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Potential of pineapple waste: Bioactive compounds and their biological significance in human health

Potencial de los residuos de piña: Compuestos bioactivos y su importancia biológica en la salud humana

Casas-Rodríguez, A.D.[1], González-Martínez, D.W.[1], C. Contreras, S.A.[1], Ascacio-Valdés, J.A.[1], Dávila-Medina, M.D.[1], Chávez-González, M.L.[1], Sepúlveda-Torre, L.[1*]

[1]Departamento de Investigación en Alimentos, Facultad de Ciencias Químicas Universidad Autónoma de Coahuila, Blvd. Venustiano Carranza and J. Cárdenas s/n, Col. Republica Oriente, 25280 Saltillo, México.

**Autor para correspondencia: leonardo_sepulveda@uadec.edu.mx*

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Resumen

El documento revisa el potencial de los residuos de piña como fuente de compuestos bioactivos y su importancia para la salud humana. Se resalta que la industria alimentaria genera grandes cantidades de residuos de piña, como cáscara, corazón y corona, los cuales contienen carbohidratos, proteínas, minerales, vitaminas y enzimas con efectos beneficiosos. Los compuestos bioactivos más relevantes identificados en los residuos incluyen polifenoles, taninos y bromelina. Estos presentan propiedades antioxidantes, antimicrobianas, antiinflamatorias, anticancerígenas y antidepresivas. La investigación destaca que estos compuestos pueden ayudar en la prevención de enfermedades crónicas y tienen aplicaciones en las industrias farmacéutica, alimentaria y cosmética. En términos de extracción, se han desarrollado diversas técnicas, desde métodos convencionales como maceración y Soxhlet hasta tecnologías emergentes como ultrasonidos y microondas. Se enfatiza la necesidad de optimizar estos procesos para una mejor obtención y aprovechamiento de los compuestos activos. Los residuos de piña han demostrado ser efectivos en la reducción del estrés oxidativo, la inhibición del crecimiento de bacterias y la modulación de respuestas inflamatorias. La bromelina, en particular, ha sido estudiada por sus efectos contra infecciones y enfermedades neurodegenerativas. Además, se ha encontrado que los extractos de piña pueden tener efectos antidepresivos al influir en los niveles de serotonina. En conclusión, la valorización de los residuos de piña representa una oportunidad para el desarrollo de productos funcionales y terapias naturales.

Palabras clave: Subproductos, polifenoles, antioxidante, antimicrobiano, antiinflamatorio.

Abstract

This document reviews the potential of pineapple waste as a source of bioactive compounds and its importance for human health. It highlights that the food industry generates large quantities of pineapple waste, such as peel, core, and crown, which contain carbohydrates, proteins, minerals, vitamins, and enzymes with beneficial effects. The most relevant bioactive compounds identified in the waste include polyphenols, tannins, and bromelain. These have antioxidants, antimicrobial, anti-inflammatory, anticancer, and antidepressant properties. The research highlights that these compounds can aid in the prevention of chronic diseases and have applications in the pharmaceutical, food, and cosmetic industries. In terms of extraction, various techniques have been developed, from conventional methods such as maceration and Soxhlet extraction to emerging technologies such as ultrasound and microwave extraction. The need to optimize these processes for better extraction and utilization of active compounds is emphasized. Pineapple waste has been shown to be effective in reducing oxidative stress, inhibiting bacterial growth, and modulating inflammatory responses. Bromelain has been studied for its effects against infections and neurodegenerative diseases. Furthermore, pineapple extracts have been found to have antidepressant effects by influencing serotonin levels. In conclusion, the valorization of pineapple waste represents an opportunity for the development of functional products and natural therapies.

Keywords: Subproducts, polyphenols, antioxidants, antimicrobial, anti-inflammatory.

INTRODUCTION

The pineapple (*Ananas comosus* L.) belongs to the *Bromeliaceae* family, which is made up of 46 genera and 2,000 species (Kavuthodi and Sebastian, 2018). It is one of the most produced fruits in the world, cultivated mainly in Indonesia (3,156, 576 ton in 2023), Philippines (2,944,260 ton in 2023), Costa Rica (2,937,807 ton in 2023), Brazil (2,387,tons per years), China Continental (2,093,596 ton in 2023), India (1,828,000 ton in 2023), Nigeria (1,615,622 ton in 2023), Nigeria (1,615,622 ton in 2023), Mexico (1,272,559 ton in 2023), Thailand (1,258,028 ton in 2023) and Colombia (853,169 ton in 2023) (Aili Hamzah et al., 2021; FAO. FAOSTAT).

However, in recent years the food industry has been growing and with it the demand for food, which has generated greater processing of fruits and vegetables; and the pineapple fruit is no exception since around 25 to 50% of waste is generated, corresponding to the peel, heart, crown and leaves (Banerjee et al., 2018; Kocakaplan et al., 2024; Sánchez-Hernández et al., 2015). This type waste generate great interest in recent years due to contain carbohydrates, proteins, cellulose, minerals, vitamins, enzymes and bioactive compounds that benefits to human health (Mohd Ali et al., 2020). To obtain bioactive compounds have been studied different methods, such as conventional ones (maceration or Soxhlet) (Dewi and Simamora, 2023; Muñoz Acevedo et al., 2021), technologies emerging (ultrasound or microwave) (Vargas-Serna et al., 2022; Zampar et al., 2022). As well as biotechnologies (fermentation in solid or liquid state) (Polania-Rivera et al., 2023).In accordance with the above, the objective of the present work was to analyze the bioactive compounds present in pineapple residues and their main biological activities, highlighting their application in the food, pharmaceutical and cosmetic industries, as well as their contribution to human health.

Pineapple (*Ananas comosus* L.)

The pineapple (*Ananas comosus* L.) is a plant belonging to the Bromaliaceas family, which can measure between 1 or 2 m in height. The fruit is made up of the stem, leaves, peduncle, fruit, crown and roots (León-Yáñez et al., 2019; Uriza-Ávila et al., 2018). This fruit is considered rich in flavor and aroma, as well as high nutritional value, depending on the variety of pineapple its characteristics vary (Vieira et al., 2022). For the pineapple to continue to have its characteristic flavors and smells, the geographical area, temperature, humidity, soil properties, as well as daily exposure to the sun, constant watering and an optimal pH must be taken into account (Lobo and Yahia, 2017; Uriza-Ávila et al., 2018).

Composition of pineapple waste and its benefits

Pineapple contains an important nutritional content, which gives the fruit its sweet and juicy properties, in addition to multiple benefits for human health; This can be attributed to the variety and the maturity of the fruit, as well as the climatic conditions and its proper management for harvest (Ajayi et al., 2022; Mohd Ali et al., 2020). Among the main components of pineapple are water (86g/100g), carbohydrates (13.12g/100g), proteins (0.54g/100g), lipids (0.12g/g), fibers (1.54g/100g), minerals (potassium 109mg/100g; magnesium 12mg/100g), and vitamin C (47.8mg/100g) (Uriza-Ávila et al., 2018).

It has been proven that pineapple waste (center, crown and peel) is also rich in carbohydrates, minerals, vitamins and bioactive compounds. Among the benefits of this fruit is that it has anti-cancer properties, is effective as a diuretic, eliminates intestinal worms, prevents ulcers, helps reduce lipids (Banerjee et al., 2018), cardiac oxidative stress, helps constipation and gastrointestinal function, in addition to being antiarthritic, lipid-lowering, antidiabetic (Uriza-Ávila et al., 2018), also having certain benefits in regulating emotional stability (Nurrahma et al., 2024), anti-malarial and anti-inflammatory (Ajayi et al., 2022; Kargutkar & Brijesh, 2018) (Figure1). It has been described that bromelain can treat bacterial infections, bronchitis, pneumonia, sinusitis, parasitic gastrointestinal infection (Mohd Ali et al., 2020).

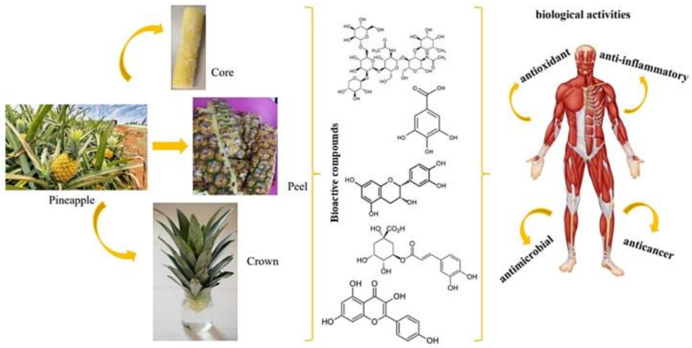


Figure 1. Graph of pineapple bioactive compounds and their biological activities.

Pineapple peel

Within the processing of pineapple, around 25 to 50% of waste is generated and among them is pineapple peel (Sánchez-Hernández et al., 2015). It has been shown that the peel has a high nutritional value, including sugars such as sucrose, glucose and fructose, organic acids, minerals, cellulose, bioactive compounds, among others (Lourenço et al., 2021).Various vitamins such as C, A, and E have been found, as well as carotenoids, oils, fatty acids, hemicellulose (Rico et al., 2020). Although bromelain is the main enzyme in pineapple waste, cellulase, xylanase and pectinase have also been found (Meena et al., 2022a).

Pineapple core

The heart of the pineapple represents around 15% of the pineapple fruit, according to what was studied by (Kodagoda & Marapana, 2017).The proximal analysis of the heart of the pineapple is composed of moisture content (84.90 ± 0.23%), crude protein (3.67 ± 0.05 g/100 g), fat (2.35 ± 0.15 g/100g), crude fiber (9.14 ± 013 g/100g), ash (1.70 ± 0.15 g/100g), carbohydrates (83.03 ± 0.32 g/100g) and minerals such as potassium (247.70 ± 32.80 mg/100g), calcium (8.73 ± 0.34 mg/100g), iron (1.61 ± 0.23 mg /100g) and manganese (1.63 ± 0.54). They also contain various enzymes, such as bromelain, β-glucosidase, cellulase, among others (Banerjee et al., 2018; Paz-Arteaga et al., 2023b). It has been determined that the core of the pineapple has a higher content of glucose and fructose, as well as vitamin C (Polanía et al., 2023). The core of the pineapple is one of the most important wastes since bromelain and fiber are obtained, since it has various applications (Fissore et al., 2023).

Pineapple crown

The crown represents around 2.7 to 5.9% of the fruit (Polanía et al., 2023). The proximal composition of pineapple is composed of protein (0.7%), ash (7.37%), crude fat (3.5%), rough fiber (62.5%) (Baidhe et al., 2021). A composition of carbon (39.50%), hydrogen (5.51%), nitrogen (13.82%) and sulfur (0.46%) has been found, as well as various enzymes such as bromelain and cellulase (Yazid and Roslan, 2020). The pineapple crown is one of the wastes that contains the most fiber, which is why within the paper industry it is a promising waste. The proximal composition of pineapple is composed of protein (0.7%), ash (7.37%), crude fat (3.5%), rough fiber (62.5%) (Baidhe et al., 2021). Table 1 shows the physicochemical composition of different pineapple waste.

Bioactive compounds

It is considered a "bioactive component or compound" of a food, that which brings a health benefit further beyond the considered rated, such as improvement in biological functions or reduction in the risk of suffering from a disease (Polanía et al., 2023). In recent years there has been great interest in fruits and vegetables because they contain this type compounds beneficial for health, likewise, it has been shown that their waste contain in a percentage of bioactive compounds, which is why they have been of interest for study since it has been proven that they can be extracted biomolecules of great value (Kainat et al., 2022; Patra et al., 2022).

Polyphenols

Bioactive compounds known as polyphenols are secondary metabolites that are found mainly in the covering layer of plants and are characteristic for their structures, since they can contain one or more aromatic rings that are linked to hydroxyl groups (Montenegro-Landívar et al., 2021; Nordin et al., 2023). Polyphenols are divided into 5 main groups which are phenolic acids (hydroxybenzoic acids and hydroxycinnamic acids), stilbenes, lignans, flavonoids (flavonoids, isoflavones,

Table 1. Physicochemical composition of pineapple waste.

Pineapple waste	Moisture (%)	Total Sugar (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Reference
Peels	88.40	82.27	8.86	1.89	1.01	1.81	Kumaresan et al., 2025
Peel	81.12	35.57	10.73	11.11	9.05	13.37	Umesh et al., 2023
Peel	3.94	73.30	3.98	4.20	2.53	12.05	Mala et al., 2024
Core	94.60	4.30	0.60	0.10	0.40	-	Mardawati et al., 2023
Core	6.49	53.83	2.19	3.79	1.47	1.26	Malini et al., 2024
Crown	-	-	0.40	4.20	-	-	Awasthi et al., 2022
Crown	9.25	75.70	5.85	7.61	1.86	-	Brito et al., 2020
Leaves	81.60	-	1.10	-	-	-	Awasthi et al., 2022
Pomace	8.39	31.24	2.33	4.88	2.16	51.00	Meena et al., 2022b
Pomace	4.11	61.81	2.01	5.15	0.84	23.27	Buvaneswaran et al., 2023

anthocyanins, flavanones, flavones, flavonols) and tannins, which is divided into two large groups the condensed and hydrolyzable (Li et al., 2023). Polyphenols have been of great interest in research since their functions benefit human health, this is due to their biological activities such as antioxidant, antimicrobial activity (Valencia-Avilés et al., 2017), antidiabetic and anti-inflammatory (Abbas et al., 2017).

Polyphenols found in pineapple waste

Phenolic Acids

The phenolics acids (PA) they are divided into two groups: hydroxybenzoic acids, which are derivatives of benzoic acid (figure 2a), its structure includes a C6-C1 carbon back bone with methoxylations and hydroxylations in the aromatic ring, and hydroxycinnamic acids; which are derived from cinnamic acid (figure 2b), are characterized by having nine carbons in their structure and a side chain double bond with a cis or trans configuration (Caruso et al., 2022; Kumar and Goel, 2019) The PA they are small molecules that they originate from shikimic and benzoic acids, characterized for having a phenolic ring and a group of acid carboxylic.

Likewise, they are known as secondary metabolite that impart the organoleptic characteristics of foods whether they have sweet or sour flavors (Liu et al., 2020; Rashmi and Negi, 2020; Spiegel et al., 2020). It has been shown that PA have properties important biological properties such as anti-inflammatory, anti-cancer, antimicrobial, antiallergic, antiviral, among others (Kumar & Goel, 2019). The PA common in pineapple waste, ferulic acid has been found, the *p*-hydroxybenzoic acid, chlorogenic acid, *p*-cumaric acid, caffeic acid, , ferulic acid, sinapic acid, in peel and crown (Mala et al., 2024; Sepúlveda et al., 2018).

In the pineapple pulp and waste it has been found, syringic acid, tannic acid, *p*-cumaric acid (Hikal et al., 2021; Segovia-Gómez and Almajano-Pablos, 2016; Vargas-Serna et al., 2022). It has been proven that the stem also contain a variety of phenolics acids, such as gallic acid, chlorogenic acid, *p*-hydroxybenzoic acid, caffeic acid and ferulic acid (Campos et al., 2020). In the pineapple leaves, ferulic acid (Tang and Hassan, 2020).

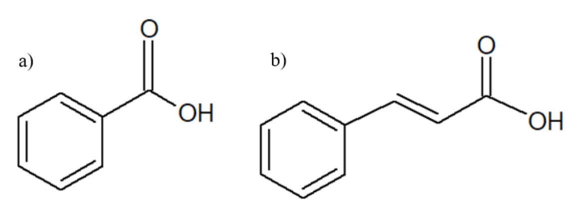
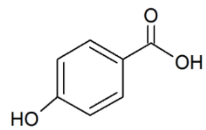
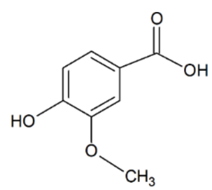
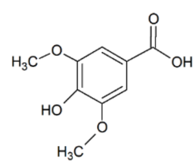
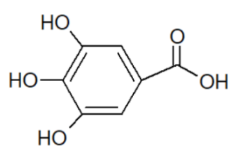
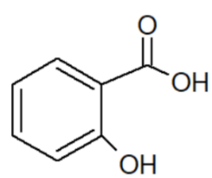
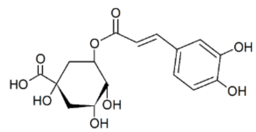
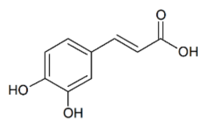
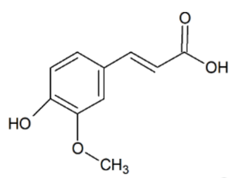
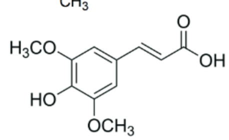


Figure 2. Base structure of the a) hydroxybenzoic and b) hydroxycinnamic acids.

In table 2, you can observe the structures of some PA found in pineapple waste, these have been of great interest since they have various applications both in the food, cosmetic or pharmaceutical industry.

Table 2. Structure of phenolic acids found in pineapple waste (peel, core and crown).

Phenolics acids	Chemical Structure	Applications	Reference
p-Hydroxybenzoic acid (PHBA)		Manufacture of pharmaceutical for brain disease. Improvement in the intestinal microbiota.	(Zhang et al., 2013; Han et al., 2022)
Vanillic acid		Pharmaceutical industry due to its anticancer, anti-inflammatory, antioxidant and other activities.	(Matejczyk et al., 2024)
Syringic acid		Food packaging manufacturing Pharmaceutical potential due to its antioxidant, anti-inflammatory and antitumor activity.	(Huang et al., 2024; Da Silva et al., 2023)
Gallic acid		Edible film manufacturing Used as a dietary supplement	(Bhatia et al., 2022; Xiang et al., 2024; Bilawal et al., 2021)
Salicylic acid		Pharmaceutical potential Potential preservative in food Used as a biostimulator for crops	(Chen et al., 2023a; Chen et al., 2023b)

Chlorogenic acid		Used in pharmaceuticals to combat various diseases Used for skin care	(Nguyen et al., 2024; Rodrigues et al., 2023)
Caffeic acid		Used for skin care Has potential use in combating COVID-19 Potential use in reducing food allergenicity	(Rodrigues et al., 2023; Taysi et al., 2023; Pi et al., 2023)
Ferulic acid		Used in cardiovascular and cerebrovascular diseases Feed for different animal species.	(Zhang et al., 2021; Zheng et al., 2024)
Sinapic acid		Used as a drug, due to its potent biological activities	(Pandi & Kalappan, 2021)

Flavonoids

Flavonoids originate from the phenylalanine and melonyl-CoA pathway. They are composed of a diphenyl-propane backbone containing a benzene ring linked to a pyrone ring and finally to a phenyl ring in position 2 or 3. Flavonoids are classified into various groups, including flavones, flavanols, flavanones, chalcones, anthocyanins, and isoflavones (Figure 3)(Alseekh et al., 2020; Li et al., 2023; Pei et al., 2020).

Other characteristics of flavonoids are that they may contain glycosidic centers (C) and *O*-glycosides, depending on the union of the sugar (Satari et al., 2021). Currently they have been of great interest, since they have properties beneficial such as a potential antioxidant, antivirals, anti-inflammatory, anticancer, and antibacterial (Dobrzynska et al., 2020; Ravula et al., 2021). It has been proven that flavonoids can be used therapeutically, combating depression, dementia, lupus and even heart disease (Satari et al., 2021).

In another research work studied three types pineapple (smooth cayenne, Tainung 17 and Tainung 19), where using the pulp, peel and stem, for the quantification of flavonoids, the extracts were obtained from 5 g of the waste in 50 mL of ethanol and another extraction with 50 mL of water and kept stirring for 1 h, it was shown that the ethanolic extracts obtained a higher yield than aqueous ones (7.8 to 15.0 µg RE/mg and from 5.64 to 23.5 µg RE/mg, respectively) (Huang et al., 2021).

Currently, pineapple waste continues to be studied to be used as food ingredients functional, they made the characterization of pineapple peels to be used as an ingredient for crackers, showed that they contained a total flavonoid concentration of 267.97 mg QE/100 g, and antioxidant activity (Mala et al., 2024). Pineapple residues contain: flavones, isoflavones, flavanols, flavanones, quercetin, quercetin dihydrate, epicatechin gallate, quercetin-3-glucuronide, diosmin, kaempferol and catechin. (Mohsin et al., 2020; Sayago-Ayerdi et al., 2021; Suleria et al., 2020).

Condensed tannins

Condensed tannins or proanthocyanidins (Figure 4) are oligomers or polymers of flavan-3-oleyes. Condensed tannins has two homocyclic aromatic rings (A and B) present and a heterocyclic ring (C) (Li et al., 2023; Smeriglio et al., 2017). These compounds have a high molecular weight and can react with aldehydes. In addition to interacting with proteins and carbohydrates through hydrogen bonds (Das et al., 2020; Valencia-Hernandez et al., 2021).

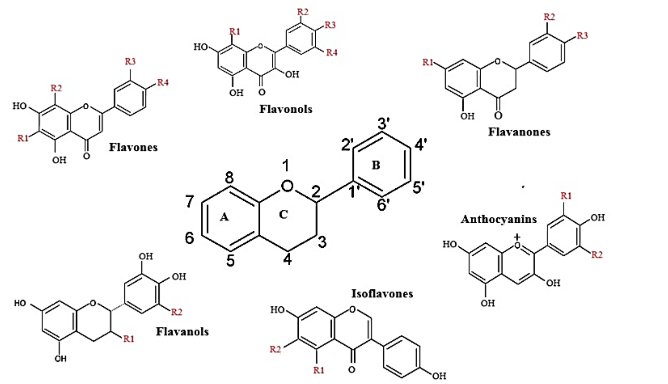
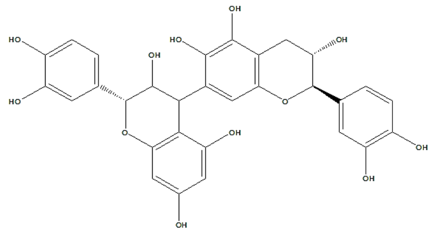


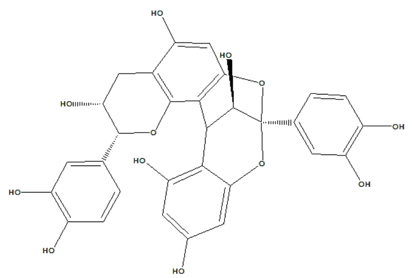
Figure 3. Structure of flavonoids (structures obtained in PubChem, 2025).

Proanthocyanidins are classified into two types: type A, which are characterized by an additional bond between C2 – C7 of the basic units of condensed tannin and the types B, with additional links between C4 – C4, and although it is not very common also links between C4 – C6 (Smeriglio et al., 2017; Valencia-Hernandez et al., 2021; Watrelot and Norton, 2020). The most common procyanidins include epicatechin and epigallocatechin (Smeriglio et al., 2017). Condensed tannins are the most abundant compared to hydrolyzable tannins; these are generally found in fruits, vegetables, stems, legumes, trees, and flowers (Sharma, 2019).

The condensed tannins have been of great interest since they have antioxidant, antibacterial, antiviral, antiparasitic, anti-inflammatory and antidiarrheal activity (Tong et al., 2022). Others benefits of condensed tannins is that they can reduce blood pressure, as well as improve the coagulation process (Sarkar et al., 2021). A recent study, the solid state fermentation process using *Rhizopus oryzae* was evaluated, the authors concluded that the pineapple peel is a potential source of condensed tannins (Polania-Rivera et al., 2023).



Procyanidin B1



Procyanidin A2

Figure 4. Examples of chemical structure of condensed tannins.

Bromelain

Bromelain (Figure 5) belongs to the group of proteolytic enzymes, being one of the most studied of this group, it is mainly found in plants of the Bromeliaceae family (Varilla et al., 2021). This enzyme is known as protease, which breaks down proteins by cutting the amino acid chains (Chakraborty et al., 2021).

Bromelain include other components such as glycosidases, phosphatases, ribonucleases, cellulases, proxidases and glycoproteases, these are in different proportions, depending on different factors such as the location of the fruit, the soil, weather conditions, extraction method and depending on the part of the pineapple, as well as with a pH of 6 to 7 (stem) and pH 3 to 8 (in the fruit) (Colletti et al., 2021; Hikisz and Bernasinska-Slomczewska, 2021).

The bromelain is still being investigated since it has been found to have important biological properties such as anti-inflammatory, antidiabetic, and anticancer., cardioprotective, immunomodulatory, antioxidants (Hikisz & Bernasinska-Slomczewska, 2021; Kumar et al., 2023). During the pandemic, it was shown that bromelain inhibits the infection of VeroE6 cells by SARS-CoV-2 (Kritis et al., 2020; Tallei et al., 2021). They have been demonstrated that bromelain has beneficial effects in reducing neurotoxicity through antioxidant effects against Alzheimer's (Eraky et al., 2023; Kumar et al., 2022).

It has been proven that bromelain combined with antibiotics more effective in relieving various infections such as rhinosinusitis, bronchitis, pneumonia, sinusitis, infections rectal, of the urinary tract and of the respiratory tract (Locci et al., 2024). The bromelain used in the food, brewing, meat processing, textile, and cosmetic industries because it has low toxicity, is well absorbed by the body, and maintains its biological activity (Hikisz and Bernasinska-Slomczewska, 2021; Varilla et al., 2021).

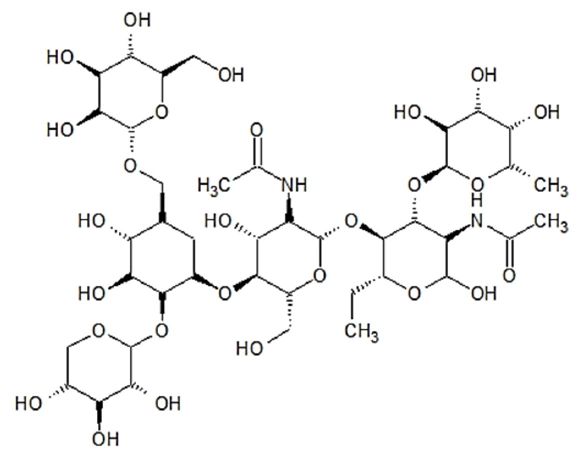


Figure 5. Chemical structure of bromelain.

Biological activities of bioactive compounds found in pineapple waste

Antioxidant activity.

Antioxidant compounds have been of great importance for human health, this is because oxidative stress in cells is related to a wide range of diseases such as cancer, cardiovascular, diabetes or neurodegenerative diseases (Martí-Quijal et al., 2021). The antioxidant capacity is known for its ability to inhibit oxidative degradation, acting mainly against free radicals, due to this the antioxidant compounds are divided according to their reaction mechanism, first are the primary antioxidants, which come from the formation of free radicals; the secondary ones, which inactivate the free radicals already formed and finally the tertiary antioxidants, which repair oxidative damage (Huet-Breña, 2017).

For the compounds to have efficient antioxidant activity, various factors must be taken into account, such as structural properties, temperature or the characteristics of the substrates (Munteanu and Apetrei, 2021). Among the most used tests for determination of antioxidant activity is ABTS (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)), DPPH (2,2-diphenyl-1-picrylhydrazyl) and FRAP (Ferric ion Reducing Antioxidant Power), which are based on the transfer of electrons (Christodoulou et al., 2022).

On the other hand, characterize the bioactive compounds from the peel, core and crown of the pineapple using ultrasound extraction methods The DPPH assay was carried out for the determination of antioxidant activity, giving the best crown extracts were tested at 50% ethanol determined that the 3-methylglutaric acid compounds, threonine, valine and α-linolenic acid, contributed to the antioxidant activity (Azizan et al., 2020). In table 3, some bioactive compounds are observed found in pineapple waste that have activity antioxidant.

Antimicrobial activity

Antimicrobial activity consists of the inhibition of microorganisms that can affect food, vegetables, water, among others (Gunwantrao et al., 2016). Antimicrobial activity is attributed to the chemical interference of bioactive compounds with the synthesis or vital function of the bacteria.

Bioactive compounds, have been studied to use as antimicrobial agents to inhibit bacteria which can grow in the food; as the food is very susceptible to contamination from gram-negative or gram-positive bacteria (Fouda-Mbanga & Tywabi-Ngeva, 2022), such as *Listeria monocytogenes*, *Escherichia coli* (Kumariya et al., 2019), *Pseudomona aeruginosa,* and *Staphylococcus aureus* (Vaou et al., 2021).

Different methods have been studied to determine this activity, among which are disk and well diffusion tests, one of the most used techniques because it is low-cost and simple, and the vial cell counting method, which is generally used to evaluate antimicrobial efficiency (Abdollahzadeh et al., 2021).

Recent studies have shown that extracts of the waste of pineapple are effective to act as antimicrobial agents, extracts contain bioactive compounds that one effective in inhibiting bacterial growth. In table 4 we can see different examples of obtaining extracts from pineapple waste, which have antimicrobial activity. Not only bioactive compounds have proven to be an effective source of antimicrobial effect, but also the characteristic proteolytic enzyme of pineapple (Bromelain) since its non-stick capacity prevents bacteria from adhering to the surface, thanks to the functional groups. which contains bromelain (Agrawal et al., 2022; Gupta, 2022).

Anti-inflammatory activity

The inflammation it is an immune response when an infection or injury occurs in the body, and this is divided into two, the first is the acute one, which occurs immediately after injury and lasts only a few days, while the second is the chronicle and this it is longer lasting (Goh et al., 2022; Moreno-Ley et al., 2021). In turn, is something complex since different processes are involved, such as the migration of leukocytes, activating factor platelet, among others (Oliveira et al., 2022). To carry out the deflating process have been treated mainly with steroidal or non-steroidal anti-inflammatory drugs (Hou et al., 2020).

There is a wide variety of ointments and drugs, however, nowadays the treatments applied for muscular or gastrointestinal inflammation are more natural. For example, some authors studied pineapple peel extracts, demonstrating anti-inflammatory activity significant in reducing exudate formation, inflammatory cell count, and levels of nitrite, tumor necrosis factor alpha, and interleukin-6 (Ajayi et al., 2022). On the other hand, evaluated the process of fermentation in state solid with *Lactobacillus plantarum*, *L. rhamnosus* and *Aspergillus oryzae,* using pineapple peel as a substrate, to obtain bioactive compounds with anti-inflammatory activity. The authors concluded that pineapple extracts are a promising source of compounds with anti-inflammatory activity (Ortega-Hernández et al., 2023).

Table 3. Activity antioxidant of bioactive compounds from pineapple waste.

Part of the pineapple	Extraction method	Main Compounds	Results	Reference
Crown	Solvent extraction	*p*-coumaric acid ferulic acid 4-hydroxybenzaldehyde	DPPH: 244.7; ABTS: 467.8; FRAP: 762.6 µgTE/g	(Brito et al., 2021)
Peel	Soxhlet, supercritical fluids, solvent extraction	Ferulic acid	DPPH: 45%	(Madhumeena et al., 2021)
Peel	Solid state fermentation	Gallic acid Chlorogenic acid Caffeic acid Cinnamic acid	DPPH: 59.76 % ABTS: 73.66 %	(Polania-Rivera et al., 2023)
Peel	Maceration	Catechin Acidvinyl Synaptic acid	DPPH: 2,364.08 mg Trolox/100 g FRAP: 1,365.14 mg $FeSO_4$/100g	(Mala et al., 2024)
Peel and core	Maceration	Total phenolic	DPPH: 34.80–36.45 µmol Trolox.g $^{-1}$ dry matter FRAP: 25.60–27.09 µmol Trolox.g $^{-1}$ dry matter ABTS: 41.43–42.19 µmol Trolox.g $^{-1}$ dry matter dry	(Santos et al., 2021)
Peel Bagasse	**S**upercritical fluid extraction (SFE) Pressurized liquid extraction (PLE)	Caffeic acid Ferulic acid	SFE: ABTS 0.15-3.38 µM TE/g dw FRAP: 0.85-11.17 µM TE/g dw PLE: ABTS 9.09-57.93 µM TE/g dw FRAP 11.28-56.03 µM TE/g dw	Maia and Fasolin, 2025
Peel	Microwave assisted extraction	Total phenolic Total flavonoid	DPPH: 68-84 % (inhibition)	Harith et al., 2023

Peel	Ultrasound assisted extraction	Gallic acid Syringic acid Caffeic acid Coumaric acid Ferulic acid	ABTS: 0.020 µM Trolox/g DPPH: 0.025 µM Trolox/g	Zampar et al., 2022

Table 4. Pineapple waste extracts with antimicrobial activity.

Pineapple waste	**Extraction Method**	**Compounds**	**Methodology**	**Studied Pathogen**	**Results**	**Reference**
Peel	Maceration, etahanol and methanol extracts	Gallic acid Catechin Epicatechin Ferulic acid Quercetin Kaempferol	Agar diffusion (at two extract concentrations, 75 mg/mL and 40 mg/mL) Minimum Inhibitory Concentration (MIC)	*Bacillus cereus,* *S. aureus,* *E. coli,* *Salmonella typhimurium*	The highest zone of inhibition at 75 mg/mL was obtained against *E. coli*, reaching ± 21.0 mm. MIC: 0.62 mg/ml methanol extracts and 1.25 mg/mL ethanol extracts against *B. cereus.*	(Jatav et al., 2022**)**
Peel	Maceration, methanol extracts of 70%	Flavonoids, tannins, alkaloids and phenols	Agar diffusion, with different concentrations of extract (0 ppm, 500 ppm, 1000 ppm, 1500 ppm, 2000 ppm)	*B. subtilis*, *E. coli* and *Candida albicans*	The 2000 ppm conc. showed the highest percentage against *C. albicans* (7.5 ± 0.17 mm)	(Dewi and Simamora, 2023)
Peel Stem Heart	Maceration extracts with distilled water	-	Agar diffusion Minimum Inhibitory Concentration (MIC)	*Aeromonas hydrophila*	Inhibition zone: 7.96 ± 0.20 mm and MIC: 125 mm/L	(Khumsrisuk et al., 2022)
Peel and crown	Solid-state fermentation	Chloretin 2'-*O*-xylosyl-glucoside Feruloyl tartaric acid	Minimum Inhibitory Concentration (MIC)	*S. aureus* and *L. monocytogenes*	Effective against *S. aureus* and *L. monocytogenes*, with MIC: 50 mg/mL and 12.5 mg/mL, respectively	(Paz-Arteaga et al., 2023a)

Peel	Soxhlet (extracts with, petroleum ether, ethyl acetone, etganol water, tetracycline y DMSO)	-	Agar diffusion	*S. aureus, E. coli P. aeruginosa , Vibrio cholera Klebsiella pneumoniae*	*P. aeruginosa with* tetracycline (24 ± 0.15 mm) *S. aureus* with ethyl acetate (16 ± 0.08 mm) *E. coli* with ethyl acetate (20 ± 0.12 mm) *V. cholerae* with ethyl acetate (20 ± 0.12 mm) *K. pneumoniae* with ethyl acetate (16 ± 0.08 mm)	(Lubaina et al., 2019)
Peel, stem, peel core and crown	Maceration (extracts with sodium acetate buffer)	Bromelain	Minimum Inhibitory Concentration (MIC)	*S. aureus* and *P. acne*	*P. acne* was found susceptible against the purified fractionates at concentrations as low as 19 lg/ml of the fruit extract	(Abbas et al., 2021)

Not only the extracts methanolic or ethanolic have been shown to be effective for significant inflammatory activity, but bromelain has also been shown to have anti-inflammatory properties. However, the molecular mechanisms underlying its anti-inflammatory effects are not well understood. Some authors investigated the effects of crude and purified bromelain on lipopolysaccharide-induced inflammation in macrophages RAW 264.7. The bromelain pretreatment reduced proinflammatory cytokines and mediators, which were related to the downregulation of iNOS and COX-2 expressions (Insuan et al., 2021). Another research evaluated the anti-inflammatory activity of bromelain from pineapple stem powder in a cream preparation. It observed its in vitro stability, optimizing three different cream formulas to determine the most stable one. The anti-inflammatory test showed a stable concentration of 34.41%, 32.06% and 37.82%, indicating that the pineapple stem powder has moderate anti-inflammatory activity (Masbagusdanta et al., 2020).

Anticancer activity

Cancer is one of the diseases furthermore such throughout the world, this is mainly due to genetic mutations as well as various anticancer agents that influence cell functions (Kurniawan et al., 2021). Treatments against cancer are generally divided into pharmacological therapy and non-pharmacological therapy, such as chemotherapy. However, it has several adverse effects (Chen et al., 2020; Kciuk et al., 2023).

That is why they are looking for other alternatives such as bioactive compounds, since it has been shown that various compounds help fight various types of cancer. It has been shown that the bromelain and flavonoids that contain pineapple, have anticancer activity by inducing apoptosis in cancer cells through p53 induction mechanisms, upregulation of Bcl-2, which is an antiapoptotic protein, upregulation of Bax, which is a proapoptotic protein, induction of caspases, decreases the expression of COX2 and regulates the MAPK and Akt/PKB pathway to inhibit the NF-kB pathway (Nida & Haryoto, 2022).

The effectiveness of bromelain (extracted from pineapple peel and crown) was evaluated against two breast cancer cell lines (MDA-MD 231 and MCF-7), in addition to evaluating the anti-inflammatory effect (against the COX-2 gene). The results of the present article indicate that bromelain (at a concentration of 200 µg/ml), had a significant effect in reducing cell viability in the cancer lines studied; furthermore, it was observed that bromelain induced apoptosis and reduced the expression of the COX-2 gene, suggesting its potential as an anticancer and anti-inflammatory agent (Mohamad & Sedrah, 2023).

Antidepressant activity

Depression is a global health disease which affects one in ten people; this disease can affect behavior, motivation, thoughts, feelings, among other emotional factors (Chen et al., 2022; Singh et al., 2021). Depression is associated with oxidative stress levels, since if there is an excess of these molecules, it produces damage causing nervous inflammations, thus causing depressive states (Black et al., 2015).

Currently, different drugs (fluoxetine, sertraline, paroxetine among others) have been used to combat depression, however, the drugs have been found to have undesirable side effects (Rakib et al., 2020). Therefore, new alternatives are sought for the creation of new antidepressants, which do not become harmful to health, in a study it was demonstrated that methanolic extracts of pineapple peel are effective in combating depression, reducing the inactivity time of rats during tail suspension tests. Dosing (3.25, 7.5 and 15 mg/kg) produced an increase in active behavior, suggesting improved motivation and reduced despair, thus promoting healthier alternatives to traditional medications (Kafeel et al., 2016).

In a more recent study, the effect of pineapple (*Ananas comosus*) pulp on lipopolysaccharide (LPS)-induced depressive behaviors in rats was investigated. Pineapple pulp was administered for 28 days prior to LPS injection, resulting in a reduction in immobility time and an increase in serotonin levels. The findings suggest that pineapple pulp may have antidepressant properties by enhancing tryptophan availability (Nurrahma et al., 2024).

CONCLUSION

This document highlights the valorization of pineapple waste, emphasizing its richness in bioactive compounds such as polyphenols, tannins, and bromelain. These compounds possess diverse biological activities, including antioxidant, antimicrobial, anti-inflammatory, anticancer, and antidepressant properties. The review highlights the potential of these compounds in the prevention of chronic diseases and their application in the pharmaceutical, food, and cosmetic industries. This work lays a solid foundation for future research into the characterization and use of these bioactive compounds in the development of natural therapies and functional products.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data availability

No data was used for the research described in the article.

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