Solanum Alkaloids and Their Corrosion Inhibition applications: A Short Review

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Abstract

This review investigates Solanum Steroid Alkaloids, which are devised on five groups Solanidanes, Spirosolanes, 22,26-Epiminocholestanes, 22,26-Epimino-16,23-epoxycholestanes and 3-aminospirostanes. Then their biosynthesis with their corrosion inhibitive action on different metals in aggressive media such as HCl, H_2SO_4, by using all analytical methodologies like weight loss measurements (WL) as chemical measurements, potentiodynamic polarization (PDP) and electrochemical impedance spectroscopy (EIS) as electrochemical ones. The study indicates that the corrosion rate increases as function of the acidic concentration increases, but decreases in function of the green inhibitor concentration increases. This report reveals that of alkaloids compounds act as an efficient inhibitor and as mixed-type inhibitor.

Keywords: *Solanum Tuberosum* extract; mild steel; acid solution; corrosion inhibitor； WL; PDP; EIS.

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1. Introduction

The damage by corrosion generates not only high cost for inspection [1], repairing and replacement [2], but in addition these constitute a public risk [3], thus the necessity of developing novel substances that behave like corrosion inhibitors especially in acid media [4] to stop the deterioration of materials. There always exists a need for developing new sustainable corrosion inhibitors [5]. Meanwhile, acid solutions are widely used in industry such as acid pickling of iron and steel [6-8], chemical cleaning and processing [9], and ore production and oil well acidification [10]. The use of hydrochloric acid in pickling of metals [11], acidization of oil wells [12] and in cleaning of scales [13] is more economical, shows efficient and trouble-free, compared to other mineral acids [14]. However, there are several methods of protecting mild steels from corrosion, including the use of corrosion inhibitors [15-20], which are chemical substances that retard corrosion when added to a corrosive medium in low concentrations [21]. These inhibitors were divided into two types: inhibitors from synthetic compounds [22] and green inhibitors from essential oils and plant extracts [23]. Most synthetic compounds have good anticorrosive action, but most of them are highly toxic to humans and the environment [24]. These inhibitors can cause temporary or permanent damage to the system of organs such as the kidneys or liver, or disrupt the enzyme system in the body [25]. This has led to the development of non-toxic corrosion inhibitors such as Tryptamine [26], L-ascorbic acid [27], theobromine (chocolate) [28], and Indazole [29], Ceftriaxone [30], Cefotaxime [31], sulfa drugs [32], antibacterial drugs [33], antifungal drugs [34], Linseed oil [35]. Prabhu et al. [36] reported the inhibitor activity of tramadol on mild steel in HCl and H_2SO_4. But despite this development, the use of plant extract-based inhibitors is the most appropriate because they are renewable, readily available, ecologically acceptable, environmentally friendly, and inexpensive can be obtained by simple extraction procedures [37-38]. Considerable efforts have been made recently in our group to explore extracts of plant materials as corrosion inhibitor for mild steel in acid media. To this end, we have investigated black pepper extract and its isolated Piperine, the natural oil extracted from pennyroyal mint (Mentha pulegium, PM) and they all show promise as effective corrosion inhibitor for mild steel in acid media [39–44]. This work was therefore undertaken to assess the corrosion inhibition potential of solanum tuberosum extract [45-49] for the corrosion of mild steel in acidic media using gravimetric and electrochemical techniques.

2. Solanum steroid alkaloids

This family compounds are a subgroup of steroid alkaloids. The chemical structures of all members contain the intact, unchanged C_{27} carbon skeleton of cholestane, but with differing heterocyclic ring systems. In principle, 5 structural types are distinguished: *solanidanes* (e.g., solanidine), *spirosolanes* (e.g., solasodine), 22,26-epiminocholestanes (e.g., solacongestidine), 22,26-epimino-16,23-epoxycholestanes (e.g., solanocapsine), and 3-aminospirostanes (e.g., juribidine). To date almost 100 such compounds have been isolated and structurally characterized from more than 350 plant species, mostly of the family of Solanaceae (especially Solanum and lycoperscion species), but occasionally also from the Liliaceae (see Table 1) [50].

Table1: Data and occurrence of Solanum steroid alkaloids.

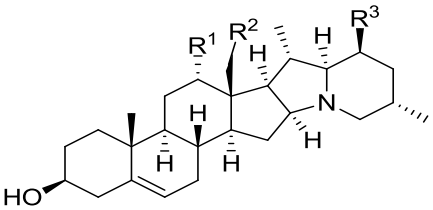
Steroid alkaloid	Mol. For.	Occurrence
Solanidanes		
Solanidine	$C_{27}H_{43}NO$	*Solanum tuberosum* and other S. species
Demissidine	$C_{27}H_{45}NO$	*S. demissum* and other species, Lycoppersicon
Leptinidine	$C_{27}H_{43}NO_2$	*S. chacoense*
Rubijervine	$C_{27}H_{43}NO_2$	*V. album and other V. species*
Isorubijervine	$C_{27}H_{43}NO_2$	*V. album and other V. species*
Spirosolanes		
Solasodine	$C_{27}H_{43}NO_2$	*S. nigrum, S. dulcamara, and other S. species*
N-Hydroxysolasodine	$C_{27}H_{43}NO_3$	*S. robustum*
Soladulcidine	$C_{27}H_{45}NO_2$	*S. dulcamara and L.pinpinellifolium*
Tomatidenol	$C_{27}H_{43}NO_2$	*S. tuberosum, S. dulcamara*
Tomatidine	$C_{27}H_{45}NO_2$	*L. esculentum, S. demissum and other S. species*
Soladunalinidine	$C_{27}H_{46}N_2O$	*S. dunalianum*
22,26-Epiminocholestanes		
Solacongestidine	$C_{27}H_{45}NO$	*S. congestiflorum*
Solafloridine	$C_{27}H_{45}NO_2$	*S. congestiflorum, S. umbellatum and S. verbascifolium*
Verazine	$C_{27}H_{43}NO$	*V. album and other V. species*
Etioline	$C_{27}H_{43}NO_2$	*V.grandiflorum and other V. species*
22,26-Epimino-16,23-epoxycholestanes		
Solanocapsine	$C_{27}H_{46}N_2O_2$	*S. pseudocasicum and S. species*
3-Deamino-3b-hydroxysolanocapsine	$C_{27}H_{45}NO_3$	*S.aculeatum (roots)*
Pimpifolidine (Solanocardinol)	$C_{27}H_{45}NO_3$	*L.pinmpinellifolium (roots)*
22-Isopimpifolidine	$C_{27}H_{45}NO_3$	*L.pinmpinellifolium (roots)*
3-Aminospirostanes		

Jurubidine	$C_{27}H_{45}NO_2$	*S. paniculatum and S. torvum(roots)*
Isojurubidine	$C_{27}H_{45}NO_2$	*S.paniculatum (roots)*

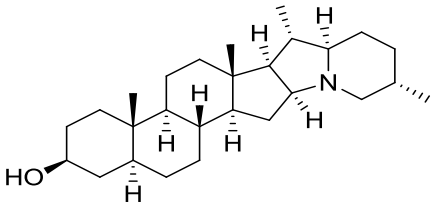
The compounds rarely occur as the free alkaloids but are mostly present in the form of glycosides. Thus, they are aglycones (genins) obtained by acid or enzymatic hydrolysis of the glycosides.

2.1. *Solanidanes*

The solanidane are tertiary bases with a heterocyclic indolizidine ring system. In most cases they differ by the presence or absence of double bound or, the number and positions of the hydroxy groups (Figure 1).



$R^1 = R^2 = R^3 = H$: Solanidine
$R^1 = R^2 = H$, $R^3 = OH$: Leptinidine
$R^1 = OH$, $R^2 = R^3 = H$: Rubijervine
$R^1 = R^3 = H$, $R^2 = OH$: Isorubijervine



Demissidine
5α-Solanidan-3β-ol

Figure 1: Solanidane alkaloids

2.2. *Spirosolanes*

The spirosolane alkaloids can be divided into two series that differ in their stereochemistry at C-22 and C-25 [(22R, 25R)-series as in solasodine and the (22S, 25S)-series as tomatidenol]. For 3β-aminospirosolanes and N-hydroxysolasodine see [51-53] and their structures in figure 2.

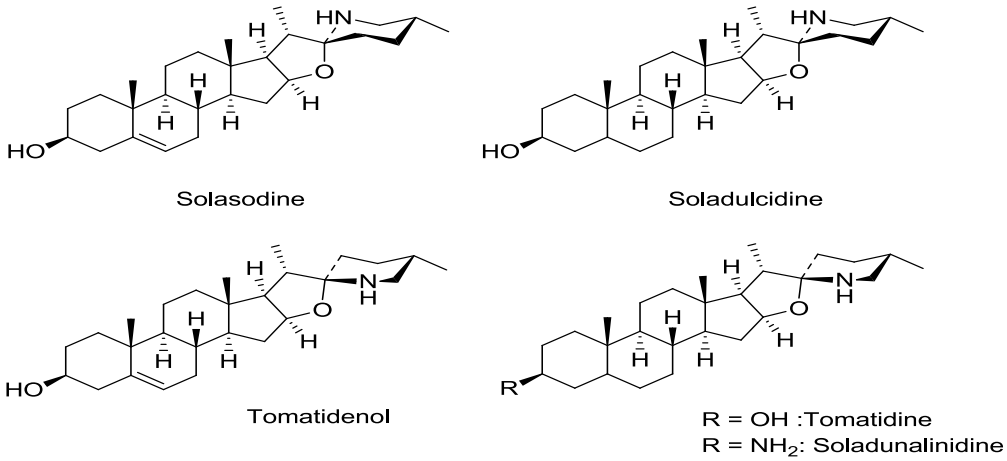


Figure 2 : Spirosolane alkaloids

2.3. *22,26-Epiminocholestanes* (16,28-secosolanidanes)

The alkaloids of this group can be assigned to two main classes which again differ in their stereochemistry at C-25 (solacongestidine: 25*R*, verazine: 25*S*). The epimeric 16β-hydroxy compounds cyclize spontaneously and stereospecifically to give the corresponding spirosolanes, this is not possible for the 16α-compounds for steric reasons. Of the large number of reported compounds four are shown below in figure 3.

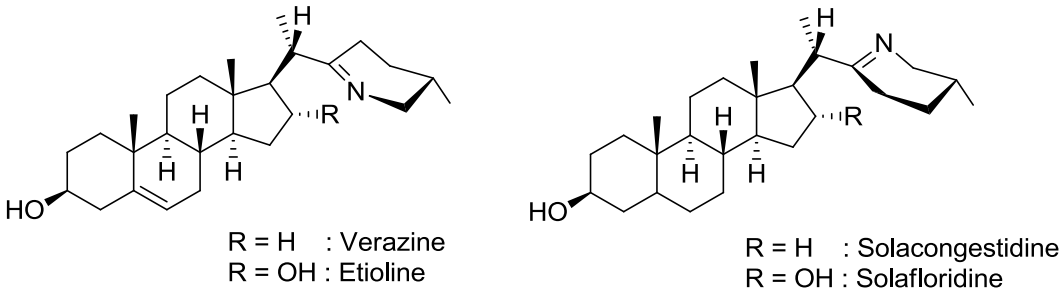


Figure 3: 22,26-Epiminocholestane alkaloids

2.4. *22,26-Epiminocholestane* alkaloids (16,23-epoxy-16,28-secosolanidanes)

Alkaloids with this skeleton have as yet only been isolated from a few *Solanum* and *Lycopersicon* species. One member known since 1229 is *solanocapsine*. It occurs only as the free alkaloid. In 3-deamino-3β -hydroxysolanocapsine the 3β -amino group has been replaced by 3β -hydroxy group. Two 16,23,25-isomers of this compound are *pimpifolidine* (solanocardinol) and 22-isopimpifolidine (isosolanocardinol, with additional 22 β–H) [54–56] shown in figure 4.

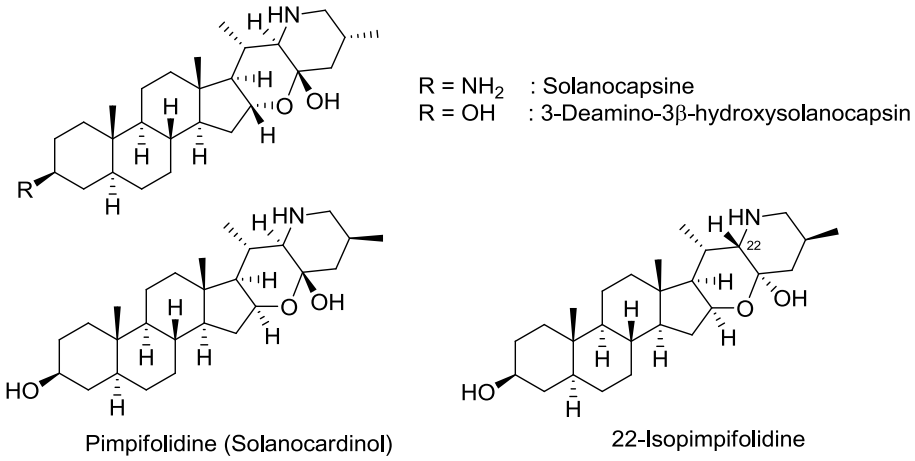


Figure 4: 22,26-Epimino-16,23-epoxycholestane alkaloids

2.5. *3-Aminospirostanes*

Jurubidine is identical with 3-deoxyneotigogenin-3β-amine. It is formed by hydrolysis of jurubine [(25S)-3β -amino-26-(β–D-glucopyranosyloxy)-5a-furostan-22α-ol] isolated from the roots of *Solanum paniculatum* and *S. torvum*. The corresponding (25R)-stereoisomer of jurubidine (isojurubidine) and the 6α or 9-hydroxylated compounds are found in the same plants (figure 5).

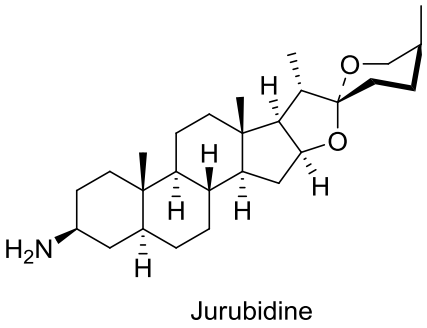


Figure 5: Structure of Jurubidine

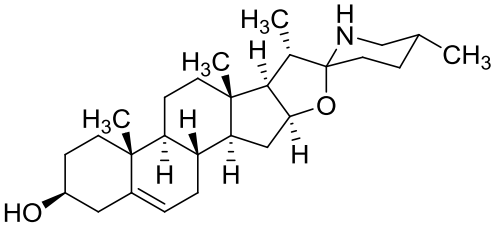
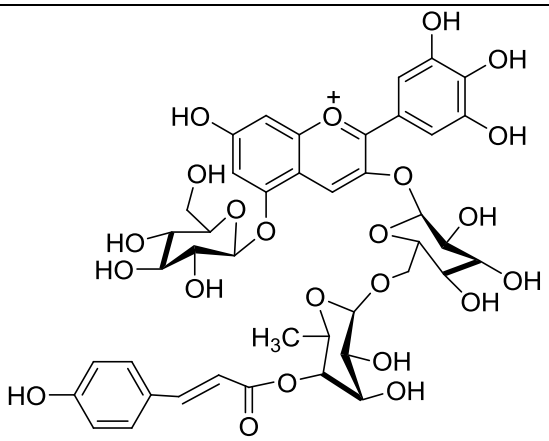
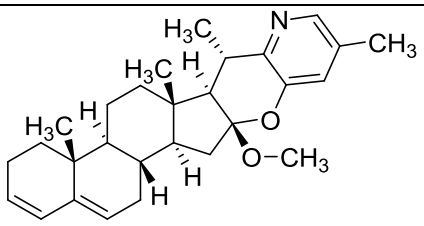
3. Biosynthesis

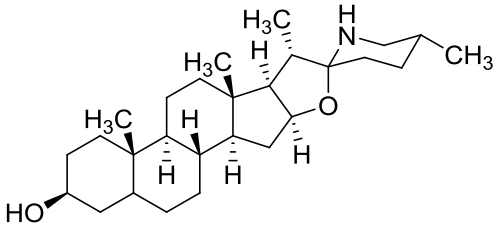
The biosynthesis proceeds analogously to that of the steroid sapogenins and is often coupled with latter via cycloartenol, cholesterol, and (25R)-or (25S)-26-aminocholest-5-en-3β-ol((steroid alkaloids) or (25R)-(25S)-cholest-5-ene-3β, 26-diol (steroid sapogenins). For details, see [57-59]. Steroid sapogenins with the same configuration at C-25 generally occur in the plants together with Solanum steroid alkaloids. For more details about synthesis please see [60-62].

4. Solanum alkaloids uses and their corrosion inhibition applications

Solasodine and tomatidenol are used in the commercial synthesis of hormonally active steroids. Solasodine is obtained on an industrial scale from Solanum laciniatum (e.g., New Zealand, Australia and Mexico), S. marginatum (Ecuador), and S. Khasianum (India) [63-65]. For toxicity and pharmacological activity of some compounds see [66-70], and Solanum steroid alkaloid glycosides. In table 2 we gather some examples of the application of these alkaloids in the corrosion inhibition of metals in aggressive media.

Table 2: corrosion inhibition of solanum alkaloids

Plant used	Metal / medium	Major constituents	Inhibition efficiency %	Ref.
Solanum tuberosum	**Steel/HCl** **Steel / H_2SO_4**		**87.05** **93.28**	**[71]** **[72]**
Solanum melongena	**Steel /NaCl**		**75**	**[73]**
Solanum violaceum	**Steel/ HCl**		**89.30**	**[74]**

Solanum trilobatum	**Steel / HCl**		**99.6**	**[75]**

5. Conclusion

In the present short review, the corrosion inhibitory effect of *Solanum alkaloids* extracts for mild steel in HCl, H_2SO_4 and NaCl solutions were explored. These natural products were excellent corrosion inhibitors due to low cost and eco-friendliness.

Reference

[1] Baorong Hou, Xiaogang Li, Xiumin Ma, Cuiwei Du, Dawei Zhang, Meng Zheng, Weichen Xu , Dongzhu Lu and Fubin Ma, (2017). The cost of corrosion in China, npj Materials Degradation 1, 4 ; doi:10.1038/s41529-017-0005-2.

[2] Rhys Jones, Neil Matthews, Daren Peng, Nam Phan, Trung Nguyen, (2018). Chapter Sixteen - Applications of SPD to Enhance the Structural Integrity of Corroded Airframes, Aircraft Sustainment and Repair, 863-905, https://doi.org/10.1016/B978-0-08-100540-8.00016-9

[3] Ridha, M., Fonna, S., Huzni, S., Ariffin A.K., (2013). Corrosion risk assessment of public buildings affected by the 2004 tsunami in banda aceh, Journal of Earthquake and Tsunami, 07, 01, 1350004 , https://doi.org/10.1142/S1793431113500048

[4] Hammouti, B., Aouniti, A., Taleb, M., Brighli, M., Kertit, S., (1995). L-Methionine methyl ester hydrochlorid as corrosion inhibitor of iron in 1M HCl, Corrosion, 51 N°6 411-416.

[5] Verma, C., Ebenso, E. E., Quraishi, M. A., Hussain, C. M., (2021). Recent developments in sustainable corrosion inhibitors: design, performance and industrial scale applications, Mater. Adv., 2, 3806-3850. DOI: 10.1039/D0MA00681E

[6] Lee, J., Kang, Y., Kim, J-S., Park, J., Lee, J-J., Kim, B-K., (2020). Electrochemical Descaling of Metal Oxides from Stainless Steel Using an Ionic Liquid–Acid Solution, *ACS Omega*, 5, 25, 15709-15714. DOI: 10.1021/acsomega.0c02163

[7] Wang, X-F., Liu, X-Y., Su, F., Li, J-S., Zhu, Z-M., Sang, X-J., Zhang, L-C., (2022). Enhanced Corrosion Resistance of Carbon Steel in Hydrochloric Acid Solution by Polyoxometalate-Estertin Derivatives, *ACS Omega*, 7,5, 4429-4443, DOI: 10.1021/acsomega.1c06276

[8] Krishnegowda, P.M., Venkatesha, V. T., Krishnegowda, P.K.M., Shivayogiraju, S. B., (2013). Acalypha torta Leaf Extract as Green Corrosion Inhibitor for Mild Steel in Hydrochloric Acid Solution, I*ndustrial & Engineering Chemistry Research*, 52, 2, 722-728, DOI: 10.1021/ie3018862

[9] Huang, J., Jianquan Luo, J., Chen, X., Feng, S., Wan, Y., (2020). How Do Chemical Cleaning Agents Act on Polyamide Nanofiltration Membrane and Fouling Layer?, Industrial & Engineering Chemistry Research, 59, 40, 17653-17670. DOI: 10.1021/acs.iecr.0c03365

[10] Mutel, C. L., Hellweg, S., (2009). Regionalized Life Cycle Assessment: Computational Methodology and Application to Inventory Databases, *Environmental Science & Technology*, 43, 15, 5797-5803. DOI: 10.1021/es803002j

[11] Li, Y., Xin, Y., Wang, X., Li, S., (2020). Fixed Bed Reactor Pyrolysis of Rape Straw: Effect of Dilute Acid Pickling on the Production of Bio-oil and Enhancement of Sugars, *Industrial & Engineering Chemistry Research*, 59, 39, 17564-17574. DOI: 10.1021/acs.iecr.0c02011

[12] Ge, J., Sun, X., Liu, R., Wang, Z., Wang, L., (2020).Emulsion Acid Diversion Agents for Oil Wells Containing Bottom Water with High Temperature and High Salinity, ACS Omega, 5, 45, 29609-29617. DOI: 10.1021/acsomega.0c04767

[13] Niu, J.J., Wang, J.N., (2009). A Novel Self-Cleaning Coating with Silicon Carbide Nanowires, *The Journal of Physical Chemistry B*, 113, 9, 2909-2912. DOI: 10.1021/jp808322e.

[14] Bouklah, M., Ouassini, K., Hammouti, B., El Idrissi, A., (2006). Corrosion inhibition of steel in sulphuric acid by pyrrolidine derivatives, Appl. Surf. Sci., 252 N°6, 2178-2185.

[15] Znini, M., (2019). Application of Essential Oils as green corrosion inhibitors for metals and alloys in different aggressive mediums, Arabian Journal of Medicinal & Aromatic Plants, No 3, 1-34.

[16] Guerraf, A.E., Titi, A., Cherrak, K., (...), Touzani, R., Hammouti, B., Lgaz, H.; (2018). The Synergistic Effect of Chloride Ion and 1,5-Diaminonaphthalene on the Corrosion Inhibition of Mild Steel in 0.5 M Sulfuric Acid: Experimental and Theoretical Insights.; Surfaces and Interfaces; 13, 168-177.

[17] Titi, A., Mechbal, N., El Guerraf, A., (...), Touzani, R., Chung, I.-M., Lgaz, H. (2018). Experimental and Theoretical Studies on Inhibition of Carbon Steel Corrosion by 1,5-Diaminonaphthalene; Journal of Bio- and Tribo-Corrosion; 4(2), 22.

[18] Louadi, Y.E., Abrigach, F., Bouyanzer, A., (...), Touzani, R., Zarrouk, A., Hammouti, B. (2017). Theoretical and experimental studies on the corrosion inhibition potentials of two tetrakis pyrazole derivatives for mild steel in 1.0 M HCl; Portugaliae Electrochimica Acta; 35(3), 159-178.

[19] Kaddouri, Y., Takfaoui, A., Abrigach, F., (...), Touzani, R., Sdassi, H.; (2017). Tridentate pyrazole ligands: Synthesis, characterization and corrosion inhibition properties with theoretical investigations; Journal of Materials and Environmental Science; 8(3), 845-856.

[20] Bousskri, A., Anejjar, A., Salghi, R., (...), Touzani, R., Bazzi, L., Lgaz, H.; (2016). Corrosion control of carbon steel in hydrochloric acid by new eco-friendly picolinium-based ionic liquids derivative: Electrochemical and synergistic studies; Journal of Materials and Environmental Science; 7(11), 4269-4289.

[21] Bouklah, M., Hammouti, B., Aouniti, A., Benhadda, T., (2004). Thiophene derivatives as effective inhibitors for the corrosion of steel in 0.5 M H_2SO_4, Progress in organic coatings 49 (3), 225-228.

[22] Elmsellem, H., Youssouf, M. H., Aouniti, A., Ben Hadda, T., Chetouani, A., Hammouti, B., (2014). Adsorption and inhibition effect of curcumin on mild steel corrosion in hydrochloric acid Russian J. Appl. Chem., 87 (6), 744-753

[23] Ghazi, I., Jorio, S., M. Siniti, Fdil, R., ELAttar, H., (2021). Experimental and theoretical studies on corrosion inhibitory action of Peganum harmala (L.) seeds extract on carbon steel in 1M HCl, Mor. J. Chem. 9 N°3, 542-563

[24] Ostovari, A., Hoseinieh, S.M., Peikari, M., Shadizadeh, S.R., Hashemi, S.J., (2009). Corrosion inhibition of mild steel in 1 M HCl solution by henna extract: A comparative study of the inhibition by henna and its constituents (Lawsone, Gallic acid, α-d-Glucose and Tannic acid). Corrosion Science, 51.9, 1935-1949. https://doi.org/10.1016/j.corsci.2009.05.024

[25] Moretti, G., Guidi, F., Grion, G., (2004). Tryptamine as a green iron corrosion inhibitor in 0.5 M deaerated sulphuric acid Corros. Sci. 46, 387.

[26] Anejjar, A., Id El Mouden, O., Batah, A., Bouskri, A., Rjoub, A., (2017). Corrosion inhibition potential of ascorbic acid on carbon steel in acid media, Appl. J. Envir. Eng. Sci. 3 N°1, 36-46, https://doi.org/10.48422/IMIST.PRSM/ajees-v3i1.7432

[27] Elmsellem, H., Elyoussfi, A., Steli, H., Sebbar, N. K., Essassi, E. M., Dahmani, M., El Ouadi, Y., Aouniti, A., El Mahi, B., Hammouti, B., (2016). The theobromine (chocolate) as green inhibitor of mild steel corrosion in hydrochloric acid: Electrochemical and theoretical quantum studies, Der Pharma Chemica, 8N°1, 248-256

[28] Zouitini, A., Kandri Rodi, Y., Elmselem, H., Chahdi, H. Steli, H., Ad, C., Ouzidan, Y., Essassi E. M., Chetouani, A., Hammouti, B., Zouitini, A., (2018). Corrosion Inhibition Behavior of Indazole Derivative as a Green Corrosion Inhibitor for Mild Steel in Hydrochloric Acid: Electrochemical, Weight Loss and DFT Simulations Studies, Mor. J. Chem. 6 N°3, 391-403

[29] Shukla, S.K., Quraishi, M.A., (2009). Ceftriaxone: a novel corrosion inhibitor for mild steel in hydrochloric acid, J. Appl. Electrochem. 39, 1517–1523 doi:10.1007/s10800-009- 9834-1.

[30] Shukla, S.K., Quraishi, M.A., (2009). Cefotaxime sodium: A new and efficient corrosion inhibitor for mild steel in hydrochloric acid solution, Corros. Sci. 51, 1007.

[31] M.M. El-Naggar, Corrosion inhibition of mild steel in acidic medium by some sulfa drugs compounds, Corros. Sci. 49 (2007) 2226.

[32] Abdallah, M., (2004). Antibacterial drugs as corrosion inhibitors for corrosion of aluminium in hydrochloric solution, Corros. Sci. 46, 1981-1996.

[33] Obot, I.B., Obi-Egbedi, N.O., Umoren, S.A., (2009). Antifungal drugs as corrosion inhibitors for aluminium in 0.1 M HCl, Corros. Sci. 51, 1868-75.

[34] Afia, L., Salghi, R., Benali, O., Jodeh, S., Warad, I., Ebenso, E., Hammouti, B., (2015). Electrochemical Evaluation of Linseed Oil as Environmentfriendly Inhibitor for Corrosion of Steel in HCl Solution, Port. Electrochim. Acta, 33(3), 137-152.

[36] Prabhu, R.A., Shanbhag, A.V., Venkatesha, T.V., (2007). Influence of tramadol [2-[(dimethylamino)methyl]-1-(3-methoxyphenyl) cyclohexanol hydrate] on corrosion inhibition of mild steel in acidic media, J. Appl. Electrochem. 37, 491-497. http://dx.doi.org/10.1007%2Fs10800-006-9280-2

[37] Oguzie EE, Oguzie KL, Akalezi CO, et al. (2013). Natural products for materials protection: corrosion and microbial growth inhibition using *Capsicum frutescens* biomass extracts. ACS Sustainable Chem Eng. 1, 214–225.

[38] Radojčić I, Berković K, Kovač S, et al. (2008). Natural honey and black radish juice as tin corrosion inhibitors. Corros Sci. 50, 1498–1504.

[39] Bouyanzer, A., Hammouti, B., Majidi, L., (2006). Pennyroyal oil from Mentha pulegium as corrosion inhibitor for steel in 1 M HCl. Materials Letters, 60.23, 2840-2843. https://doi.org/10.1016/j.matlet.2006.01.103

[40] Dahmani, M., Et-Touhami, A., Al-Deyab, S.S., Hammouti, B., Bouyanzer, A., (2010). Corrosion inhibition of C38 steel in 1 M HCl: A comparative study of black pepper extract and its isolated piperine. Int. J. Electrochem. Sci, 5.8, 1060-1069.

[41] Arrousse, N., Salim, R., Kaddouri, Y., Zahri, D., El Hajjaji, F., Touzani, R., Jodeh, S., (2020). The inhibition behavior of two pyrimidine-pyrazole derivatives against corrosion in

hydrochloric solution: Experimental, surface analysis and in silico approach studies. Arabian Journal of Chemistry, 13.7, 5949-5965. https://doi.org/10.1016/j.arabjc.2020.04.030

[42] Bouklah, M., Daoudi, W., Hammouti, B., Touzani, R., Radi, S., Ramdani, M., Salghi, R., (2020). Inhibitor adsorption processes in mild steel/new bipyrazole derivatives/hydrochloric acid system. Materials Today: Proceedings, 27, 3209-3216. https://doi.org/10.1016/j.matpr.2020.04.507

[43] Khattabi, M., Benhiba, F., Tabti, S., Djedouani, A., El Assyry, A., Touzani, R., Zarrouk, A., (2019). Performance and computational studies of two soluble pyran derivatives as corrosion inhibitors for mild steel in HCl. Journal of Molecular Structure, 1196, 231-244. https://doi.org/10.1016/j.molstruc.2019.06.070

[44] Kaddouri, Y., Takfaoui, A., Abrigach, F., El Azzouzi, M., Zarrouk, A., El-Hajjaji, F., Sdassi, H., (2017). Tridentate pyrazole ligands: synthesis, characterization and corrosion inhibition properties with theoretical investigations. *J. Mater. Environ. Sci*, *8*.3, 845-856.

[45] Mozaffari Majd, M., Kordzadeh-Kermani, V., Ghalandari, V., Askari, A., Sillanpää, M., (2022). Adsorption isotherm models: A comprehensive and systematic review (2010−2020), Science of the Total Environment, 812, 151334.

[46] Huang, L., Yang, K.-P., Zhao, Q., (...), Wang, J.-Y., Wu, Y.-C., (2022). Corrosion resistance and antibacterial activity of procyanidin B2 as a novel environment-friendly inhibitor for Q235 steel in 1 M HCl solution, Bioelectrochemistry, 143, 107969.

[47] Zhao, B., Sun, Z., Liu, Y., An overview of in-situ remediation for nitrate in groundwater, Science of the Total Environment, 804 (2022)149981.

[48] Nambiar, N.K., Brindha, D., Punniyakotti, P., Venkatraman, B.R., Angaiah, S., (2022). Derris Indica Leaves Extract as a Green Inhibitor for the Corrosion of Aluminium in Alkaline Medium, Engineered Science, 17, 167-175

[49] El housse, M., Hadfi, A., Karmal, I., (...), Mohareb, S., Driouiche, A., (2022). Valorization of Crocus Sativus L waste extracts as efficient, eco-friendly and economical inhibitors of scaling: Experimental and computational investigations, Journal of Molecular Liquids, 344, 117718.

[50] Steglich, E., Fugmann, B., Lang-Fugmann, S., (2000). Rompp encyclopedia natural products, Ed Georg Thieme Verlag pp 593-595.

[51] Ripperger, H., Porzel, A., (1992). *N*-Hydroxysolasodine from *Solanum robustum*, Phytochemistry 31, 1837-1839.

[52] Yuan, B., Byrnes, D.R., Dinssa, F.F., Simon, J.E., Wu, Q., (2019). Identification of Polyphenols, Glycoalkaloids, and Saponins in Solanum scabrum Berries Using HPLC-UV/Vis-MS, Journal of Food Science, 84(2), 235-243.

[53] Ripperger, H., (1998). Chapter Two Solanum steroid alkaloids -an update, Alkaloids: Chemical and Biological Perspectives, 12(C), 103-185.

[54] Ripperger, H., Porzel, A., (1994). Pimpifolidine and 22-isopimpifolidine, 22,26-epimino-16,23-epoxycholestane alkaloids from the wild tomato *Lycopersicon pimpinellifolium*, Phytochemistry, 35, 813-815.

[55] Friedman, M., (2002). Tomato glycoalkaloids: Role in the plant and in the diet, Journal of Agricultural and Food Chemistry, 50(21), 5751-5780.

[56] Yahara, S., Uda, N., Yoshio, E., Yae, E., (2004). Steroidal Alkaloid Glycosides from Tomato (Lycopersicon esculentum), Journal of Natural Products, 67(3), 500-502.

[57] Jastrzebska, I., (2020). Synthesis and application of steroidal 22,16β-carbolactones: A review, Journal of Steroid Biochemistry and Molecular Biology, 199,105592

[58] Erthmann, P.Ø., Agerbirk, N., Bak, S., (2018). A tandem array of UDP-glycosyltransferases from the UGT73C subfamily glycosylate sapogenins, forming a spectrum of mono- and bisdesmosidic saponins, Plant Molecular Biology, 97(1-2), 37-55

[59] Wina, E., Muetzel, S., Becker, K., (2005). The impact of saponins or saponin-containing plant materials on ruminant production - A review, Journal of Agricultural and Food Chemistry, 53(21), 8093-8105

[60] Ringdahl, B., Chan, R.P.K., Craig, J.C., Manske, R.H.F., (1981). Protoberberine alkaloids: Chiroptical properties and absolute configuration, Journal of Natural Products, 44(1), 75–79

[61] Manske, R.H.F., (1977). Alkaloids unclassified and of unknown structure, Alkaloids: Chemistry and Physiology, 16(C), 511–556

[62] Holland, H.L., MacLean, D.B., Rodrigo, R.G.A., Manske, R.F.H., (1975). A new synthesis of spirobenzylisoquinolines. Analogues of sibiricine and corydaine, Tetrahedron Letters, 16(49), 4323–4326

[63] Bednarz, H., Roloff, N., Niehaus, K., (2019). Mass Spectrometry Imaging of the Spatial and Temporal Localization of Alkaloids in Nightshades, Journal of Agricultural and Food Chemistry, 67(49), 13470-13477

[64] Weissenberg, M., (2001). Isolation of solasodine and other steroidal alkaloids and sapogenins by direct hydrolysis-extraction of Solanum plants or glycosides therefrom, Phytochemistry, 58(3), 501-508

[65] Roddick, J.G., Weissenberg, M., Leonard, A.L., (2001). Membrane disruption and enzyme inhibition by naturally-occurring and modified chacotriose-containing Solanum steroidal glycoalkaloids, Phytochemistry, 56(6), 603-610

[66] Algradi, A.M., Liu, Y., Yang, B.-Y., Kuang, H.-X., (2021). Review on the genus Brugmansia: Traditional usage, phytochemistry, pharmacology, and toxicity, Journal of Ethnopharmacology, 279,113910

[67] Farah, A.A., Tota, S.A., Eltayeib, A.A., Gobara, A.H., Farah, A.A., Tota, S.A., Eltayeib, A.A., Gobara, A.H., (2021). Phytochemical screening and hematological effects of bioactive components of aqueous and methanolic extracts of leaves and seeds of datura innoxia on male wistar rat, Israa University Journal of Applied Science, 5(1), 204-219

[68] Belhaj, S., Chaachouay, N., Zidane, L., (2021). Ethnobotanical and toxicology study of medicinal plants used for the treatment of diabetes in the High Atlas Central of Morocco, Journal of Pharmacy and Pharmacognosy Research, 9(5), 619-662

[69] Mandlik, D.S., Namdeo, A.G., (2021). Pharmacological evaluation of Ashwagandha highlighting its healthcare claims, safety, and toxicity aspects, Journal of Dietary Supplements, 18(2), 183-226

[70] Potterat, O., (2010). Goji (Lycium barbarum and L. chinense): Phytochemistry, pharmacology and safety in the perspective of traditional uses and recent popularity, Planta Medica, 76(1), 7-19

[71] Bothi Raja, P., Sethuraman, M.G., (2009). Solanum tuberosum as an inhibitor of mild steel corrosion in acid media, Iranian Journal of Chemistry and Chemical Engineering, 28(1), 77-84

[72] Raja, P.B., Sethuraman, M.G., (2010). Solanum nigrum as natural source of corrosion inhibitor for mild steel in sulphuric acid medium, Corrosion Engineering Science and Technology, 45(6), 455-460

[73] Maurya, S., Jaiswal, A., Ji, G., Prakash, R., (2021). Waste Solanum melongena stem extract for corrosion inhibition of mild steel in 1M NaCl, Materials Today: Proceedings, 44, 2716-2720

[74] Wang, X., Gu, Y., Zhang, Q., Xu, L., Li, X., (2019). Rose, gardenia, and Solanum violaceum extracts as inhibitors of steel corrosion, International Journal of Electrochemical Science, 14(9), 8405-8418

[75] Shyamala, M., Kasthuri, P.K., (2011). A comparative study of the inhibitory effect of the extracts of ocimum sanctum, aegle marmelos, and solanum trilobatum on the corrosion of mild steel in hydrochloric acid medium, International Journal of Corrosion, 2011,129647