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Sorghum halepense (Zacate Johnson) as a potential natural corrosion inhibitor

Sorghum halepense (Zacate Johnson) como potencial inhibidor natural de la corrosión

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Abstract

Corrosion inhibitors can trigger health and/or environmental problems due to their toxicity. For this reason, it has been suggested to use plant extracts as natural corrosion inhibitors, because they represent a rich source of chemical compounds, they are non-toxic, biodegradable and abundant in nature. *Sorghum halepense* is a herbaceous weed, commonly known as johnson grass, belongs to the family *gramíneae* or *poaceae*, the choice of this plant is due to its zero cost and easy availability.
In this systematic review, were used keywords such as *Sorghum halepense* johnson grass, phytochemistry, phytotherapy, phytoremediation, antidiabetic, antioxidant, cytotoxicity, antifungal, antimicrobial, anticancer, biological activity, medical activity, allelochemicals, among others. To do this, were used databases such as Scielo, Dialnet, Redalyc, Google Scholar, DOAJ, Wiley online library, BioOne, EBSCOHost, Knovel, ScienceDirect, SpringerLink y VirtualPro. Previous studies on this weed have reported its therapeutic potential against cancer, diabetes, prostatitis, hepatoprotective activity, antioxidant, antimicrobial, antifungal, as well as abortifacient and placental delivery in veterinary medicine. In view of the numerous organic molecules present in this plant, this study proposes *Sorghum halepense* as a potential natural corrosion inhibitor.

***Sorghum halepense*, Anticorrosive, Natural inhibitor, Herbaceous, Environmental**

Resumen

Los inhibidores de la corrosión pueden desencadenar problemas de salud y/o ambientales debido a su toxicidad. Por esta razón, se ha sugerido el uso de extractos de plantas como inhibidores naturales de la corrosión, debido a que representan una rica fuente de compuestos químicos, no son tóxicos, son biodegradables y abundantes en la naturaleza. *Sorghum halepense* es una maleza herbácea, comúnmente conocida como zacate johnson, pertenece a la familia *gramíneae* o *poaceae*, la elección de esta planta se debe a su nulo costo y su fácil disponibilidad. En esta revisión sistemática, se utilizaron palabras clave como *sorghum halepense*, zacate Johnson, fitoquímica, anticorrosivo, fitoterapéutico, fitorremediación, antidiabético, antioxidante, citotoxicidad, antifúngico, antimicrobiano, anticancerígeno, actividad biológica, actividad médica, aleloquímicos, entre otros. Para ello, se utilizaron las bases de datos como Scielo, Dialnet, Redalyc, Google Scholar, DOAJ, Wiley online library, BioOne, EBSCOHost, Knovel, ScienceDirect, SpringerLink y VirtualPro. Los estudios previos sobre esta maleza han reportado su potencial terapéutico contra el cáncer, diabetes, prostatitis, actividad hepatoprotectora, antioxidante, antimicrobiano, antifúngico, así como abortivo y expulsión de placenta en animales. En vista de las numerosas moléculas orgánicas presentes en esta planta, este estudio propone al *Sorghum halepense* como potencial inhibidor natural de la corrosión.

***Sorghum halepense*, Anticorrosivo, Inhibidor natural, Herbaceos, Ambiental**

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Introduction

Corrosion is defined as the destructive attack of a metal by chemical or electrochemical reaction with the environment (Revie, 2008). Metallic materials, especially iron and carbon alloys are widely used as construction materials due to their high mechanical strength and low cost. However, most metals and their alloys in their pure form are highly reactive and susceptible to corrosive degradation.

The wear and tear of carbon steel structures has been associated with aggressive environmental conditions characterised by high relative humidity and long periods of hot temperatures during summer and autumn; similarly, rainfall and the presence of anthropogenic pollutants have been considered as contributing factors to the increase of corrosion phenomena. Approximately 25% of annual steel production is destroyed by corrosion (Ávila & Genescá, 2013). For countries for which data is available, the cost of corrosion represents approximately 3 to 4% of GDP (Okoroafor, 2004, Op. Cit. Fayomi et. al., 2019).

Due to the impact of corrosion on the economy, industry and health, researchers have become interested in the use and development of techniques for corrosion prevention and control (Shaw & Kelly, 2006). There are chemical compounds called corrosion inhibitors which are generally compounds whose reactive species react with the metal to produce a protective film at the metal-environment interface, thus inhibiting corrosive reactions (Shukla et.al., 2011; Gomez, 2019).

To minimise metal loss in acidic, saline and other aggressive environments, the use of corrosion inhibitors has been used. A good corrosion inhibitor must be economically viable, non-toxic to the environment and humans, and have a high inhibition efficiency.

Most synthetic compounds are good corrosion inhibitors, however, most are highly toxic to humans and the environment. They often cause temporary or permanent damage to organs such as the kidneys and liver. For these reasons, the identification, extraction and evaluation of natural substances that act as more environmentally friendly inhibitors has been undertaken (Santamaria, 2021; Singh et. al., 2012).

A large number of chemical compounds, especially heterocyclic compounds, are present in seed, fruit, leaf and flower extracts of various plants, which have shown a favourable response in reducing the corrosion rate. The inhibitory effect is attributed to the adsorption of these organic substances on the metal surface, blocking the active sites or forming a protective layer (Ibidem).

Although some plants and their phytochemical characteristics have been reported to have corrosion inhibitory activity, the vast majority of plants have not been properly studied as natural inhibitors. For example, of the more than 300,000 plant species on earth, only a few (less than 1%) have been fully studied for their characteristics as natural corrosion inhibitors (Al-Otaibi et. al., 2014).

Phytochemical study of Sorghum halepense revealed the presence of vitamins, steroids, saponins, alkaloids, reducing sugars, tannins, glycosides, flavonoids, phenols, terpenes, carbohydrates, and proteins. These structures exhibit chemical characteristics that make them candidates to bind to the metal surface and thereby form a protective layer (Hassannejad & Nouri, 2018; Nair, 2017).

After reviewing the different research works where natural extracts obtained from plant seeds are evaluated to inhibit the corrosion of carbon steel, and considering that nowadays it is essential to develop practices that help the preservation of the environment and health, the evaluation of the Sorghum halepense plant as a possible natural corrosion inhibitor is proposed. This work is organised as follows: Section I shows the introduction, Section II presents in a general way the method for systematic reviews, the application of the systematic review protocol and the extraction of information are also described. Section III describes the results. Finally, section IV shows the conclusions of this work.

Methodology to be developed

Description of the method

"The term Systematic Review (SR) is used to refer to a specific research methodology developed for the purpose of collecting and evaluating the available evidence pertaining to a focused topic (Biolchini, Gomes, Cruz, & Travassos, 2005)".

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This section presents the steps to follow for the development of the systematic review process proposed by Biolchini *et al*.

A. Protocol development: rigorous and iterative phase. It covers the general plan for the systematic literature review.

1. Question formulation: section where the important research questions to be answered during the SR are identified. In this section the research objectives should be clearly defined.

2. Identification and selection of sources: section whose objective is to identify and select the sources where the search for primary studies will be carried out. It consists of the following sections: definition of source selection criteria, language of the studies, identification of sources, selection of sources after evaluation, verification of sources.

3. Study selection: this section aims to identify primary and secondary studies. Studies are selected after application of inclusion and exclusion criteria.

B. Information extraction: phase in which the search for studies in the defined sources is executed, the studies found are evaluated against the defined criteria.

1. Definition of the criteria for inclusion of information (ICinf) and exclusion of information (ECinf), the objective of which is to define the criteria with which the information will be evaluated.
2. Templates for information extraction: this section aims to record the primary studies derived from the selection process.
3. Execution of the extraction: section in which the evaluation of the studies is carried out using the defined criteria.

C. Summary of results: phase in which the results obtained from the application of the SR protocol development phase and the information extraction phase are shown, with the aim of presenting the data resulting from the selected studies.

Systematic review of Sorghum halepense (Johnson grass) as a potential natural corrosion inhibitor.

Development of the protocol.

(a) Formulation of the question.

(1) Focus of the question:

This research was conducted to propose Sorghum halepense plant as a potential natural corrosion inhibitor.

(2) Scope and quality of the question
(a) Problem:

Nowadays, corrosion of metals is an inevitable process and to combat it, various corrosion inhibitors are used, mostly of synthetic nature; which, are mostly characterised by producing serious environmental and health problems, that is why, it is required to promote the use of natural corrosion inhibitors. Based on this, the proposal arises to investigate the properties possessed by Sorghum halepense, and if the chemical constituents present in this weed can contribute in the control of the corrosion phenomenon.

Question:

Is it possible to propose Sorghum halepense (Johnson grass) as a weed with potential as a natural corrosion inhibitor?

Which chemical structures of Sorghum halepense are capable of conferring natural corrosion inhibitor activity?

(b) Key words and synonyms:

Definitions used to solve the research question were Sorghum halepense, Johnson grass, anti-inflammatory, antifungal, antiparasitic, phytochemical, antioxidant, phytochemical composition, antidiabetic, larvicidal activity, cytotoxicity, 1976, 1990, 1999, 2008, 2012, 2013, 2013, 2014, 2015, 2017, 2010, 2020.

(c) Intervention:

Sorghum halepense as a potential natural corrosion inhibitor.

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(d) Effect:

Studies to identify the chemical properties of the plant Sorghum halepense that may attribute to it the property of a natural corrosion inhibiting agent.

(a) Population:

Publications related to the phytochemical composition of Sorghum halepense and its medicinal and other uses.

(b) Application

Scientific community searching for natural corrosion inhibiting agents.

a) Identification and selection of sources

(1) Definition of the source selection criteria:

- Use keyword search mechanisms.
- Publications recommended by other authors.
- Publications available on websites.

(2) Language of studies:

- Spanish
- English
- ●Portuguese

(3) Source identification
(4) Source finding methods

To conduct this systematic review, research was carried out using web search engines.

(4) Search string

With the combination of the list of identified words, logical connectors "AND", "OR" and "NOT" were used and a basic general search string was obtained (see table 1).

Keywords with logical operators
("*Sorghum halepense*" OR "Zacate Johnson" AND "*antidiabeti*" OR "*antioxidant*" OR "antifungal" OR "anticancer" OR “cytotoxic” OR “antibacterial” OR “analgesic” OR “antidiabetic” OR “hepatoprotective” OR “*larvicida*” OR "muscle *relaxant*" OR "*Phytochemical* the *Sorghum halepense*")

Table 1 Search chain
Source: Own Elaboration

List of sources

- Google Academic
- Redalyc
- SciELO
- Dialnet
- DOAJ
- Wiley online library
- BioOne

Selection of sources after evaluation of criteria

The sources were checked for compliance with the previously defined criteria, and the list of sources, shown in the table below, was established. 2.

Number	Sources
1	Google Academic
2	Redalyc
3	SciELO
4	Dialnet
5	DOAJ
6	Wiley online library
7	BioOne

Table 2 Sources used
Source: Own Elaboration

Verification of sources

Three researchers from the Research Group of the Academic Body UNACAM-CA-63 "CORROSION AND GREEN CHEMISTRY", from the Corrosion Research Centre (CICORR), the Centre for Environmental Microbiology and Biotechnology (CIMAB) and the Faculty of Chemical and Biological Sciences (FCQB) of the Autonomous University of Campeche evaluated the list of sources, where they consensually approved the list.

b) Selection of studies.
(1) Definition of studies.
(a) Definition of inclusion criteria (IC) of studies and exclusion criteria (EC) of studies.

In the definition of inclusion criteria (IC) of studies and exclusion criteria (EC) of studies, 4 and 2, respectively, were identified, which are shown in table 3 below.

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Criterion	Descriptionn
CI1	Includes publications whose titles are related to the uses of the phytochemistry of the weed Sorghum halepense.
CI2	Includes publications containing reserved words that match those defined in the search string.
CI3	Includes publications whose abstract is related to the selected topic.
CI4	Includes publications that have been partially or fully read.
CE1	Excludes publications that do not match the previous inclusion criteria.
CE2	Excludes all duplicate publications.

Table 3. Definition of inclusion and exclusion criteria for studies
Source: Own Elaboration

(a) Definition of types of studies:

Related studies on the phytochemical composition of the *Sorghum halepense* plant were analysed.

(b) Procedure for selecting studies:

Criteria were taken as the title of the publication, the abstract of each one and in some cases it was required to review the full content.

Execution of the selection:

Searches were carried out, adapting the strings to the engines of each search engine, to determine the quality of the studies, inclusion and exclusion criteria were applied.

Information extraction.

Definition of the criteria for inclusion of information (CIinf) and exclusion of information (CEinf)

Two information inclusion criteria (CIinf) and one exclusion criterion (CEinf) were identified. Table 4 shows a description of these criteria.

Criterion	Description
CI1inf	Collect information on various uses or benefits that Sorghum halepense could have.
CI2inf	Identify the phytochemistry of this plant that could attribute its use as a potential natural correction inhibitor.
CE1inf	Exclude information that is not related to the inclusion criteria defined above.

Table 4 Definition of criteria for inclusion and exclusion of informatio
Source: Own Elaboration.

b) Templates for Information Extraction

For the registration of the study identification data, a template containing the following fields was stored: title of the study, year, authors and abstract, as shown in Table 5.

Title	
Year	
Authors	
Abstract	

Table 5. *Template used for data extraction*
Source: Own Elaboration

c) Execution of the Extraction

The repertoire obtained was placed in templates for information extraction. The evaluation was done by analysing the main ideas, using the criteria of inclusion and exclusion of information. Some articles were not sufficiently redundant in the topic, so it was decided to read and interpret the introduction to get a more concise idea of the research. In this way it was possible to determine whether the articles had any relation to the topic addressed.

The information from the publications that were considered as primary was stored in the template as shown in table 6, 7, 8 and 9 where a summary of how the template was used with the analysis of one of the selected studies can be visualised.

Title	Actividad antifúngica de extractos metanólicos de Sorghum halepense contra Macrophomina phaseolina.
Year	2012
Authors	Arshad Javaid, Syeda Fakehha Naqvi and Amna Shoaib.
Abstract	The present study was designed to investigate the antifungal potential of an allelopathic herb Sorghum halepense Pers. for the management of M. phaseolina isolated from cowpea plants infected with charcoal rot. In laboratory bioassays, different concentrations of methanolic extracts of shoot, root and inflorescence of the allelopathic test grass were evaluated for their in vitro antifungal activity against M. phaseolina. Extracts of the three parts of the grass exhibited variable antifungal activity.

Table 6 Example of the template used to store the information
Source: Own Elaboration

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Title	Elemental, antimicrobial and antioxidant activities of a medicinal plant *Sorghum halepense.*
Año	2019
Authors	Abdul Yasar Khayal, Inam Ullah, Muhammad Nughman, Syed Majid Shah and Nawab Ali.
Abstract	The present study is aimed at finding out the medicinal properties of this plant. For this purpose, plant samples were collected and subjected to acid digestion to evaluate the concentration of heavy metals such as iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), lead (Pb), cadmium (Cd), chromium (Cr) and nickel (Ni) by atomic absorption spectrophotometer. The presence of heavy metals is important for medicinal plants. Then the antibacterial, antifungal and antioxidant activity in Sorghum halepense was evaluated by maceration and shed drying of the plant sample for fifteen days and crude extract, ethyl acetate, n hexane, chloroform and aqueous fractions were extracted. After careful analysis, the concentration of heavy metals was found to be high, except Cd and Cr. The crude extract and other fractions of Sorghum halepense showed good antibacterial activities against P. aeruginosa, S. epidermidis, S. epidermidis, P. aeruginosa and S. epidermidis.

Table 7 Example of the template used to store the information
Source: Own Elaboration

Title	Phytochemical analysis, cytotoxic, antioxidant and anti-diabetic activities of the aerial parts of *Sorghum halepense.*
Year	2019
Authors	Shah, M. A. R., Khan, R. A., & Ahmed, M.
Abstract	The phytochemical screening, cytotoxic activity, total phenolic content, antioxidant and antidiabetic activity of Sorghum halepense methanolic extract and its different fractions were evaluated. The methanolic extract and its various fractions revealed the presence of reducing sugars, tannins, steroids, glycosides, flavonoids in the methanolic extract where they were absent in the n hexane fraction except flavonoids. Gums and saponins were absent in all samples. The methanolic extract indicated the highest cytotoxic (80.7 ± 1.3%) and anti-diabetic (62.5%) activities. The maximum contents of total phenols (28.7 ± 1.4 mg/mL) were found in the chloroform fraction. An aqueous fraction expressed the highest antioxidant activity with 74.1 and 97.1 % free radical scavenging properties in the DPPH and ABTS assays, respectively, while, in the case of H2O2, the methanolic extract indicated the highest activity (36.9 %). In conclusion, the extract of S. halepense aerial parts is a source of compounds against cancer, diabetes and free radical-associated disorders.

Table 8 Example of the template used to store the information
Source: Own Elaboration

Title	Flavonolignans and other phenolic compounds from *Sorghum halepense*.
Year	2010
Authors	Hongjuan Huang, Yan Liu , Qinghui Meng, Shouhui Wei, Hailan Cui y Chaoxian Zhang
Abstract	Eight compounds (1-7b) were isolated from the aerial parts of Sorghum halepense in the present investigation and five of them were reported for the first time from this species. The two rare diastereomeric flavonolignans tricin-4'-O-(treo-b-guaiacylglyceryl) ether and tricin-4'-O-(erythro-b-guaiacylglyceryl) ether are from the genus Sorghum for the first time. The chemotaxonomic significance of these compounds was summarised.

Table 9 Example of the template used to store the information
Source: Own Elaboration

Results

Sorghum halepense is a herbaceous weed (Sánchez & Manuel, 2022; Estrada-Castillón et. al., 2022), belonging to the Gramineae or Poaceae family. It is a perennial Gramineae of summer cycle with cosmopolitan distribution, generally found in dry areas, irrigation ditches, crop fields and wastelands (Khayal et. at., 2019). It is also known as johnson grass, aleppo sorghum, sorghillo, maicillo, canutillo, Russian grass and cañota (Leguizamón, 2019).

Chemical composition of Sorghum halepense.

The following results on the chemical composition of Sorghum halepense were obtained from the systematic review of this study:

Previous studies of Sorghum halepense led to the isolation of durrin, taxifolin, prunasin, sorgoleone, chlorogenic acid, p-coumaric acid, p-hydroxybenzaldehyde, p-hydroxybenzaldehyde alcohol, p-hydroxybenzoic acid, floroglucinol and aliphatic acids from the rhizome of Sorghum halepense (Nicollier et. al., 1983; Czarnota et. al., 2003).

The main chemical components of Sorghum halepense are sorgoleone and dihydrosorgoleone, which are visualised in figure 1 (Baerson *et al*., 2008).

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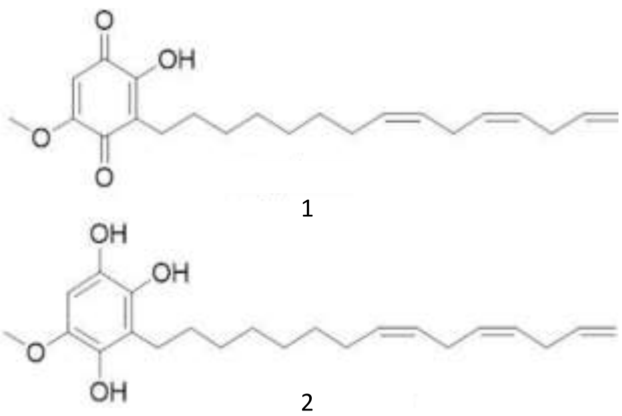

Figure 1 Sorgoleona (1) y dihidrosorgoleona (2)
Source: Glab et. al., 2017

Eight compounds were isolated from the aerial parts of Sorghum halepense, five of them are reported for the first time from this species, being tricin, luteolin, apigenin, salcholine A and salcholine B, the latter are shown in figure 2, while the rest are p-hydroxybenzaldehyde, p-hydroxybenzoic and p-hydroxycinnamic acids, in the research by Huang et. al. (2010).

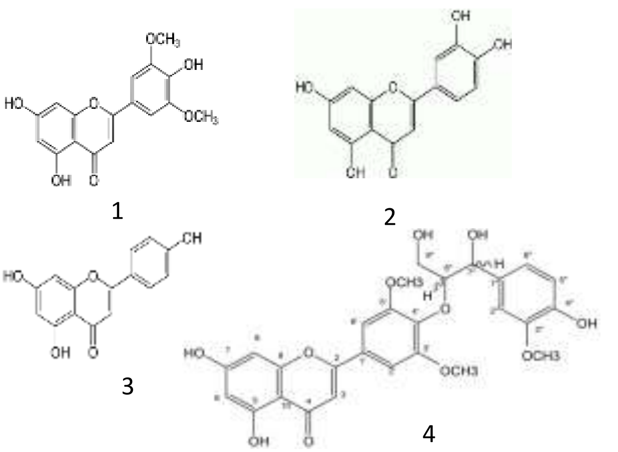

Figure 2 Compounds obtained from the aerial parts of Sorghum halepense, (1) tricin, (2) luteolin and (3) apigenin and (4) salcholine A and B
Source: Own elaboration

The flavonoids present in the leaves of Sorghum halepense that were found in the literature are shown in table 10.

Tricina	+
Flavona C-glucósidos	+
Luteolina	+
Apigenina	+
Apigiforol	+
Luteoforol	+

Table 10 Flavonoids in the leaves of Sorghum halepense (Tricin, Flavone C-glucosides, Luteolin, Apigenin, Apigiforol and Luteophorol)
Source: Harborne & Williams, 1976; Huang at. el., 2010

Six active substances were isolated from the chloroform fraction of the crude extract of Sorghum halepense, among which three phenolic compounds, ethyl p-hydroxybenzoate, p-hydroxybenzaldehyde and p-hydroxybenzoic acid, as well as three flavonoids, apigenin, luteolin and diosmethine, were found. On the other hand, from the ethyl acetate fraction, a cyanogenic compound, durrin, was found, these compounds can be observed in figure 3 (Liu *et al.*, 2011).

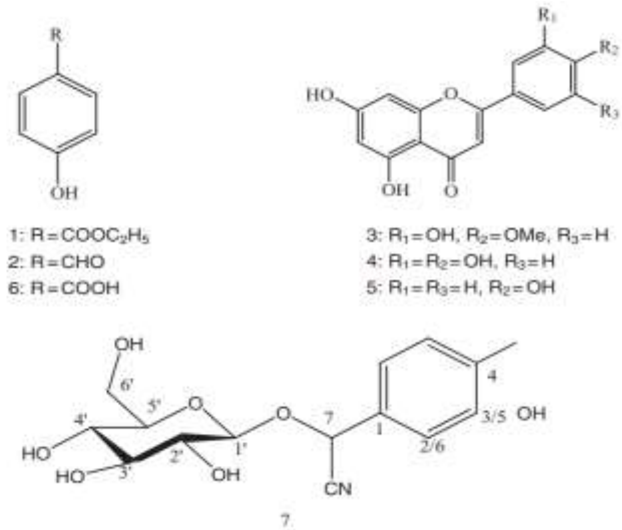

Figure 3 Chemical structures of the compounds isolated from the underground part of Sorghum halepense. 1, ethyl p-hydroxybenzoate; 2, p-hydroxybenzaldehyde; 3, diosmethine; 4, luteolin; 5, apigenin; 6, p-hydroxybenzoic acid and 7, durrin
Source: Liu et al., 2011

The content of eight essential and nine non-essential amino acids is reported, as shown in table 11.

Essential amino acids								
Ile	Leu	Lys	Met	Phe	Thr	Val	His	
2.5	7.4	1.9	2.3	3.1	3.0	4.3	1.6	
Non-essential amino acids								
Cys	Tyr	Arg	Ala	Asp	Glu	Gly	Pro	Ser
2.8	2.3	3.3	6.5	5.6	12.4	3.1	8.8	4.1

Table 11 Essential (isoleucine, leucine, lysine, methionine, threonine, phenylalanine, valine, histidine) and non-essential (cysteine, tyrosine, arginine, alanine, aspartic acid, glutamic acid, glycine, proline, serine) amino acid profile of Sorghum halepense leaves (g amino acids/100 g protein)
Source: Pérez-Gil et al, 2014.

Finally, Pérez-Gil *et. al*. also report in their study the vitamin content in Sorghum halepense panicles, as described in table 12.

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Gramineae	Thiamine	Riboflavin	Niacin
Sorghum halepense	0.79	1.2	1.9

Table 12 Vitamins in panicles of Sorghum halepense grasses (g kg-1 sample)
Source: Pérez-Gil et al, 2014

The research by Huang, Liu et. al. (2015) also mentions that Sorghum halepense root contains three phenolic compounds, p-hydroxybenzoic acid, p-hydroxybenzaldehyde and ethyl p-hydroxybenzoate, as well as two flavonoids, tricin and diosmetin, all of which are present at different growth stages.

Three rare natural products were isolated from the rhizomes of Sorghum halepense, including a new oxazolidinone named as 2,2-dimethyl-5-(4-hydroxyphenyl)-4-oxazolidinone and two derivatives of 4-hydroxymandelic acid, which are ethyl 4-hydroxymandelate and 4-hydroxymandelamide, these compounds are shown in figure 4 (Huang, Ling et. al., 2015).

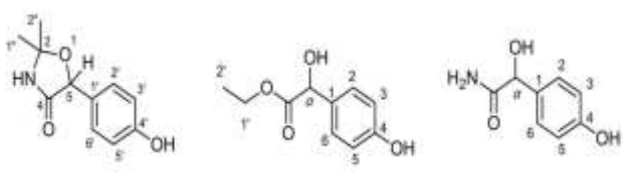

Figure 4 Compounds isolated from the rhizome of Sorghum halepense: (1) 2,2-dimethyl-5-(4-hydroxyphenyl)-4-oxazolidinone, (2) ethyl 4-hydroxymandelate, (3) 4-hydroxymandelamide
Source: Huang, Liu et. al., 2015

Phytochemical evaluation of the methanolic extract and its different fractions from the aerial parts of Sorghum halepense revealed the presence of several phytoconstituents, as well as reducing sugars, tannins, steroids, glycosides and flavonoids, all of which demonstrated cytotoxic, antioxidant and anti-diabetic properties (Shah, Khan & Ahmed, 2019). Sorghum halepense seed contains the bioactive compound p-cymene, the chemical structure of which is illustrated in Figure 5 (Banoon, 2020).

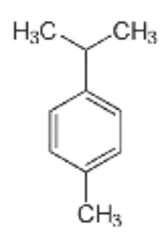

Figure 5 p-cymene compound present in the seeds of Sorghum halepense
Source: Own Elaboration

Uses and properties of Sorghum halepense

Figure 6 shows all the properties found through the literature review of Sorghum halepense.

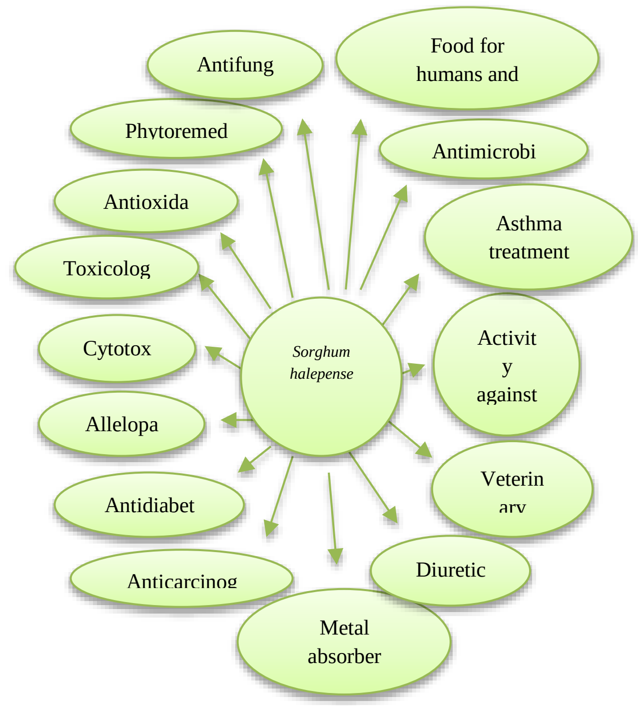

Figure 6 Various properties of *Sorghum halepense*
Source: Own elaboration

Sorghum halepense has a wide range of uses, including food, brewing, feed and fodder for livestock. Its grain is used in biscuits, unleavened bread and tortillas as a back-up in confectionery industries (Khayal et. at., 2019).

Sorghum halepense is a cyanogenic plant reported to cause poisoning. In many cases, the reports were of ingestion of cut or broken plant debris. In cyanogenic plants, cyanide is present in the form of glycosides, therefore, freshly cut or broken plant parts have free cyanide; moreover, they appear to be more palatable, favouring intoxication (Gerarldo Neto et. al., 2013). Reyes & Gudiño (1999) note that Sorghum halepense is abundant as an arvense in different regions of the country. However, it is also characterised by being toxic to cattle, sheep, horses and pigs, causing convulsions, foaming at the mouth, unconsciousness, emesis, increased respiratory rate, tachycardia, hypoxia, gait difficulties, respiratory paralysis and death. Bezerra et. al. (2012) also reported in their study that this weed not only causes intoxication in cattle, but also instability, muscle tremors, swelling, lateral decubitus and death.

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It is also characterised by its application in ethnoveterinary medicine, as an inducer of placental expulsion, in which the aerial part of the plant is used, as mentioned by Martínez & Jiménez (2017), as well as Ghasemi, Momeni & Bahmani (2013) mention that the leaves and stem of Sorghum halepense are administered externally to animals for abortion.

The aqueous extract obtained from the rhizome of Sorghum halepense is reported to contain allelopathic substances highly inhibitory to the germination of 'Santa Cruz' tomato (Lycopersicon esculentum) (Castro et. al.,1983). Studies by Acciaresi & Asenjo (2003) report that the allelopathic effect of Sorghum halepense rhizomes on the initial growth of wheat radicle is due to the leaching and decomposition of cyanogenic glycosides, tannins and phenolic acids.

The activity of crude extracts suggests that Sorghum halepense contains allelochemicals in the chloroform and ethyl acetate fractions (Liu *et al.*, 2011). Arshad et. al., (2012) reported that methanolic extracts of Sorghum halepense root and inflorescences possess antifungal properties. Khayal et. at. (2019) report in their research that crude extract of Sorghum halepense shows antibacterial activity against P.aeruginosa, K.pneumoniae, S.epidermidis, B.subtillus strains. The antimicrobial activity is possibly due to the presence of tannic acid and some phenolic compounds. On the other hand, crude extract, n-hexane fraction and chloroform fraction of Sorghum halepense are reported to exhibit antifungal activity against A. niger, A. fumigatus and A. flavus.

Hexane, ethyl ether and methyl alcohol extracts of Sorghum halepense induce cytotoxic effects on in vitro cultures of Chinese hamster ovary cells (Rodriguez et. al., 1990).

On the other hand, the leaves of this plant were recorded for the treatment of asthma, while the rhizomes as diuretic and anticarcinogenic (Tuzlacı & Erol,1999).

Due to the high content of phenolic compounds and good free radical scavenging properties of Sorghum halepense, this species represents a natural source of antioxidant agents (Gutiérrez et. Al., 2008).

The total phenolics and antioxidant activity of Sorghum halepense weed extracts are shown in table 13.

Plant species	Total phenols (mg/g)	IC50 (µg/ml)
Sorghum halepense	69,83±1,80	369,82 ± 1,01

Table 13 Total phenols and antioxidant activity of *Sorghum halepense*
Source: Avella, García & Cisneros, 2008.

Khayal et. at. (2019) also evaluated the antioxidant activity of crude extract, n-hexane, ethyl acetate and aqueous fractions of Sorghum halepense; the latter two showed excellent antioxidant activity; the chloroform fraction and crude extract did not.

The methanolic extract of Sorghum halepense rhizome is reported to be a valuable source of antioxidant and anti-diabetic compounds due to the presence of flavonoids, cardiac glycosides, terpenes, carbohydrates, steroids, alkaloids and proteins (Shah, Khan & Ahmed, 2021).

The alcoholic extracts of Sorghum halepense, exhibit potential biological activity due to their rich sources of elements that inhibit the generation of free radicals, which cause different diseases and, therefore, this plant can be used in the pharmaceutical industry in the design of drugs for the treatment of diseases related to oxidative stress (Fatima et. al., 2022; Butnariu et. al., 2012).

The seed of Sorghum halepense contains the bioactive compound p-cymene, this compound attributes to this weed the property of treatment against prostatitis (Banoon, 2020).

Conclusions

It can be concluded that the Sorghum halepense plant, despite being considered as one of the worst weeds worldwide, is also reported as a medicinal herb on the basis of its numerous therapeutic properties that this systematic review has demonstrated. It stands out as an environmentally acceptable, renewable and readily available plant.

Sorghum halepense has not been studied for corrosion inhibition purposes.

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Vitamins, steroids, saponins, alkaloids, reducing sugars, tannins, glycosides, flavonoids, phenols, terpenes, carbohydrates, and proteins, present in the leaves, aerial parts and rhizomes of Sorghum halepense, make it possible that this weed can be considered as a potential natural rust inhibitor.

This is due to the fact that these organic compounds contain in their molecular structure conjugated aromatic rings, long aliphatic chains, methoxyl, -OCH3, amino, -NH, hydroxyl, -OH groups, multiple bonds and N, O and S heteroatoms with free electron pairs. This could contribute to facilitate the adsorption of all these molecules on the metal surface, forming a protective layer and, therefore, the anticorrosive behaviour.

To confirm whether Sorghun halepense could be a potential natural corrosion inhibitor, it would be necessary to carry out tests to measure weight loss, electrochemical techniques of potentiodynamic polarisation curves (CPP), polarisation resistance, electrochemical impedance spectroscopy (EIE) and electrochemical noise (EN), among other evaluations.

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