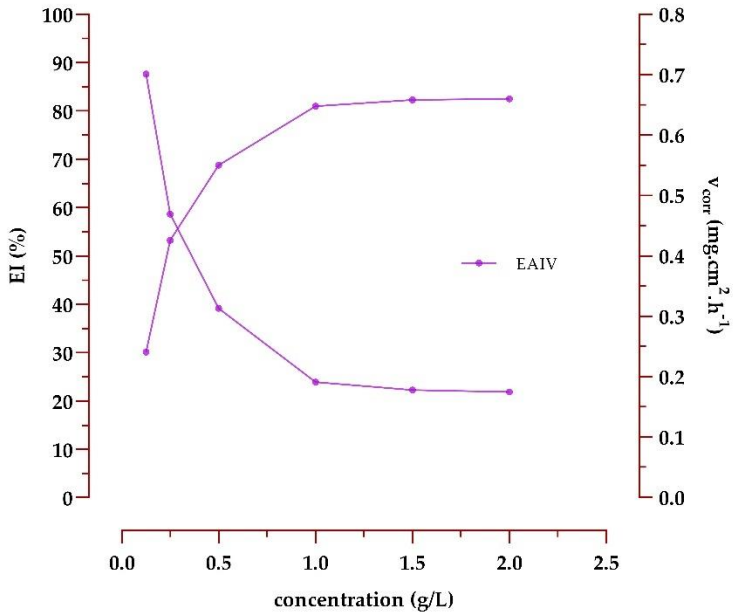

Fig.5. Variation in Corrosion Rate and Inhibitory Efficiency with Different Concentrations of Inhibitors

3.5.4. Effect of temperature:

To study the influence of this factor, we proceeded by tests of steel mass loss in 1M HCl acid without and with the addition of inhibitors (EACH, EAIV, EAMV) in a temperature range between 308 and 338K. This is done for an immersion period of one hour and at a concentration of 2 $g.L^{-1}$, for which the inhibitory efficacy is maximum at 308 K.

Table 4 : presents our extracts' corrosion rates and inhibitory efficiency values, varying with temperature.

Inhibitors	T(K)	v_{corr} $(mg.cm^{-2}.h^{-1})$	EI %	θ
(HC l M)	308	1,964	-	-
	318	2,629	-	-
	328	4,126	-	-
	338	6,794	-	-
Aqueous extract of inula viscosa L	308	0,421	78,56	0,7856
	318	0,443	75,01	0,7501
	328	0,776	74,12	0,7412
	338	1,861	72,27	0,7227

Based on Table 4 and Figure 6, it can be observed that the inhibitory efficiencies decrease while the values of the corrosion rates of mild steel increase with increasing temperature in the range 308 - 338 K, in an acidic environment, in the presence and absence of the inhibitors. The escalation in corrosion rate may be ascribed to a notable decline in inhibitor adsorption onto the contact surface as temperature rises. Adsorption and desorption, being opposing processes, tend to reach equilibrium. Hence, at elevated temperatures, increased inhibitor desorption occurs, leading to greater metal surface exposure to the acidic medium, thereby amplifying the corrosion rate.

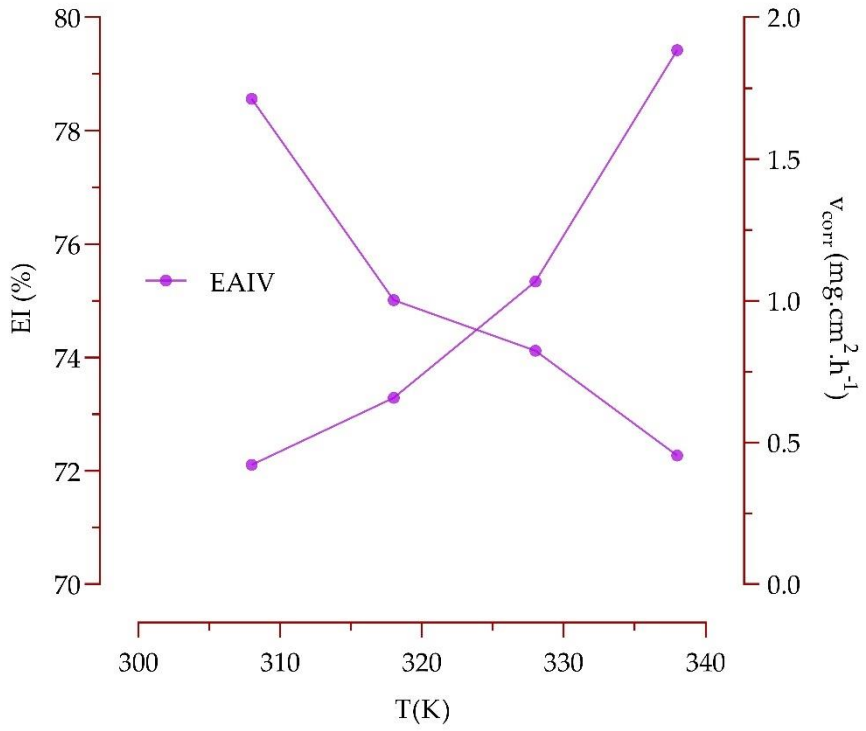

Fig.6: Temperature Dependence of Corrosion Rates and Inhibitory Efficiency in 1M HCL

3.5.5. Thermodynamic Activation Parameters

The following Arrhenius equation can express the relationship between corrosion rate v and temperature (crucial parameters to understand the mechanisms of inhibitory inhibition) :

$$v_{corr} = A.\exp\left(-\frac{E_a}{RT}\right) \quad (6)$$

A is an Arrhenius constant, Ea is the activation energy, R is the ideal gas constant, and T is the temperature.

The representations of the function Ln v_{corr} = f (T) for different solutions with or without inhibitors give us linear lines of equations:

$$Ln\ v_{corr} = Ln\ A - \frac{E_a}{RT} \tag{7}$$

By exploiting the graphs obtained, we can calculate the activation energies.

The figure 7 gives the variation of $Ln\ v_{corr}$ as a function of the inverse of the absolute temperature $\frac{10^3}{T}$ in 1M HCl medium without and with the addition of different inhibitors.

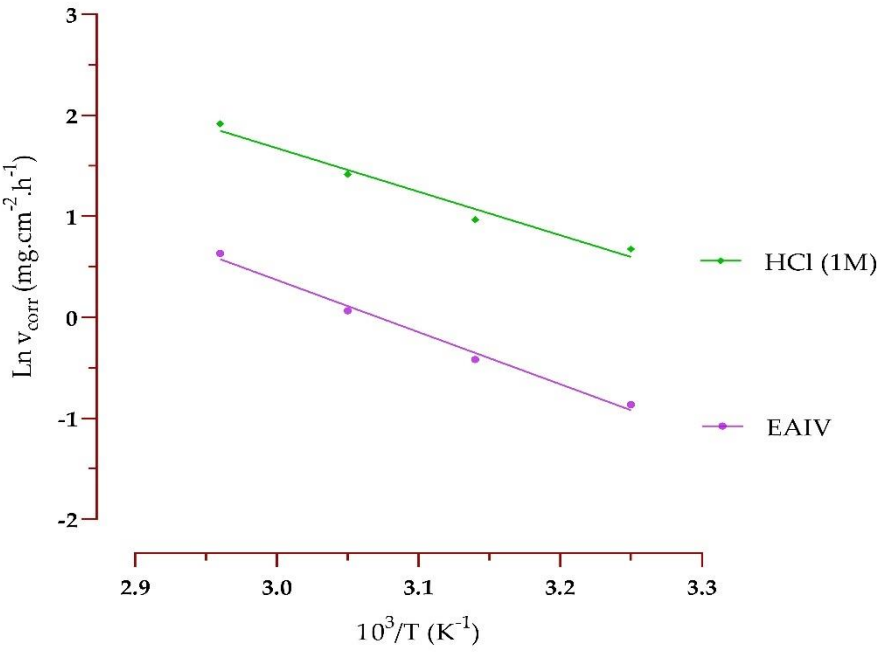

Fig.7: Arrhenius Plot of Corrosion Rates in 1M HCl Medium with and without Inhibitors

To determine the thermodynamic characteristics of activation, such as ΔH_a°, and ΔS_a° we rely on the equation of the alternative Arrhenius formula:

$$v_{corr} = \frac{RT}{Nh}\ exp\left(\frac{\Delta H_a^\circ}{R}\right)\ exp\left(-\frac{\Delta S_a^\circ}{RT}\right) \tag{ψ}$$

Where

h: Planck's constant
N : Avogadro number
R : Ideal gas constant,
T : tThe absolute temperature
ΔH_a° : The enthalpy of activatio
ΔS_a° : The entropy of activation.

The plot of $Ln\left(\frac{v_{corr}}{T}\right)$ is a straight line of the linear equation with a slope of $\frac{\Delta H_a^\circ}{R}$ and an intercept equal to $\left[Ln\left(\frac{R}{NH}\right) + \Delta S_a^\circ/R\right]$.

The linear regression coefficients are close to 1, indicating that the kinetic model can explain mild steel corrosion in 1M HCl.

The values of the activation parameters (E_a, ΔH_a°, ΔS_a°) are groubed and presented in the table :

Table 5. : Activation Parameters, Enthalpy, and Entropy of the Stainless-Steel Dissolution Reaction in 1M HCl Containing the Inhibitor.

4	$E_a(kJ/mol)$	$\Delta H_a^\circ(kJ/mol)$	$\Delta S_a^\circ(J/mol.K)$
80,31	5	1,087	-
0,214	80,31	6	1,033

Table 5 shows that the activation energy E_aThe value obtained for white (35,843 kJ/mol) is smaller than that found in the presence of inula viscosa extract inhibitor. The higher values of activation energy in the presence of inhibitors can generally be attributed to physical adsorption.
The dissolution process of mild steel is endothermic due to the positive sign of enthalpy value $\Delta H_a^\circ$and thus suggesting that the dissolution of steel is slow and difficult in the presence of an inhibitor [21].
The value of the activation entropy increases in the presence of the inhibitor, thus implying the step of an association rather than that of dissociation. This means that an increase in disorder occurs between the initial reaction stage and the formation of the activated complex [23, 24].

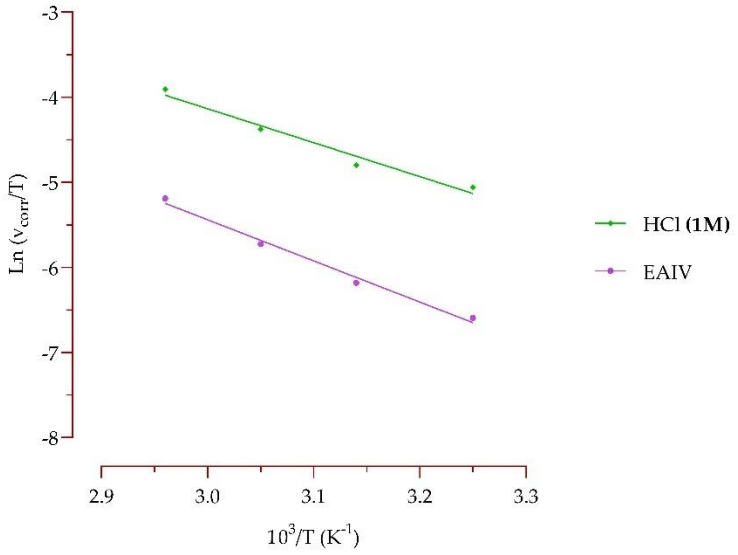

Fig. 8: Arrhenius Plot of Corrosion Rates (V) in 1 M HCl Medium in the absence and the presence of (EAIV).

The thermodynamic parameters $K_{ads}$and ΔG_{ads} can be determined from the lines of the Langmuir isotherm

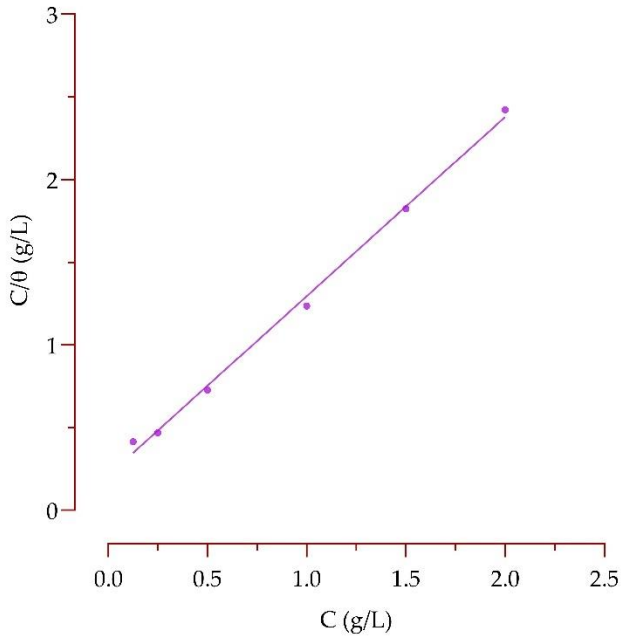

Fig.9 : Langmuir Isotherm for Adsorption of Inula viscosa Extract (EAIV) on the Steel Surface.

The analysis of these representations shows that the molecules studied adsorb on the surface of the steel according to the Langmuir model since the variation of the ratio C_{inh}/θ as a function of the inhibitor concentration is linear, and the values of the correlation coefficient are close to 1 for all inhibitors.
The following equation is presenting the adsorption constant:

$$\mathrm{K_{ads}} = \frac{1}{55{,}5} exp\left(-\frac{\Delta G^{\circ}_{ads}}{RT}\right) \qquad (\omega)$$

The value 55.5 is the concentration of the water in solution ($mol.L^{-1}$), so the standard free energy of adsorption can be calculated ΔG_{ads}.

Table 6: The characterizing parameters of the Langmuir model.

inhibitor	R^2	Pente	$K_{ads}(L/mg)$	$\Delta G^{\circ}_{ads}(kJ/mol)$
EAIV	0,9965	1,084	4733	-31,954

The negative sign of ΔG°_{a} indicates the spontaneity of the adsorption process and the stability of the adsorbed layer on the metal surface [25,26]. If the values of $\Delta G^{\circ}_{a}$is of the order of −20 kJ.mol^{-1} and less negative (physisorption). At the same time, those of the order of −40kJ.mol−1 or more negative indicate chemisorption. It is a partition or transfer of electrons between the inhibitor molecules and the surface of the metal to form a bond [27,28]. Regarding our study, it became clear that the adsorption process is spontaneous, given the negative values ΔG°_{a}obtained for our inhibitor. In addition, this value is between −40 and −20, which indicates that adsorption can involve both processes (physisorption and chemisorption)[29,30].

3.5.6. Potentiodynamic polarization curves

The polarization curves of mild steel in the corrosive medium HCl 1M in the absence and presence of different concentrations of the inhibitor EAIV are measured after polarization of the electrode at its corrosion potential E_{corr} for 30 min, are shown in the figure at 308K. The potential was swept by 1mV/s from the most cathode to anode potentials.

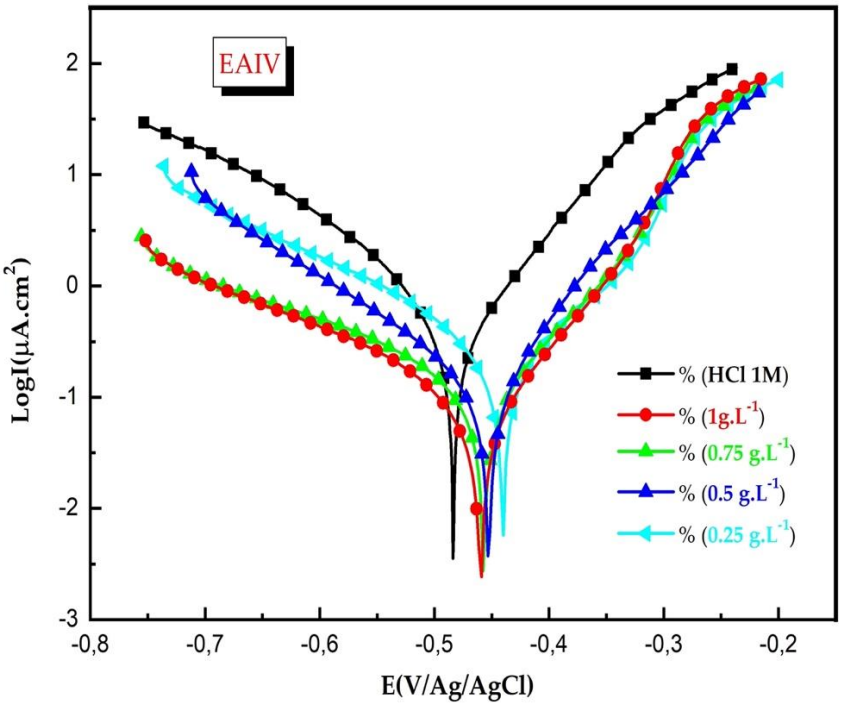

Fig.10: Polarization curve of mild steel in HCl (1M)

The corrosion parameters of steel in HCl 1M without and with the addition of different inhibitor concentrations, such as corrosion potential E_{corr}, corrosion densityi_{corr} $(\mu A.cm^{-2})$, cathodic slope $\beta_c$and inhibitory efficiency η_P(%)are combined in the table.

The percent inhibition yield (EI%) is calculated using equation () shown below :

$$E_I(\%) = \frac{I^{\circ}_{corr} - I_{corr}}{I^{\circ}_{corr}} \times 100 \qquad (10)$$

With I°_{corr} *and* I_{corr} are the density values of the corrosion current in the absence and presence of inhibitors, respectively.

Table 7. : Corrosion Parameters and Inhibitory Efficiency of Mild Steel in 1M HCl with Inula Viscosa Extract Inhibito

Middle	EI (%)				
	$C_{inh}(g.L^{-1})$	$-E_{corr}(mV, Ag/AgCl)$	$i_{corr}(\mu A/cm^{-2})$	$-\beta_c(mV.dec^{-1})$	$\eta_P\%$
Aqueous extract of inula viscosa L	0,125	0,701	30,10	0,3010	-
0,25	0,469	53,24	0,5324	132	0,5
	68,79	0,6879	41,80	1	0,191
	0,8096	435,40	1,5	0,178	82,25
	0,25	2	0,161	83,95	0,8395

IV. Conclusion

this research explores the antioxidant and anticorrosive activities of Inula viscosa L., a plant abundant in the Rif region of Morocco. The research employs Soxhlet extraction with four solvents of increasing polarity—diethyl ether, ethyl acetate, ethanol, and water—to capture a wide spectrum of phytochemicals from the plant. Phytochemical screening using the Folin-Ciocalteu method and AlCl3 assay identifies secondary metabolites like flavonoids and flavonols in the extracts. The antioxidant potential of the extracts is evaluated using DPPH and FRAP techniques. The aqueous extract exhibits notable antioxidant activity, indicating its potential therapeutic and industrial applications. Furthermore, the study investigates the anticorrosive activity of the aqueous extract, particularly its ability to inhibit mild steel corrosion in acidic media (1M HCl). The results show promising inhibitory effects, with the aqueous extract demonstrating significant corrosion inhibition. Gravimetric measurements and electrochemical techniques assess corrosion rates and inhibition efficiencies. The inhibitory efficacy increases with extract concentration, and the study delves into the influence of factors like immersion time, temperature, and activation parameters on corrosion inhibition. Overall, the research underscores the potential of Inula viscosa L. extracts as natural antioxidants and corrosion inhibitors, bridging traditional knowledge with scientific inquiry to explore medicinal plants' therapeutic and industrial applications.

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