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Behavior of *Prunus persica* as Green and Friendly Corrosion Inhibitor for Corrosion Protection

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Abstract

Prunus persica (peach) is a delicious and juicy fruit, making a valuable and healthy food. *P. persica* is an interesting specie that have been studied in different ways, one of them is as green corrosion inhibitor to protect metals. From this specie, it has been studied as juice, seeds, pomace of fruit and leaves on alloy steels immersed in acids (HCl, H₂SO₄ and H₃PO₄) and salts (NaCl, Na₂SO₄). This chapter explains briefly global importance of corrosion, how corrosion occurs and how to protect metals with corrosion inhibitors, including examples about the studies of green corrosion inhibitors and the results of *Prunus* species. The phytochemicals mixture was extracted from different tissues of peach (leaves, fruits, seeds, peels, and pomace) through different methods. All these extracts were studied to protect steel alloys immersed in different aggressive environments (acids and salts) and showed good and high corrosion inhibitions using low quantities of phytoextract (0.5 g/L) as corrosion inhibitors reaching more than 87% of corrosion inhibition efficiencies. Leaves of *P. persica* containing flavonoids like fruits and is possible to use leaves or pomace to produce green corrosion inhibitors.

Keywords: Corrosion, Green corrosion inhibitors, *Prunus persica*, Peach, metal protection

1. Introduction

The use of metals is growing up faster due to the different applications they have. Currently, different objects have been built using metals. Unfortunately, the deterioration of metallic materials is impossible to stop or avoid occurring, because the reaction of metallic materials with the present oxygen in any environment is energetically favorable and oxidation occurs spontaneously [1]. Industrially many serious and economic problems are produced for corrosion, it produces material loss on surface, and it conduce that the materials loss their mechanical properties and the structures fail making the industrial process shutting down.

In 1998 was estimated by the National Association of Corrosion Engineers (NACE) that the total annual cost generated to attend and prevent the corrosion problems in U.S.A. was closer to US \$276 billion, it was approximately equivalent to the 3.1% of the Gross Domestic Product. This inversion has been growing since

2011, becoming more than US \$2.2 trillion. While, in the same year was mentioned in the 1st Global Corrosion Summit that the corrosion cost in India was around US \$45 billion [2]. However, these estimated data are outdated, and recently closer investigation of the NACE reported that the annual global cost of corrosion has been increased approximately to US \$2.5 trillion and is equivalent to 3.4% of the global GDP [2–4]. According to a new report data, it was mentioned on 2019, it is expected that the global corrosion inhibition market will reach USD \$ 9.6 Billion by 2026 [5].

The metals importance in society through the years has raised the search for efficient alternatives to protect them. Corrosion inhibitors are one of the most used methods, as they act by decreasing the corrosion velocity and the metallic surface is protected [6]. Synthetic corrosion inhibitors is the most used in industry [6–8]. However, the excessive use of inorganic and organic synthetic corrosion inhibitors during years have been produced pollution and environmental damage [9].

Different hazards occur naturally and deliberately (such as industrial pollution, transportation accidents and damage, radioactive pollution, water pollution, petroleum pollution, etc.). The hazards of most synthetic organic compounds are commonly known, and the restrictive environmental regulations of many countries forced researchers to focus on developing cheap, nontoxic, and environmentally acceptable products [10, 11].

The metallic protection or the use of corrosion inhibitors cause significantly pollution. Therefore, environmental protection legislation raised to prevent using the environmentally unacceptable materials such as the use of chromium salts is now restricted because chromium (Cr^{+6}) is highly toxic and carcinogenic [12, 13]. Every year, billions of dollars are spent on capital replacement and methods for corrosion control in infrastructure [14, 15].

Since the nineties researchers have been searched and studied new and different alternatives for metal protection because the corrosion has drawn considerable academic and industrial attention [10, 16, 17]. Various researchers keeping these ideas in mind have been focused on studying the corrosion inhibitors activity of expired nontoxic medicines, natural molecules that come from microorganisms [18], and others have been oriented to study plant extracts which contain many natural and eco-friendly organic compounds [19]. An appropriate green corrosion control can help to avoid many potential disasters that can cause serious issues including life-loss, negative social impacts, water resource and environmental pollution. In this way green corrosion inhibition studies have become oriented towards human health and safety considerations [14, 20]. However, different studies have shown that green corrosion inhibition effect is usually found to be very low compared to synthetic organic inhibitors [10].

Likewise, it has been suggested to focus the studies in plant extracts or single natural products as corrosion inhibitors until reaching their application. Accordingly, there is an increasing demand to protect the environment by decreasing and controlling all causes, which pollute the environment, damage society's health, and affect the economy [21].

2. Corrosion

Metal corrosion is an unavoidable chemical process; it is defined as the deterioration of desired metal properties on interaction with certain elements that are present in the environment. Material's degradation is associated with the term erosion which means *“a progressive loss of original material from a solid surface due to mechanical interaction between the surface and a fluid, a multicomponent fluid -or impinging liquid or solid particles”* [22].

Chemically, corrosion is an oxide-reduction reaction; it commonly occurs an interchange or transferred the valency electrons between metal and the major element present in their environment, e.g., oxygen in air or water [23]. In the industrial practices certain processes like acidizing, acid cleaning, pickling, etc. facilitate metal corrosion, because the metal surface reacts quickly with pH solution, temperature, ions, etc. However, corrosion rate depends on the cell or environmental conditions. In the **Figure 1** is represented the electrochemical process that is carried on in the oxide-reduction reaction of steel (**Figure 1**) under aqueous system.

The corrosion occurs, in an aqueous or wet environment, when the metal is in contact with an electrolytic conducting liquid or when two dissimilar metals or alloys are either immersed or dipped partially in the electrolytic conducting solutions [20].

At anode (oxidation reaction)



Where M^{n+} (metallic ion) dissolves in solution and forms compounds such as oxide.

At cathode (reduction reactions).

In acid solution



In alkaline solution



In neutral solution

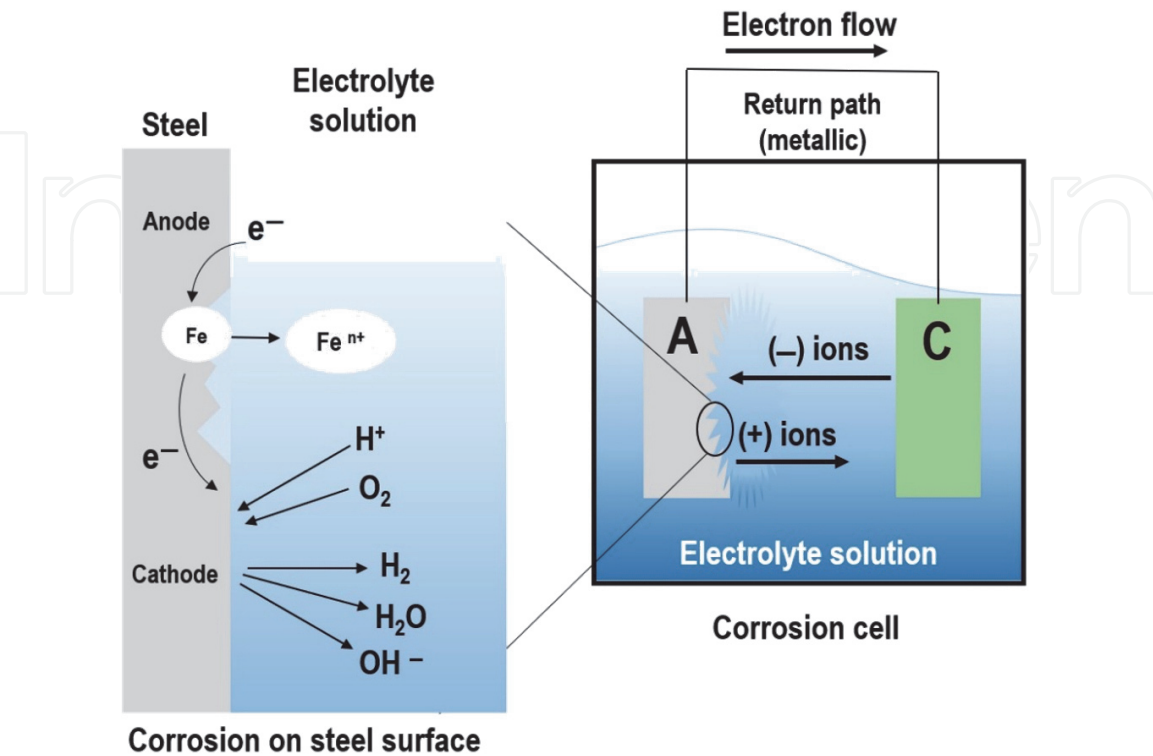


Figure 1.
Metallic corrosion (cell and metal surface).

These reactions are always associated with standard conditions to explaining the phenomenon of metal corrosion degradation (**Figure 1**).

3. Green corrosion inhibition

Metal corrosion rate could be reduced or mitigated through different strategies such as to cover the metal surface with painting or coatings; with the respective oxide that is formed through passivation or by reducing the aggressivity of the medium [24]. Those are to protect the metal and to reduce the damage.

Various authors reported the successful corrosion inhibition activity (CIA) exhibited by organic compounds, it depends on the presence of functional groups in their chemical structure, those containing elements such as *O*, *N* or *S*; such as hydroxyls (-OH), carboxyl (-COOH), carbonyl (>C=O; -CH=O); amine (-NH₂), thiols (-SH), or these elements that are included as heteroatoms (**Figure 2**).

On the other hand, other reports mentioned that aromatic rings contain double bonds and π electrons, those are important as they do favorable chelator

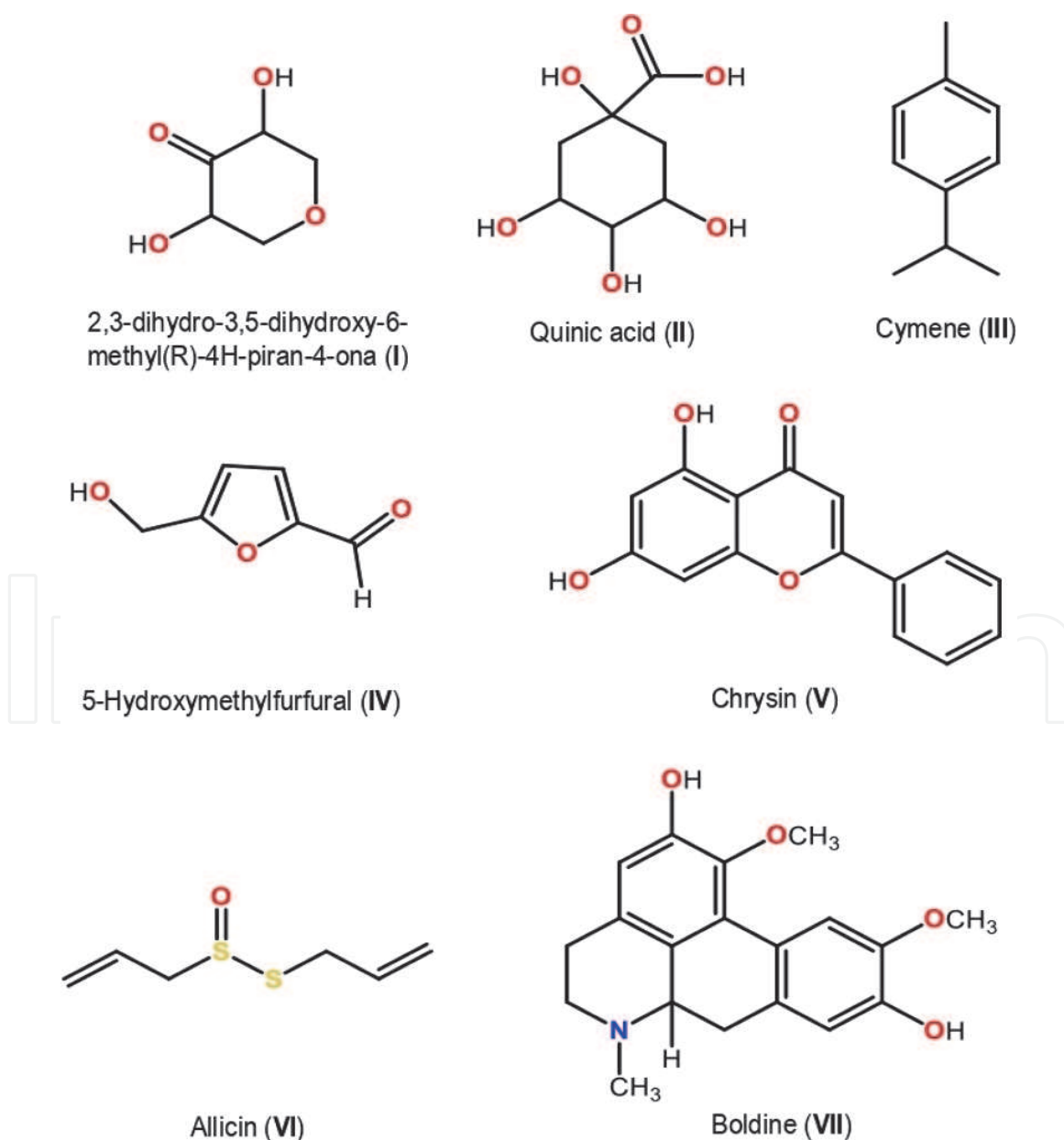


Figure 2.
General representation of organic chemical structures included heteroatoms.

interactions on the metal surface too [25, 26]. Compounds which frequently depends on the presence of functional groups in their chemical structure and electron pairs provided by heteroatoms such as N, O, P or S; these features and the presence of pi electrons as double or triple carbon–carbon bonds enable this compounds to form favorable interactions with the metal surface (**Figure 2**).

Some interesting aspect is that the nature provides different natural organic compounds, in which those chemical characteristics are present. Additionally, several of these compounds have antioxidant activity which has been related with anticorrosion activity or corrosion inhibition [27]. The interference with the flow of electrons reduces the reaction rate and gives protection to the metal.

All previous aspects motivate to perform the study of corrosion inhibition activity and to observe how the corrosion rate is reduced and how the inhibitor act and how much time gives protection to the metal surface [26–28]. In **Table 1** it is shown

| Source of green corrosion inhibitor Natural specie Type pf extract Natural products reported | Experimental conditions Metal or alloy & Electrolyte & [Green corrosion inh conc] | Inhibitive performance | Ref |
|--|---|--|------|
| <i>Argania spinosa</i> Cosmetic oil Oleic acid (fatty acids) and Schottenol (terpene) | Mild steel 1.0 M HCl 3.0 gL ⁻¹ | CIE = 81.0% By weight lost in 8 h as residence time | [29] |
| <i>Borassus flabellifer</i> Methanol and Water N. M. | Aluminum 1.0 M H ₂ SO ₄ 4.0 gL ⁻¹ | CIE _M = 65.78% CIE _W = 50.88% By weight lost in 3 h as residence time | [30] |
| <i>Khaya senegalensis</i> Acid aqueous extract N. M. | Carbon steel 1.0 M HCl 2.0 gL ⁻¹ | CIE = 91.1% By weight lost | [31] |
| <i>Lavandula multifida</i> L Essential oil Carvacrol | C38 steel 0.5 M H ₂ SO ₄ 2.0 gL ⁻¹ | CIE = 72.2% By weight lost in 6 h as residence time | [32] |
| <i>Lemon balm</i> Powder extracted using water Caryophyllene, Germacrene, Chlorogenic acid, Luteonin, Rosmarinic acid, and Citral | Mild steel 1.0 M HCl 0.8 gL ⁻¹ | CIE = 95.0% By weight lost in 12 h as residence time | [33] |
| <i>Mangifera indica</i> Powder extracted using ethanol Gallic acid, Iriflophenone, and Mangiferin | Mild steel 1.0 M HCl 1.0 gL ⁻¹ | CIE = 92.0% By weight lost in 8 h as residence time | [34] |
| <i>Salvia aucheri</i> var. <i>mesatlantica</i> Essential oil Camphor | Steel 0.5 M H ₂ SO ₄ 2.0 gL ⁻¹ | CIE = 86.12% By weight lost in 6 h as residence time | [35] |
| <i>Silybum marianum</i> Methanol extract Flavonoids: Silybin, Silychristin, Isosilybin and Silydanin | 304 stainless steel 1.0 M HCl 0.6 gL ⁻¹ | CIE = 89.7% By weight lost in 6 h as residence time | [36] |
| <i>Tragia plukenetii</i> Methanol N. M. | Mild steel 1.0 M HCl 0.5 gL ⁻¹ | CIE = 88.0% By weight lost in 3 h as residence time | [37] |

CIE, Corrosion inhibition efficiency; CIE_M, Corrosion inhibition efficiency of methanol extract; CIE_W, Corrosion inhibition efficiency of water extract; N. M., Non mentioned.

Table 1.
Studies of green corrosion inhibitor reported.

some examples of green corrosion inhibitors for some species. Green corrosion inhibitors have been positioned as a good alternative because they have come from natural sources, so they are considered less toxic, biodegradables, ecofriendly, and sustainable [1, 10, 26, 38, 39].

Traditionally the plants are used in infusion or tee, it could be the reason why in many studies have been performed water infusion as green corrosion inhibitors, however the corrosion inhibition efficiencies reported show low percentage of inhibition, one of the strategies observed in the reports is using more quantity of phytoextract to increase the corrosion inhibition efficiencies [30]. In another hand, the wide way to employ plants is in cosmetic, many works reported the study of essential oils as green corrosion inhibitor [32]. Other studies reported acid or basic extraction, it is depending on the electrolyte used, for example if the study is made in hydrochloric acid the extraction of inhibitor is made in HCl and heat [31]. These kinds of extractions are stronger and exhausted, it destroys not only the tissue, frequently modified chemically the compounds.

Organic and natural compounds are chemically sensible and thermolabile and through their functional groups reacts with acid or bases, for example the functional group alcohol in acid environment is going to transform into carboxylic acid, and tannins are going to separate into their monomeric units; other groups such as ring with oxygen as heteroatom like lactones tend to open the ring and the compounds interchange in a different position to the original. In the same way the thermolabile compounds with the heat suffer inactivation and chemical destruction [40]. The phytochemicals extraction method is an important step to recover the green corrosion inhibitor because extraction separates the desired natural products from the raw materials and follows to continue the study of chemical structure of the molecule responsible of the inhibition activity. The properties of the extraction solvent, the particle size of the raw materials, the solvent-to-solid ratio, the extraction temperature, and the extraction duration will affect the extraction efficiency [41].

The plants are considered and the diversity of phytochemical compounds could be different for the same species of plant that grew in different locations and in different tissue of the same plant biosynthesize can present different kind of natural compounds, and the kind of phytochemical biosynthesize depend on the age or stage, because it is not the same old barks than mature leaves or flowers than suckers [42]. In this way different tissue of plants have been processed, extracted, studied and reported as green corrosion inhibitors employing different alloys and electrolytes. In the **Table 2** are shown examples of specified tissue plant extracted and studied as green corrosion inhibitors.

3.1 Rosaceae family

Rosaceae is a moderately large angiosperm family in Rosales order, with about 3000 species, 3 subfamilies, 16 tribes, and 88–100 genera [55–57]. Rosaceae is a family plant producing seeds within the fruits. The fruit protects the seeds against damage from pathogens, water loss, and the other stresses. Rosaceae family have an important commercial fruit species, fruits are highly nutritious and are consumed by humans, they have benefited greatly by freshy or drier fruits including woodland strawberry (*Fragaria vesca*) [54], domesticated apple (*Malus domestica*) [58], pear (*Pyrus bretschneideri*) [59], Mei (*Prunus mume*, related to apricot) [59] and peach (*Prunus persica*) [60] and others more [61].

Different documents mentioned that peach was originated in China and then spread westward through Asia to the Mediterranean countries and later to other parts of Europe. The Spanish explorers took the peach to the New World, and in the early 1600 the fruit was found in Mexico. The large-scale commercial peach

| Source of green corrosion inhibitor Specie Tissue Solvent employed by maceration extraction Natural product reported | Experimental conditions Metal or alloy Electrolyte Inh conc [g/L] | Inhibitive performance weight lost technique | Ref |
|---|---|--|------|
| <i>Allium sativum</i> Bulbs Hexane Allicin | Carbon steel 0.5 M H ₂ SO ₄ 0.4 gL ⁻¹ | CIE _H = 96.0% | [43] |
| <i>Brugmansia arborea</i> Flowers Hexane, ketone, methanol individual maceration Hyoscyamine; Anisodamine, and Scopolamine | 1018 steel 0.5 M H ₂ SO ₄ 0.4 gL ⁻¹ (all extracts) | CIE _H = 90.0% CIE _k = 80.0% CIE _M = 78.0% | [44] |
| <i>Chenopodium ambrosioides</i> Stems and leaves Hexane N. M. | 1018 steel 0.5 M H ₂ SO ₄ 0.25 gL ⁻¹ | CIE _H = 80.0% | [45] |
| <i>Curcuma longa</i> Turmeric Hexane, methanol individual maceration Mainly Curcuminoids | 1018 mild steel 3.5% NaCl 0.1 gL ⁻¹ | CIE _H = 62.6% CIE _M = 93.7% | [46] |
| <i>Cynara scolymus</i> Fruit Methanol 2,3-dihydro-3,5-dihydroxy-6-methyl(R)-4H-piran-4-on; Quinic acid; Octadecanoic acid; 9,12-Octadecadienoic acid; 9,12-Octadecadienoic acid, methyl ester; Hexadecenoic acid and Hexadecenoic acid, methyl ester; Stigmasterol, and β-Sitosterol | 1018 steel 0.5 M H ₂ SO ₄ 1.0 gL ⁻¹ | CIE _M = 89.0% | [47] |
| <i>Equisetum arvense</i> Leaves Methanol Hexadecenoic acid; 9,12-octadecadienoic acid; oleanolic acid, methyl ester; Campesterol, and β-Sitosterol | A36 steel 0.5 M H ₂ SO ₄ 0.4 gL ⁻¹ | CIE _M = 78.0% | [48] |
| <i>Medicago sativa</i> Stems and leaves Methanol Hexadecenoic acid; 9,12-octadecadienoic; oleanolic acid; Cymene, and Limonene | 1018 steel 0.5 M H ₂ SO ₄ 0.5 gL ⁻¹ | CIE _M = 92.0% | [49] |
| <i>Mentha spicata</i> Stems and leaves Methanol Oleic acid; Stearic acid, Limonene, Cymene, and 5-hydroxymethylfurfural | 1018 steel 0.5 M H ₂ SO ₄ 0.6 gL ⁻¹ | CIE _M = 88.0% | [50] |
| <i>Peumus boldus</i> Leaves Methanol Chrysin; Boldine, and α-Tocopherol | Carbon steel 0.5 M H ₂ SO ₄ 1.0 gL ⁻¹ | CIE _M = 73.0% | [51] |
| <i>Prosopis laevigata</i> Branches Methanol Prosopine and Prosopinine | Aluminum 0.5 M H ₂ SO ₄ 0.2 gL ⁻¹ | CIE _M = 40.5% | [52] |
| <i>Rosmarinus officinalis</i> Stems and leaves Hexane, ketone, methanol individual maceration Carnosol, Carnosic acid, and Rosmarinic acid | Carbon steel 0.5 M H ₂ SO ₄ 1.0 gL ⁻¹ | CIE _H = 62.5% CIE _k = 50.0% CIE _M = 42.6% | [53] |

| Source of green corrosion inhibitor Specie Tissue Solvent employed by maceration extraction Natural product reported | Experimental conditions Metal or alloy Electrolyte Inh conc [g/L] | Inhibitive performance weight lost technique | Ref |
|---|---|--|------|
| <i>Salvia officinalis</i> Stems and leaves Methanol Carnosol, Limonene, and Rosmarinic acid | Carbon steel 0.5 M H ₂ SO ₄ 0.3 gL ⁻¹ | CIE _M = 80.0% | [54] |
| N. M., Non mentioned in the paper; CIE _H , Corrosion inhibition efficiency of hexane extract; CIE _K , Corrosion inhibition efficiency of ketone extract CIE _M , Corrosion inhibition efficiency of methanol extract. | | | |

Table 2.
Tissue of plants to obtain green corrosion inhibitors.

growing did not begin until the 19th century, in the United States. The early plantings were seedling peaches, inevitably variable, and often of poor quality. The practice of grafting superior strains onto hardy seedling rootstocks, which came later in the century, led to the development of large commercial orchards [61–65].

Peach trees are relatively short-lived as compared with some other fruit trees. In some regions orchards are replanted after 8 to 10 years, while in others trees may produce satisfactorily for 20 to 25 years or more. Trees are usually pruned annually to prevent them from becoming too tall; the upright shoots are pruned back to outgrowing laterals to produce a spreading tree and keep it open to sunlight. Small to medium-sized peach trees seldom reach 6.5 meters (21 feet) in height. Under cultivation, however, they are usually kept between 3 and 4 meters (10 and 13 feet) by pruning. The leaves are glossy green, lance-shaped, and long pointed; they usually have glands at their bases that secrete a fluid to attract ants and other insects. The flowers, borne in the leaf axils, are arranged singly or in groups of two or three at nodes along the shoots of the previous season’s growth. The five petals, usually pink but occasionally white, five sepals, and three whorls of stamens are borne on the outer rim of the short tube, known as the hypanthium, that forms the base of the flower (**Figure 3**) [61, 62].



Figure 3.
Peach tree without and with fruit and flowers.

Thousands of varieties of peach have been developed. Varieties may be freestone types, which have stones that separate easily from the ripe flesh, or clingstones, which have flesh that adheres firmly to the stone. The skin of most ripe peaches is downy or fuzzy; peaches with smooth skins are called nectarines (**Figure 4**) [65]. Worldwide, the peach is one of the most important of the deciduous-tree fruits, and China, Italy, Spain, and the United States are major producers.

Peaches and apricots belong to the same family, *Rosaceae*, also known as the rose family. Although closely related, peaches and apricots are not from the same regions. The scientific name for the peach, *Prunus persica*, denotes its abundance in Persia - modern-day Iran - despite having originated in Asia. Meanwhile, apricots (*Prunus armeniaca*) are also called armenian plums because they are known to have grown historically in this region [61]. Peach fruits come from the same family, they contain similar nutrients, including potassium, vitamin C, and beta carotene [63, 64].

However, peaches provide higher amounts of these nutrients in a single serving because of their larger size.

3.2 *Prunus persica*

Different efforts have been oriented in the search and study of species that could be applied as green corrosion inhibitors. And the peach does not an exception because has antioxidant activity and the compounds have been reported as responsible from this activity are polyphenols and carotenoids [63, 64, 66]. Likewise, the peaches are widely produced around the world because they are good and harmless for the health [66], and many products are derived from their industrializing, and it generates high quantities of agro-waste, which can be used to produce green corrosion inhibitors [67, 68]. In this way, we are interested to aim and analyze the different results reported over the activity of *P. persica* as green corrosion inhibitor.

The scientific reports on *P. persica* related to studies as green corrosion inhibitor have been organized and presented on **Table 3**.

Different tissues of peach have been used and extracted by different ways to recover natural and organic compounds to study as green corrosion inhibitors. The fruits, seeds, pomace, and gum of *P. armeniaca* have been extracted and studied

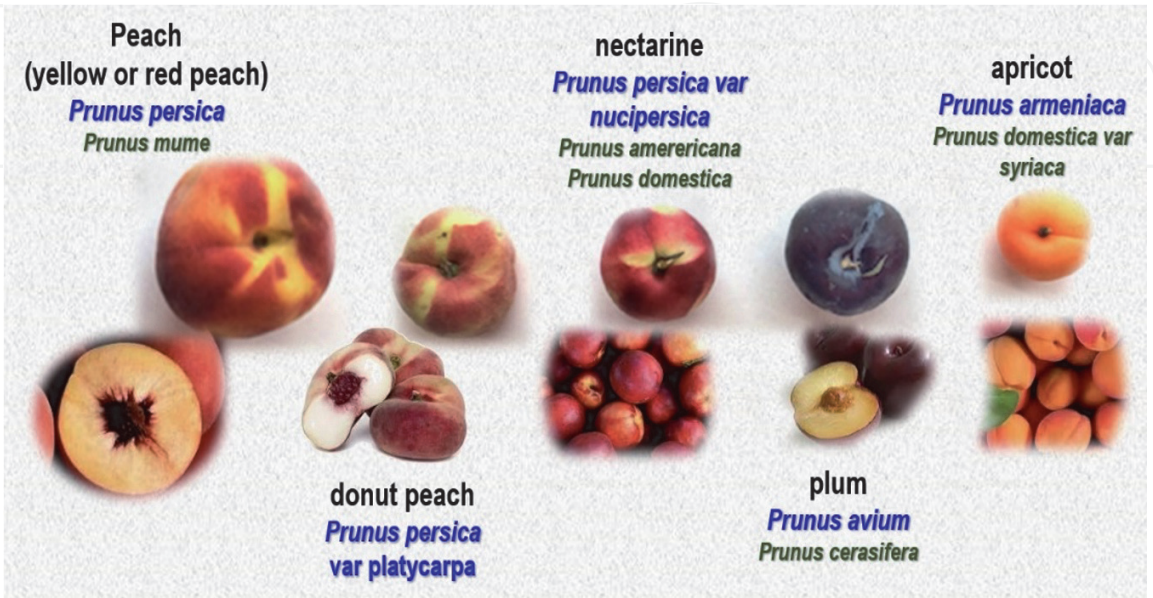


Figure 4.
Peach fruits commercially available. Common name in black color, scientific name in blue color, synonym in green color.

| Specie (common name) | Experimental conditions Alloy Electrolyte Inh conc [g/L] | Inhibitive performance | Ref |
|--|--|--|------|
| <i>Prunus armeniaca</i> L. (peach) | | | |
| Tissue Extracted technique Natural product reported | | | |
| Fruits Soxhlet extraction using 2-propanol/ethanol Octadecanoic acid; (9Z)-octadec-9-enoic acid; Linalool; α -terpineol; geraniol; nerolidol | Mild steel St7-2 0.5 M Na ₂ SO ₄ , pH 7.2 100 gL ⁻¹ | CIE by WL 97.6% in 21 days as residence time CIE by PPC 89.0% in 72 h as residence time | [69] |
| Fruits Soxhlet extraction using 95% Ethanol N. M. | Mild steel 0.5 M NaCl 0.5 gL ⁻¹ | CIE by WL 94.6% in 26 days as residence time | [70] |
| Fruits Mechanical juice N. M. | Mild steel 1.0 M H ₃ PO ₄ 40.0 gL ⁻¹ | CIE by WL 75.0% in 2 h as residence time | [71] |
| Seeds Essential oil Oleic acid; Linoleic acid; Palmitic acid; Stearic acid | C38 Carbon steel 1.0 M HCl 0.5 gL ⁻¹ | CIE by WL 84.0% in 6 h as residence time CIE by PPC 84.0% CIE by EIS 83.5% | [72] |
| Gum N. M. N. M. | Carbon steel 0.5 M H ₃ PO ₄ 0.5 gL ⁻¹ | CIE by PPC 86.0% CIE by EIS 81.0% | [73] |
| Pomace Soxhlet extraction using 2-propanol β -cyclocitral; octadecanoic acid; hexadecanoic acid; (9Z)-octadec-9-enoic acid; Terpineol; Geraniol; Nerolidol | Mild steel 0.5 M NaCl 0.5 gL ⁻¹ | CIE by WL 94.6% in 26 days as residence time | [74] |
| <i>Prunus avium</i> (sweet cherry) | | | |
| Leaves Reflux distillation with water Phenolic compounds and anthocyanins | Mild steel 0.5 M HCl 0.40 gL ⁻¹ | CIE by PPC 61.0% CIE by EIS 55.0% | [75] |
| <i>Prunus cerasus</i> (cherry) | | | |
| Fruits Mechanical compressed to obtained juice N.M. | St-37 Steel 1.0 M HCl ~40* gL ⁻¹ | CIE by PPC 94.1% CIE by EIS 92.7% | [76] |
| <i>Prunus dulcis</i> (almond) | | | |
| Fruit peels Methanol and water Catechin, Chlorogenic acid, and Isorhamnetin-3-o-rutinoside | Mild steel 0.1 M HCl 0.12 gL ⁻¹ 0.24 gL ⁻¹ | CIE by WL 93.0 and 85%, respectively CIE by PPC 09 & 83.0%, respectively CIE by EIS 92.0 and 88.0%, respectively | [77] |
| Seeds Soxhlet extraction using hexane Phenolic compounds, Saponins, Tannins, Flavonoids, and proanthocyanidins | Mild steel 1.5 M HCl 150 gL ⁻¹ | CIE by WL 68.0% in 20 h as residence time | [78] |
| <i>Prunus persica</i> (Peach) | | | |
| Leaves Methanol maceration | 1018 Carbon steel 0.5 M H ₂ SO ₄ 0.60 gL ⁻¹ | CIE by WL 80.0% CIE by PPC 92.0% CIE by EIS 97.0% | [79] |

| Specie (common name) | Experimental conditions Alloy Electrolyte Inh conc [g/L] | Inhibitive performance | Ref |
|--|---|--|------|
| Kaempferol, Quercetin, Rutin, Ursolic acid, Daucosterol, and β -Sitosterol | | | |
| Pomace Ultrasound dissolved in 2-propanol/ethanol/water Cinnamaldehyde, Thymol, Decosanal, α -Terpineol, and Linalool | Carbon steel 0.5 M NaCl 0.8 gL ⁻¹ | CIE by WL 80.0% in 45 h as residence time | [80] |
| Fruits Mechanical compressed to obtained Juice N.M. | Mild steel 1.0 M HCl 0.05 gL ⁻¹ | CIE by WL 88.0% at 50° C CIE by PPC 90.0% | [81] |

N. M., Non mentioned in the paper; CIE_H, Corrosion inhibition efficiency of hexane extract; CIE_k, Corrosion inhibition efficiency of ketone extract CIE_M, Corrosion inhibition efficiency of methanol extract.

Table 3.
Species of Prunus studied as green corrosion inhibitors.

as green corrosion inhibitors [72–74] against mild and carbon steel using salts [69, 70, 74] and acids as electrolytes [71–73]. The corrosion inhibitor efficiencies reported are between 75 to 94 percent [69–74]. The fruit and pomace extracted by Soxhlet using ethanol and isopropanol reaching high corrosion inhibition efficiencies [69, 70, 74]. The natural compounds reported for the active extract are fatty acids and terpenes [69, 72, 74].

The leaves of *P. avium* extracted by reflux distillation using water, was tested as green corrosion inhibitor against mild steel immersed in hydrochloric acid, the corrosion inhibition efficiency reported were 55 percent when 0.4 g/L of the extract was used [75]. The juice of fruits of *P. ceracus* obtained by mechanical compressed was tested against St-37 steel immersed in hydrochloric acid. The electrochemical test permitted to observe that the corrosion inhibition efficiency upper 90 percent when 40 g/L of juice was used [76].

The fruit peels and seeds of *P. dulcis* have been extracted using methanol and water individually and studied as green corrosion inhibitors against mild steel in hydrochloric acid, the corrosion inhibition efficiencies reported were high for fruit peels [77] compared those reported for seeds [78].

The leaves, fruits, and pomace of *P. persica* have been extracted individually by maceration, ultrasound and compressed mechanical and studied individually against carbon and mild steel immersed in sulfuric acid [79]; sodium chloride [80] and hydrochloric acid [81]. The corrosion inhibition efficiencies reported were more than 80 percent.

The phytoextracts from *Prunus* show they can inhibit the corrosion rate of steel alloys in acid and saline environments. These reports shown the importance of continue studying peach as green corrosion inhibitor to find the organic molecule responsible of the inhibition activity, and search to modeling isotherms, obtain Gibbs free energies and Density functional theory (DFT) studies to understanding the involved mechanisms on the green corrosion inhibition.

The best natural material of peach to obtain and for particular interest as green corrosion inhibitor could be the leaves, because these are not commercial than fruits, and in orchards many threes are pruned, and the leaves are disposable as residues. Other kind of residues from peaches are produced by the food industry or

jam and juice factories, they discarded and waste dispose peels, seeds, and pomace of peaches (**Figure 5**).

Recently was reported the use and approval of peaches waste to produce green corrosion inhibitors with prolonged activity on mild steel [82]. Different compounds are chemically detected and reported from *Prunus* genus like sterols, phenolics, flavonoids and polyphenols (**Table 3, Figure 6**), some characteristic compounds are studied as corrosion inhibitors.

The inhibition performance of loquat (*Eriobotrya japonica*) leaves extract for the corrosion of mild steel in 0.5 M H₂SO₄ were investigated. The weight loss method shown a corrosion inhibition efficiency of 91.0% using 50% (V/V) of extract. High performance liquid chromatograph (HPLC) of loquat extract shows the presence of Ursolic acid (**VIII**) as chemical component in the green inhibitor [83].

β -Sitosterol (**IX**) inhibiting the corrosive effect that has produced 1 M H₂SO₄ solution on the mild Steel. The inhibition efficiency increased with increasing inhibitor concentration and decreased when increasing temperature. The maximum inhibition efficiency of β -sitosterol (500 ppm) was 95%. Electrochemical studies indicated that isolated β -sitosterol acted as a good corrosion inhibitor [84].

In another hand, the potential of flavonoid extract of *Erigeron floribundus* was studied as green inhibitor for the corrosion of mild steel in 2 M HCl solution using gasometric method. The results indicated that the extract acts as corrosion inhibitor by adsorption on mild steel surface. The inhibition efficiency of the flavonoid extract was 93.1% using 2.0 g/L of the inhibitor [85].

The *Hemerocallis fulva* extract obtained using methanol as solvent was tested as corrosion inhibition on aluminum, in a 1 M H₂SO₄ solution. Results obtained show a maximum inhibition efficiency of about 89% at 600 ppm and 303°K. Kaempferol (**X**) and other phytochemicals were detected by ultra-high-performance liquid chromatography as the major components of *Hemerocallis fulva* methanol extract [86].

According to the literature flavonoids were found in the infusions of *Baccharis trimera*. Quercetin (**XI**) was used representative of flavonoids and was studied as

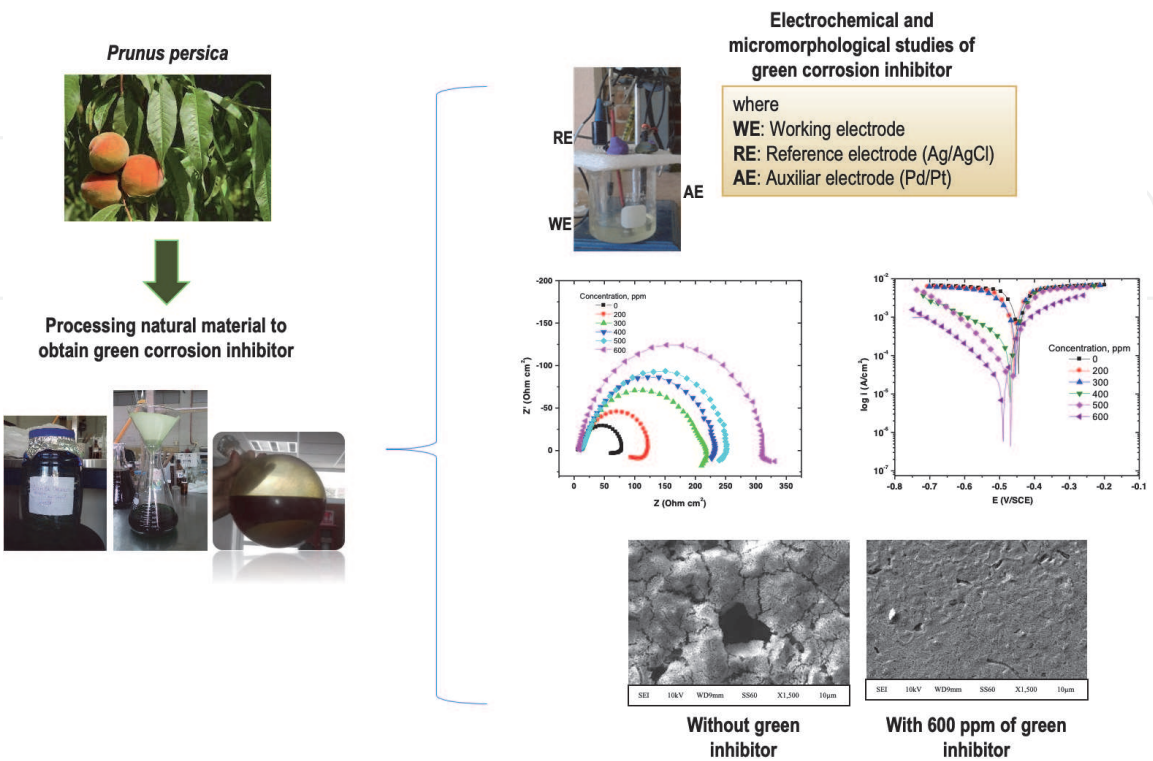


Figure 5.
Obtaining and studying the green corrosion inhibitor of *Prunus persica*.

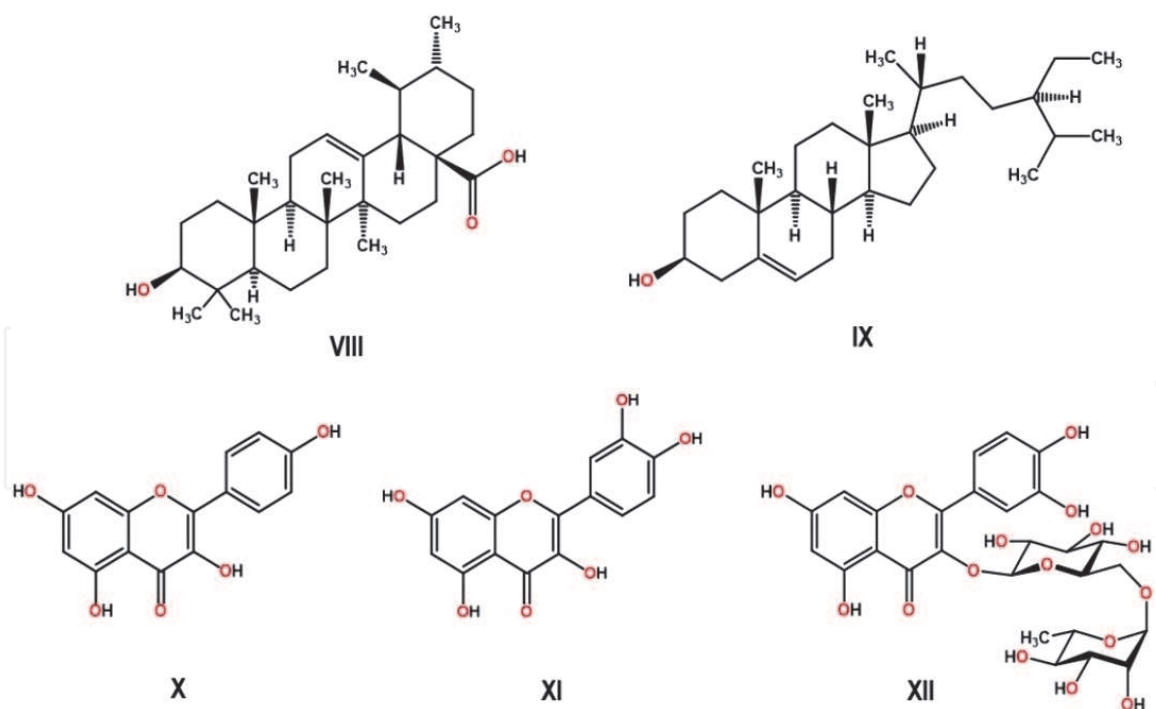


Figure 6.
 Natural compounds reported for *Prunus persica*.

corrosion inhibitor on mild steel immersed in 1 M HCl solution, the results shown that Quercetin gives protection when it was employed at 100 mg/L [87].

Cryptostegia grandiflora leaf extract was evaluated for its anti-corrosion property on mild steel in 1 M H₂SO₄, reported that 500 ppm of the inhibitor achieved a maximum corrosion inhibition efficiency of 87.54%. One of the flavonoids present in green inhibitor was Rutin (XII) [88].

Folin–Ciocalteu reagent was used to assess total phenolic content present in apricot samples and were compared with the blue complex formed of gallic acid using as a standard. Aluminum chloride method was used for the detection of total flavonoid content producing a yellow color due to the presence of flavonoids; in this case Quercetin was used as a standard for the measurement of flavonoids. The results shown that fruits of *Prunus armeniaca* and leaf of *Prunus persica* contained flavonoids, phenolic compounds, and tannins [89]. Showing the chemical structures of flavonoids, they contain more oxygen atoms through them, these compounds made a greater number of interactions with metal surface.

Phytochemicals frequently are considered “organic, natural and safe compounds”. However is adequate, proper, and scientifically correct to determine that green corrosion inhibitors are not toxic substances at the concentration are active as corrosion inhibitors, and at the same time to confirm they are safe to the human and environment. Are few reports of green corrosion inhibitors with good corrosion inhibition efficiencies that included the determination of toxicity.

However, for *P. persica* green corrosion inhibitor was determined there toxicity by the *Artemia salina* lethality and toxicity against *Lactuca sativa* (Lettuce) seeds germination. Both bioassays give valuable information to determine that the active substances as green corrosion inhibitors have not an environmental impact on their application. The results showed that methanol extract *P. persica* leaves produced the LC₅₀ (necessary concentration to produce 50% of the deaths) for *A. salina* with 1568 ppm of green corrosion inhibitor. The active concentration of *P. persica* as a corrosion inhibitor was 600 ppm, this concentration not produced toxicity for *A. salina*. However, at the same concentration *P. persica* extract produced 45% of the

germination index of *L. sativa*. Indicating that lettuce seeds were more sensible than *A. salina* to methanol extract of *P. persica* leaves [79].

4. Conclusions

The phytoextracts extracted from *Prunus persica* shown the capacity to protect alloy steels of corrosion immersed in acid or saline aggressive environments. The flavonoids could be the responsible compounds to metal protection because they contain oxygen atoms in their chemical structure, each oxygen atom has two lone pairs of electrons through made favorable physical interactions on the metal surface to establish metal and protect it.

The high content of flavonoids was found in leaves and pomace of *P. persica*, they are taking advantage of making novel green corrosion inhibitors and open a new window to study chemically and electrochemically the present compound in leaves as corrosion inhibitors. The Phytochemicals contains in the methanol *P. persica* leaves used as a green corrosion inhibitor at 600 ppm are highly toxic for lettuce.

Conflict of interest

The authors declare no conflict of interest.

Appendices and nomenclature

| | |
|--------------------------------|--|
| M | Molar |
| H ₂ SO ₄ | Sulfuric acid |
| HCl | Chloride acid |
| gL ⁻¹ | grams per liter |
| ppm | parts per million |
| N. M. | Non mentioned in the paper |
| CIE _H | Corrosion inhibition efficiency of hexane extract |
| CIE _k | Corrosion inhibition efficiency of ketone extract |
| CIE _M | Corrosion inhibition efficiency of methanol extract. |
| WL | weight lose |
| PPC | Potentiodynamic polarization curves |
| EIS | Electrochemical Impedance Spectroscopy |
| HPLC | High performance liquid chromatograph |
| LC ₅₀ | Lethal concentration, 50% |

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