Bioactive compounds and potential applications of *Aloe vera* (l.) in the food industry

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Keywords:

Aloe vera (L.)
Chemical composition
Bioactive compound
Food industry

Article history:

Received 15.05.2023
Received in revised form 19.09.2023
Accepted 29.12.2023

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DOI:
10.24263/2304-974X-2023-12-4-6

Abstract

Introduction. The purpose of the review is to characterize the bioactive compounds present in *Aloe vera* and to consider the possibilities of its application in the food industry.

Materials and methods. Data collection involved searching multiple databases, including Google Scholar, ScienceDirect, PubMed, SpringerLink, and Wiley Online Library. The search queries encompassed a wide range of terms, such as bioactive compound; *Aloe vera*; potential application of *Aloe vera* in the food industry; anti-inflammatory, antioxidant, anti-bacterial, anti-fungal, antiviral, and antiseptic properties of *Aloe vera*'s bioactive compounds.

Results and discussion. The discussion outlines the chemical composition, bioactive compounds of *Aloe vera* plant; and potential applications of *Aloe vera* in the food industry. *Aloe vera* is rich in various components, including polysaccharides (55%), sugars (17%), minerals (16%), proteins (7%), lipids (4%), and phenolic compounds (1%). This plant contains numerous bioactive compounds such as flavonoids, phenolic acids, tannins, mono- and polysaccharides (mannose-6-phosphate, acemannan and glucomannan), polyphenols, coumarin, proanthocyanidin, alkaloids, anthraquinone derivatives, aloe-emodin, aloin, aloesin, saponin, chromones, β- carotene, vitamin C, vitamin E, enzyme bradykinase, and steroids, making it a valuable pharmaceutical and cosmetic raw material. Aloe vera demonstrates diverse health benefits having emollient, purgative, anti-inflammatory, antioxidant, antimicrobial, anti-helmenthic, antifungal, and antiseptic properties. Depending on the purpose of using, leaves of *Aloe vera* could be processed by whole-leaf processing, mechanically filleted or manual filleted processing to obtain *Aloe vera* gel. After that, the gel could be used for production of juice, concentrate and powder products. The products of *Aloe vera* are natural functional ingredients or additives for the fortification of food products from vegetable sources to improve food quality, prolong the shelf life of vegetables and fruits, improve acceptability of food, enhance the growth of probiotics cultures, and could be also used in the pharmaceutical and cosmetic industries. The main areas of *Aloe vera* applications in the food industry include edible coatings production, fruits preservation, and beverages, dairy, confectionary, and sport nutrition products processing.

Conclusion. The products from *Aloe vera* plant and its bioactive compounds can act as a promising human health, prolong the shelf life of vegetable and fruits, and enhance the growth of probiotics cultures. Safety should be considered when using *Aloe vera* products.

Introduction

Plants produce a wide array of chemical compounds to support their growth and development. These compounds can be broadly categorized into primary and secondary metabolites. Primary metabolites are directly involved in essential processes like photosynthesis, translocation, and respiration. On the other hand, secondary metabolites are smaller organic molecules derived from primary metabolites and are typically around 3000 daltons in molecular weight (Twaij and Hasan, 2022). Secondary metabolites can be classified into four major classes: terpenoids, phenolic compounds, alkaloids, and sulphur-containing compounds (Guerriero et al., 2018). These secondary metabolites play a crucial role in plants and have various beneficial properties for humans. They are known for their antioxidant, anti-inflammatory, antimicrobial, anticoagulant, antidiabetic and lipid-lowering properties (Teoh, 2015). Specific compounds found in plants, such as flavonoids including chalcones, flavones, flavanols, flavanones, anthocyanins, and isoflavones; phenylpropanoids, which are involved in the production of essential aromatic amino acids such as phenylalanine and tyrosine; terpenes with antitubercular and anticancer activities; and N-containing compounds (caffeine, nicotine, cocaine and morphine), could be used in the anxiolytic, analgesic, and hallucinogenic treatments (Twaij and Hasan, 2022). Bioactive compounds refer to secondary metabolites extracted from plants. It has been found that they have pharmacological or toxicological effects on living organisms. They also found a widespread application in the food and pharmaceutical, as well as in cosmetic industries (Pai et al., 2022). The bioactive compounds of plants have many important benefits for current and future use in medicine (Wawrosch and Zotchev, 2021).

Bioactive constituents presented in vegetables, fruits, and whole grains are essential for the human body (Pai et al., 2022). These bioactive compounds include carotenoids, flavonoids, carnitine, choline, coenzyme Q, dithiolethiones, phytosterols, phytoestrogens, glucosinolates, polyphenols, vitamins and minerals (Hamzalıoğlu Gökmen, 2016). Currently, they are intensively studied to evaluate their physiological, behavioral, and immunological properties for potential practical application (Huang and Chen, 2022).

Aloe vera is a perennial green herb with bright yellow tubular flowers that is extensively distributed in hot and dry areas of North Africa, the Middle East of Asia, the Southern Mediterranean, and the Canary Islands. The colorless mucilaginous gel from *Aloe vera* leaves has been extensively used for pharmacological and cosmetic applications (Sánchez et al., 2020). *Aloe vera* contains polysaccharides (55%), sugars (17%), minerals (16%), proteins (7%), lipids (4%), phenolics (1%) (Kumar et al., 2019) and numerous bioactive compounds that have benefits for human health (Gangadharan et al., 2019). *Aloe vera* is one of the oldest and most traditional medicinal plants with biological activity that is why it is applied for medicinal purposes, food, and is used in food processing (Martínez-Burgos et al., 2022). *Aloe vera'* leaves contain numerous vitamins, minerals, natural sugars, enzymes, amino acids, and as well rich in various bioactive compounds that exhibit a wide spectrum of beneficial properties including emollient, purgative, anti-inflammatory, antioxidant, antimicrobial, anthelmintic, antifungal, aphrodisiac, and antiseptic actions (Hong et al., 2018; Lanka, 2018; Sánchez et al., 2020). In addition, *Aloe vera'* gel and extracts have been scientifically confirmed to be effectiveness in treating gastrointestinal disorders, lowering low density lipoprotein, increasing high density lipoprotein, and decreasing blood glucose level (Martínez-Burgos et al., 2022). Application of plant additives, which have pharmacological properties, in the manufacturing of traditional products to increase their health value is a new trend in food production (Stabnikova et al., 2021). The present review explores new information related to *Aloe vera*'*s* the bioactive compounds and potential

applications of *Aloe vera* in the food industry. The new information was searched from the publications (original papers) published in English in peer-reviewed scientific journals of the Web of Science, Scopus, Pubmed, Google Scholar database. The major objective of this review is to summarize the most research on the bioactive compounds present in *Aloe vera* and its potential application in the food industry.

Materials and methods

Data collection involved searching multiple databases, including Google Scholar, ScienceDirect, PubMed, SpringerLink, and Wiley Online Library. The search queries encompassed a wide range of terms, such as bioactive compound; *Aloe vera*; potential applications of *Aloe vera* and its bioactive compounds in the food industry; anti-inflammatory, antioxidant, anti-bacterial, anti-fungal, antiviral, and antiseptic properties. The study was not subject to any restrictions regarding research methodology of the study, sample size, or outcome measurement.

Results and discussion

General characteristic of *Aloe vera*

Worldwide, *Aloe vera* is a popular herbal medicine that has antibacterial and antioxidant properties, maintains cholesterol and blood sugar levels, and body weight. Therefore it has a wide field of applications that include pharmaceuticals, cosmetics, and food.

According to the taxonomic classification, *Aloe vera* is representative of Kingdom, *Plantae*; Class, *Magnoliophyta*; Order, *Asparagales*; Family, *Asphodelaceae/Xanthorrhoeaceae*; Genus, *Aloe* L.; Species, *Aloe vera* (L.) Burm. f.

Aloe plants contain important chemical constituents in their swollen and succulent leaves because of their surviving ability in hot and dry conditions (Yadeta, 2022). *Aloe vera* is an arborescent, perennial, xerophytic, succulent, thick and short-stemmed plant; is green in color and about 12 – 19 inches (30 –50 cm) in length, and is commonly grown in arid regions of India, Africa, Asia, Europe and the Americas (Mitra et al., 2023).

The genus *Aloe* includes approximately 600 species. The natural components isolated from various species of the genus *Aloe*, including anthraquinones and their glycosides, anthrols, chromones and their glycosides, pyrones, steroids, triterpenes, vitamins, coumarin, flavonoids, lignin, proteins, alkaloids, glycoproteins, and naphthalene (Rehman et al., 2017). The leaf of *Aloe vera* has 3 layers: (1) the first layer is called the gel with the characteristics of viscous, colorless, and clear, which contains water (99%), amino acids, glucomannans, vitamins, and lipids and sterols; (2) the second central layer contains holding latex with the characteristics of bitter, yellow and red aloin; glycosides and anthraquinones; and (3) the outermost thick layer has a protective function that synthesize carbohydrates and proteins (Mitra et al., 2023). The *Aloe vera* fresh leaf contains fibers, proteins, organic acids, minerals, monosaccharides, and polysaccharides (Liu et al., 2019; Zhang et al., 2018). Generally, *Aloe* leaf contains more than 200 nutritional substances, including vitamins, minerals, amino acids, and active enzymes (Yadeta, 2022). Image of *Aloe vera* leaves is shown in Figure 1.

Aloe flesh has jelly-like consistency and contains water (96%) and dry matter (4%), which contains protein (6.86%), fat (2.91%), dietary fibre (73.35%), ascorbic acid (0.004%), and ash (16.88%) (Hęś et al., 2019). It could serve as an ingredient that is used in some food

and beverage products, functional and nutraceutical foods, edible coatings/films due to benefits of its bioactive phytochemicals. Some *Aloe* species are used as cooked vegetables and raw eating; as ingredients in food and beverage products such as soft drink: Aloe sports drink with electrolyte, Aloe vera lemon juice, diet drink with soluble fiber, health drink, hangover drink with B vitamin, amino acids and acetaminophen, healthy vegetable juice mix, tropical fruit juice with *Aloe vera*, and Aloe vera yogurts (Yadeta, 2022).

Figure 1. ***Aloe vera*** **leaves**

Chemical composition of ***Aloe vera***

Chemical composition of *Aloe vera* depends on the geographical location, type of soil, harvest time, conditions of cultivation, and variety (Hęś et al., 2019; Quispe et al., 2018). Approximate chemical composition of *Aloe vera* gel is shown in Table 1.
Besides compounds shown in Table 2*, Aloe vera* contains 20 of the 22 human required amino acids and 7 of the 8 essential amino acids, vitamin E, vitamin B12, provitamin A – β-carotene, folic acid and choline. It contains a wide spectrum of enzymes including aliiase, amylase, alkaline phosphatase, oxidase, catalase, bradykinase, carboxypeptidase, cellulase, lipase, peroxidase and cylooxygenase, and carboxypeptidase. Carbohydrates of *Aloe vera* include monosaccharides (glucose and fructose) and polysaccharides (glucomannans/polymannose). Hormones auxins and gibberellins present in *Aloe vera* have anti-inflammatory action and help in wound healing. It also contain steroids (cholesterol, campesterol, β-sisosterol, and lupeol), γ-linolenic and arachidonic fatty acids, lignin, saponin, terpenes, and phenolic compounds (Arshad et al., 2015; Lanka, 2018; Mitra et al., 2023; Narsih and Agato. 2016; Rehman et al., 2017; Sánchez et al., 2020; Surjushe et al., 2008).

Table 1

Chemical composition of *Aloe vera* gel

Compounds	Values	References	Compounds	Values	References
Macronutrients, mg/100 g			**Phenolic compounds, mg/100 g**		
Moisture	96 300	Elbandy et al., 2014	Pyrogallol	18.518	Elbandy et al., 2014
Protein	44	Añibarro-Ortega et al., 2019	Gallic acid	0.339	
Ash	150		Catechin	0.457	
Fat	17		Chlorogenic acid	0.160	
Carbohydrates	630		Catechol	1.105	
Dietary fibre	840		Caffeic acid	0.153	
Crude fibre	120		Vanillic acid	0.069	
Organic acids	111		Caffeine	0.117	
Minerals, , mg/100 g			Ferulic acid	1.509	
Potassium,	127.46	Elbandy et al., 2014	p-Coumaric acid	0.532	
Calcium	71.46		Benzoic acid	3.322	
Sodium	49.65		Ellagic acid	2.535	
Magnesium	20.74		Salicylic acid	2.204	
Zinc	0.114		Cinnamic acid	0.658	
Copper	0.034		Chrysin	0.195	
Flavonoids, mg/100 g					
Hesperidin	2.271	Elbandy et al., 2014	Narengenin	37.521	Elbandy et al., 2014
Rosmarinic acid	1.382		esperetin	1.014	
Rutin	1.138		Kaempferol	0.205	
Quercitrin	0.572		Apigenin	0.322	

Bioactive compounds present in *Aloe* species

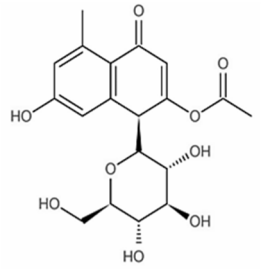
Bioactive compounds of *Aloe vera* have an anti-inflammatory effect. The biological activities of compounds from *Aloe vera* such as aloe-emodin, aloin, aloesin, emodin, acemannan have been studied (Sánchez et al., 2020). Rehman et al. (2017) showed that C-glucosyl chromones (named aloeverasides A and B) isolated from the resin of *Aloe* species is a bioactive compound. It has a glucose moiety at the C-8 position. The C-glucosyl chromones was also detected in many *Aloe* species such as *Aloe angelica*, *Aloe arenicola*, *Aloe comptonii*, *Aloe dabenorisana*, *Aloe distans*, *Aloe erinacea*, *Aloe melanacantha*, *Aloe meyeri*, *Aloe mitriformis*, *Aloe pearsonii*, *Aloe peglerae*, and *Aloe yavellana* (Rehman et al., 2017).

Aloe vera contains antioxidants, which may increase the shelf-life and nutritional value of food. Antioxidant activity has been demonstrated in *Aloe vera* leaf's skin, flowers, and gel (Hęś et al., 2019).

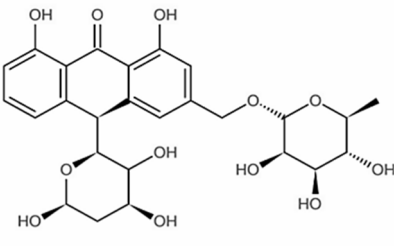
Table 2 presents the chemical structure of some bioactive compounds present in *Aloe vera*.

Table 2

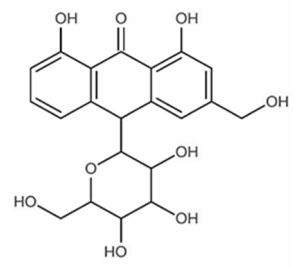
Chemical structure of some bioactive compounds present in *Aloe vera*



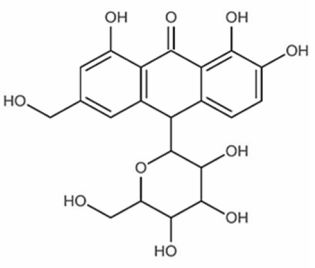
Aloisin



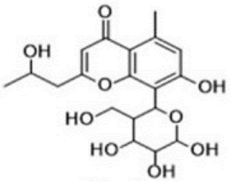
Aloinoside



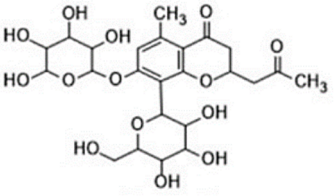
Aloin



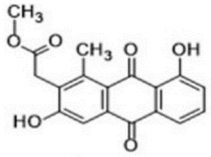
Hydroxyaloin



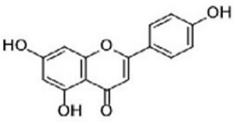
Aloesinol



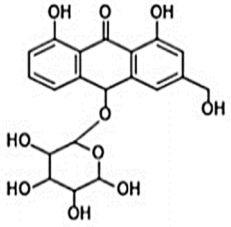
Aloeresin B



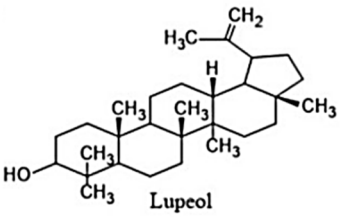
Aloesaponarin



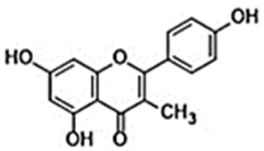
Apigenin



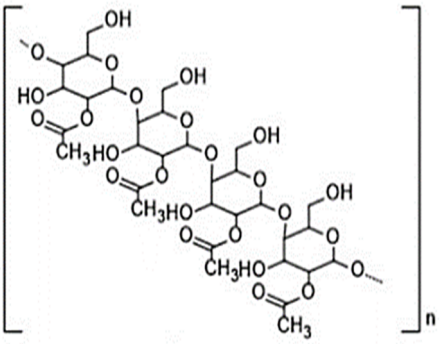
Barbaloin



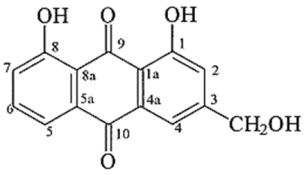
Lupeol



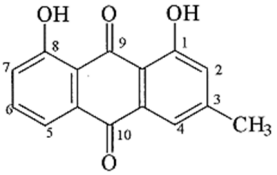
Naringenin



Acemannan



Aloe-emodin



Chrysophanol

Properties of bioactive compounds from *Aloe vera*

Function properties of several bioactive compounds present in *Aloe vera* are shown in Table 3.

Table 3

Functions of several bioactive compounds present in *Aloe vera*

Bioactive compound	Function/Properties	Reference
Polysaccharides	Anti-inflammatory	Cock I. E., 2015 Lawrence et al., 2009 Massoud et al., 2022
Acemannan (Acetylated mannan)	Immune-stimulating	Sierra-Garcíaa et al., 2014
Mannose-6-phosphate Glucomannans	Anti-inflammatory	Lanka, 2018 Mitra et al., 2023
Polyphenols	Antioxidant, anti-inflammatory	Babu and Noor, 2020 Olubunmi and Anthony, 2011
Flavonoids	Antioxidant activity by radical scavenging and prevention of oxidative cell damage	Olubunmi and Anthony, 2011 Semerel et al., 2022

Proanthocyanidins (polyphenolic bioflavonoids)	Antioxidant activity by eliminating hydroxyl radicals	Olubunmi and Anthony, 2011
Phenolic acids	Antioxidant property	Semerel et al., 2022
Tannins	Antioxidant property	Olubunmi and Anthony, 2011
Alkaloids	Antiseptic and bactericidal activities	
Anthraquinones (aloin, anthranol, barbaloin, isobarbaloin, aloetic acid, aloe-emodin and ester of resistannol, cinnamic acid, chrysophannic acid and emodin)	Antioxidant, antimicrobial, antifungal, antiviral, and laxative properties	Lawrence et al., 2009 Mitra et al., 2023 Rehman et al., 2017 Sadiq et al., 2022 Syed et al., 2022 Zeng et al., 2020
Aloe-emodin	Anticancer, antivirus, anti-inflammatory, antibacterial	Semerel et al., 2022 Zeng et al., 2020
Aloin	Anti-inflammatory	
Aloesin	Anticancer, anti-inflammatory, immunomodulatory	Semerel et al., 2022 Zeng et al., 2020
Saponin	Antimicrobial and anti-inflammatory	Lawrence et al., 2009 Olubunmi and Anthony, 2011
Chromones	Antioxidant	Semerel et al., 2022
Vitamins A (beta-carotene), C and E Vitamins B1, B2, B6, B12, folic acid, and choline	Antioxidant	Lanka, 2018 Grune et al., 2010 Higashi-Okai et al., 2006 Massoud et al., 2022
Enzymes: Aliiase, alkaline phosphatase, amylase, oxidase, carboxypeptidase, catalase, cellulase, lipase, cylooxygenase, and peroxidase	To break down sugars, proteins and fats	Lanka, 2018 Mitra et al., 2023 Arshad et al., 2015 Massoud et al., 2022
Enzyme: Bradykinase	Helps to reduce excessive inflammation	Lanka, 2018
Minerals: Calcium, chromium, copper, selenium, magnesium, manganese, potassium, sodium, and zinc	Essential minerals of various enzyme systems and antioxidant action	Mitra et al., 2023 Arshad et al., 2015 Massoud et al., 2022
Organic acids: Sorbate, salicylic acid, uric acid	Antiseptic	Lanka, 2018 Mitra et al., 2023
Hormones: Auxins and gibberellins	Wound healing; anti-inflammatory	Lanka, 2018 Mitra et al., 2023
Steroids (Campesterol, β-sisosterol, lupeol, and fatty acids (γ-linolenic acid andarachidonic acid)	Anti-inflammatory and antiseptic	Mitra et al., 2023

Aloe vera is a medicinal plant. Several bioactive constituents from *Aloe vera* have been identified and used in therapeutic applications for disease prevention and treatment through the modification of biological and genetic activities. *Aloe vera* displays function as an antioxidant through free radical- and superoxide radical-scavenging activities; anti-inflammatory activities *via* inhibition of prostaglandin E2 production from arachidonic acid; and also inhibition of various transcription factors and the activities of enzymes including lypoxygenase and cyclooxygenase. *Aloe vera* exhibits antimicrobial effects due to the ability to destroy bacterial cell walls (Arshad et al., 2015). Aloe vera' extract possesses anti-inflammatory and vasodilatory properties *via* cyclooxygenase inhibition by salicylic acid (a COX inhibitor). Emodin and emolin, anthraquinone derivatives, demonstrate anti-inflammatory properties because they are competitive inhibitors of thromboxane synthase (Zeng et al., 2020).

Anti-inflammatory properties of *Aloe vera*

Wound healing in the human body is going through the four stages, including hemostasis, inflammation, proliferation, and remodeling (Guo et al., 2010; Landén et al., 2016). The healing process of wounds or burns can be accelerated through medical intervention, including through the use of *Aloe vera* (Arbab et al., 2021). It was shown in the several studies that application of *Aloe vera* can reduce inflammation and enhance wound healing on living organisms by the inhibition of thromboxane (an inhibitor of wound healing) (Hekmatpou et al., 2019). The anti-inflammatory activity of extracts of *Aloe vera* adventitious root displayed through the modification of elementary and secondary metabolites *via* salicylic acid elicitation (Lanka, 2018). *Aloe vera* gel also helps to enhance the amount of collagen in wounds and collagen cross-linking leads to promote wound healing (Hekmatpou et al., 2019). Due to the action of glucomannan, a polysaccharide rich in mannose, together with gibberellin, which is a growth hormone, fibroblasts are stimulated, promoting proliferation and wound healing. (Massoudi et al., 2022). Aloesin enhances the wound healing process by reducing wound inflammation, stimulating fibroblast proliferation, collagen synthesis and activating of the Smad and MAPK signaling proteins in the process such as cell migration, angiogenesis, and tissue development (Wahedi et al., 2017).

The anti-ulcer effect of the bioactive compounds of *Aloe vera* in anti-inflammatory drugs without non-steroids induced peptic ulcers in rats was proven. The bioactive compounds inhibiting the cyclooxygenase pathway led to reduced production of prostaglandin E2 from arachidonic acid. The anti-inflammatory activity of extracts of *Aloe vera* adventitious root displayed through the modification of elementary and secondary metabolites *via* salicylic acid elicitation (Lanka, 2018)

Anti-bacterial, anti-fungal, antiviral, and antiseptic properties of *Aloe vera*

Antimicrobial resistance is one of the major public health problems that lead to reduction of the synthetic drugs effectiveness (Leitgeb et al., 2021). Meanwhile, the growth of bacteria, fungi, and viruses could be inhibited by action of some bioactive compounds. Antimicrobial action of bioactive compounds from medicinal plants have been known for a long time. Applications of such substances, having antioxidant and anti-inflammatory activities, for the development of new therapeutic drugs to suppress microbial infections could reduce oxidative damage and inhibit inflammatory pathways. Bioactive compounds can directly scavenge free radicals, protect against oxidative damage, prevent the generation of pro-inflammatory cytokines, and reduce the activity of inflammatory enzymes (Dar et al., 2023).

Aloe species have been used in traditional medicine for treating skin and digestive problems, wound healing, anti-inflammatory, and antimicrobial properties (Leitgeb et al., 2021). Bioactive compound of *Aloe vera* inhibited the growth of *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella typhi*, *Actinobacillus actinomycetemcomitans,* and *Porphyromonas gingivalis* (Arshad et al., 2015). Anthraquinone derivatives emodin, Aloe-emodin, aloin, and chrysophanic acid from *Aloe vera* have both antimicrobial and anti-inflammatory activities. Anthraquinones perform the antimicrobial activity by altering solute transport through membranes, cell walls, and fatty acid elongation (Zeng et al., 2020). Several antiseptic agents present in *Aloe vera* such as triterpenoid lupeol, salicylic acid, urea nitrogen, cinnamic acid, phenols, and sulfur display actions against fungi, bacteria, and viruses (Lanka, 2018).

Each ingredient of the *Aloe* gel has its own mechanism of action, acting synergistically or individually (Lawrence et al., 2009). The antimicrobial and inhibitory activities of *Aloe vera* gel against oral pathogenic bacteria have been proven at the concentrations of 100% and 50%. At lower concentration there was no antibacterial effect (Jain et al., 2016). The ethanol extracts of *Aloe vera* from leaves and roots have been used against skin infections alongside conventional antibiotics (Arbab et al., 2021). The antiviral activity of Aloe extracts was carried out indirectly by stimulating the immune system and directly by anthraquinones. For example, the anthraquinone aloin inactivates various enveloped viruses including *Herpes simplex*, *Varicella zoster*, and *Influenza* (Lanka, 2018).

Potentially bioactive compounds include salicylates, magnesium lactate, acemannan, lupeol, campesterol, β-sitosterol, aloin A, and anthraquinones. The *Aloe vera* is an antibacterial agent, effectively kills or greatly reduces or eliminates the growth of *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Streptococcus pyogenes*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Propionibacterium acne*, *Helicobacter pylori*, *Bacillus subtilis*, *Bacillus cereus*, and *Salmonella typhi* (Lawrence et al., 2009). The *Aloe vera* based hydrogels demonstrated antibacterial effects for Gram-positive bacteria *Staphylococcus aureus* and Gram-negative bacteria *Pseudomonas aeruginosa* (Chelu et al., 2023).

Antioxidant properties of *Aloe vera*

Oxidative stress has been identified as a factor contributing to various diseases, such as atherosclerosis, arthritis, cardiovascular disorders, Alzheimer's disease, and cancer. Therefore, antioxidants play a crucial role, and there is a growing inclination to substitute synthetic antioxidants with natural alternatives (Lourenço et al., 2019). The antioxidants are used as an adjunct to initial intervention aimed at inhibiting systemic effects of oxidant species. The antioxidant effect of *Aloe vera* depends on the activity of glutathione peroxidase, superoxide dismutase enzymes, and phenolic antioxidants (Zeng et al., 2020). Some *Aloe* species have medicinal characteristics and high economic values, such as *Aloe djiboutiensis*, originating from Djibouti, East Africa and used as a medicinal plant in Djibouti. *Aloe djiboutiensis* contained some bioactive compounds such as aloin A, aloin B, and isoaloeresin D (Hinokidani et al., 2022). *Aloe* extracts have antioxidant effects. Many constituents, such as vitamins, amino acids, carbohydrates, and phenolic compounds are active in controlling or neutralizing reactive oxygen species. Free radical production is balanced through the antioxidative defense system of human body, and any alteration occurring between the generation of reactive oxygen species and its neutralization by antioxidant defenses causes oxidative stress, which plays a role in the pathogenesis of diseases (Arshad et al., 2015).

Phenolic compounds as the most important secondary metabolites in many medicinal plants have antioxidant activities allowing them to act as reducing agents, hydrogen donors,

and radical scavengers (Leitgeb et al., 2021). APS-1, a polysaccharide from *Aloe vera,* has the antioxidant function and the protection of heart tissue. APS-1 contains a high content of rhamnose and arabinose in polysaccharide fraction. Aloe emodin displays anti-cancer potential against hepatoma cells. Aloin displays anti-cancer activity by inhibiting the tumor angiogenesis by inactivating the signal transduction and activators of transcription 3 pathway. Aloe polysaccharides were proven to have the effects for antitumor activity against sarcoma 180 cells (Babu and Noor, 2020).

Methods for screening, extracting, identifying, and isolation of bioactive compounds from *Aloe vera*

Collecting bioactive chemicals from medicinal plants is an initial step in the discovery and development of new drugs. Many methods for screening, extracting, identifying, and isolation of bioactive metabolites from medicinal plants have been performed. Table 4 shows the methods applied in therapeutic applications (Dar et al., 2023).

New methods for isolation of bioactive substances from *Aloe vera* are proposed. Thus, ultrasound-assisted extraction (UAE) is known as method used for the extraction of thermo-labile compounds (Ivanov et al., 2021). The advantages of UAE are decreasing extraction time and temperature, low consumption of energy, and increasing the rate of extraction. Ultrasonic-assisted extraction was proposed to be used to obtain of aloin and aloe-emodin compounds from *Aloe vera* (Gansukh et al., 2018; Kamble et al., 2021).

Potential applications of *Aloe vera* in the food industry

The global *Aloe vera* hydrogel market is expected to reach USD 712.3 million by 2032, at a compound annual growth rate of 7.8% from 2022 to 2032 (Chelu et al., 2023). *Aloe vera* has antibacterial, antioxidant, anti-inflammatory and other functional properties. So, it has been popular for applications in various fields including food preservation, sustainable packaging, cosmetics and pharmaceutical industries. *Aloe vera* has functional bioactive compounds and has been used in health drinks and other beverages in the form of powder. As a natural food preservative, *Aloe vera* can protect food products from oxidative and microbial deteriorations, extend the shelf life of food products, improve their texture, and enhance nutritional/health-promoting values (Kumar et al., 2022; Yadeta, 2022). For example, *Aloe arborescens* and *Aloe vera* are frequently employed in the production of dairy products like yogurt and ice cream, acting as a food preservative, while *Aloe ferox* finds application in the processing of fruit juices and confectionery products (Yadeta, 2022).

Aloe vera is a popular plant having many functional compounds that are beneficial for human health. The U.S. Food and Drug Administration approved *Aloe vera* as a food flavoring agent in accordance with good manufacturing practices. The study on the processing of therapeutic and high nutritional mango nectar by supplementation of mango pulp with *Aloe vera* gel showed that the supplementation with 20–25% *Aloe vera* gel allowed to produce high quality functional mango nectar containing natural preservative ingredients resulted in a dramatic fall in the levels of total bacterial counts (decreased from $\log_{10}$ 3.9 ± 0.06 CFU/ml to $\log_{10}$ 2.05 CFU/ml) (Elbandy et al., 2014).

The main areas of *Aloe vera* applications in the food industry include edible coatings production, fruits preservation, and beverages, dairy, confectionary, and sport nutrition products processing (Figure 2).

Table 4

Identification of bioactive compounds in *Aloe vera*

Step	Identification of bioactive compounds in *Aloe vera*	Reference
Initial screening of phytochemicals from *Aloe vera*	This is an initial step for the identifying bioactive compounds present in medicinal plants based on certain types of chemicals, including alkaloids, flavonoids, terpenoids, phenolics, and glycosides. Common phytochemical screening techniques: color reactions, thin-layer chromatography (TLC), and spot tests	Dar et al., 2023
Collection of *Aloe vera* gel	Leaves of *Aloe vera* were cut, washed with distilled water, surfaces were sterilized by 70% ethyl alcohol followed by 0.1% $HgCl_2$, peeled, and gel was collected	Lawrence et al., 2009
Extract preparation	Extraction of bioactive substances is performed by ethanol or methanol from *Aloe vera* gel. The *Aloe vera* powder was obtained from the fresh leaf gel by drying in the oven at 80°C for 48 h and then powdered. The obtained powder was soaked in 200 ml of the solvents (ethanol or methanol) for 24 h to collect an extract. The extract was filtered, evaporated, and the dried extract was used in powder form	Lawrence et al., 2009
Extraction of bioactive compounds	Techniques: Maceration, percolation, supercritical fluid extraction (SFE), ultrasonic extraction, and Soxhlet extraction	Dar et al., 2023
Separation, purification, and analysis of bioactive compound	Based on bioactive compound characteristics: for the separation and quantification of substances, Gas chromatography (GC) and High-performance liquid chromatography (HPLC) techniques are used. For the separation and purification of specific compounds, Column chromatography, flash chromatography, and thin-layer chromatography (TLC) are also used	Dar et al., 2023
Antibacterial activity of *Aloe vera* gel or extract	Bioactive compound destroys cell membranes and inhibits enzymes. Agar Well Diffusion Technique: About 0.1ml of Aloe vera gel extracts was poured into each well (5 mm in diameter, contained sterile nutrient agar) swabbed with an overnight bacterial broth culture, and then incubated at 37°C ± 0.2°C. Antibacterial activity in terms of zones of inhibition (mm) was recorded after 24 h of incubation	Dar et al., 2023 Lawrence et al., 2009
Antiviral activity	Bioactive compounds can be antiviral agents by inhibiting the replication of toxic virus	Dar et al., 2023
Bioassays and bioactivity Screening	Bioassays: the biological activities evaluation of isolated compounds, such as antimicrobial, antioxidant, anti-inflammatory, anticancer, and other pharmacological properties. Bioassays techniques: disk diffusion method, broth microdilution method, antioxidant assays, enzyme inhibition assays, and cell-based assays	Dar et al., 2023

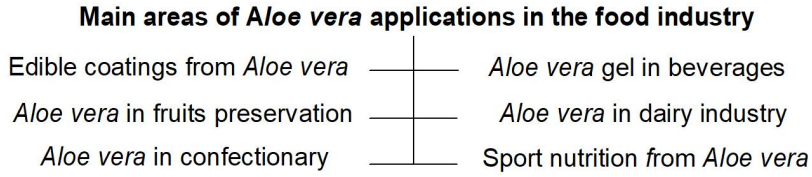


Figure 2. Main areas of *Aloe vera* applications in the food industry

The processing of *Aloe vera* leaves to obtain *Aloe vera* gel could include whole-leaf processing, mechanical filleting, or manual filleting, depending on the intended use (Hęś et al., 2019). *Aloe vera* gel is a natural hydrocolloid consisting mainly of polysaccharides. The approximal composition of *Aloe vera* gel consists water (96 %), and dry matter (4 %), which contains organic acids (22.8 %), dietary fiber (18.8 %), polysaccharides (8.8 %), protein (4.7%), lipids (2.7 %), and ash (16.0 %) (w/w). *Aloe vera*'s bioactive compounds are aloin, aloe emodin, anthraquinones, and acemannan. The gel has antioxidant and antimicrobial effects and can increase the shelf-life of fruits and vegetables by acting as a semipermeable barrier for gases and water vapor, decreasing the respiration and ripening processes of the fruit, thus maintaining weight, firmness and content of valuable compounds (Nicolau-Lapeña et al., 2021).

Figure 3 presents products from *Aloe vera* plant used in the food industry, including gel, juice, concentrate, and powder (Ahlawat & Khatka, 2011).

Figure 3. Products from *Aloe vera* plant used in the food industry

Aloe vera gel is utilized as a natural functional ingredient or additive to fortify food products sourced from plants. This application aims to enhance food quality, extend the shell life of vegetables and fruits, reduce microbial pathogens, preserve the antioxidant activity of bioactive compounds, improve product acceptability and promote the growth of probiotic cultures (Hęś et al., 2019). In the study of Nagpal et al. (2012) it was shown that the addition of *Aloe vera* juice at a concentration of 5% (v/v) into the growth media of Lactobacilli showed that the juice addition promoted the growth of *Lactobacillus acidophilus*, *Lactobacillus plantarum*, and *Lactobacillus casei* effectively, as evident from the fall in pH and increased acidity, as well as from the improved generation time. At concentrations of 15 to 25% (v/v), the growth was not affected compared to the control. However, at concentrations higher than 25% (v/v), the growth was inhibited (Nagpal et al., 2012).

Edible coatings with *Aloe vera*

The edible coating is an environmentally friendly technology, often applied to fresh-cut fruit products. Among them, *Aloe vera* gel is potentially applicable because of containing several functional components. The main advantage of *Aloe vera* coating is that additives can be incorporated into the polymer matrix to enhance its properties to improve the safety, nutritional, and sensory attributes of fresh fruits (Suriati, 2022). Utilizing edible and biosafe coatings derived from the *Aloe vera* plant in fruit preservation aims to establish a barrier that restricts the exchange of moisture and oxygen, as well as the movement of solutes in the products (Yadeta, 2022). In a study conducted by Mahajan and colleagues (2021), an edible film made from *Aloe vera* (15%), glycerol (14%), and carrageenan (15%), was employed to enhance the microbial and lipid oxidative stability of frozen dairy products. This edible film exhibited antibacterial properties, stabilized lipid oxidation in frozen dairy products, and showed potential commercial application for improving the storage stability of such products (Mahajan et al., 2021).

Aloe vera gel coating is quite effective in extending the shelf life of various perishable food items depending on the dosage of gel used (Maan et al., 2021). The study of Benítez et al. (2015) indicated that *Aloe vera* edible coating could extend the postharvest shelf life and maintain the sensory properties of minimally processed kiwifruit through the storage period. *Aloe vera* edible coating extended the shelf life and maintained the quality of kiwifruit slices by 11 days at 4±1 °C (Benítezet al., 2015). In addition, the study Farooq et al. (2022) has proved that aloe vera-based coating in combination with chitosan is a successful and effective way to prolong the shelf life and sustain the quality attributes of tomatoes during storage of 12 days at 8 °C.

***Aloe vera* gel in beverages**

The use of *Aloe vera* gel in the food industry is mainly to provide functional ingredients, especially used to prepare health food drinks and other beverages. Additionally, it can be added to juices for better digestion, health benefits, and amino acid and mineral supplements. In the production of *Aloe vera* juice, the shelf life of the product will vary depending on the type of *Aloe vera* used (Hasan et al., 2023). In the juice product processing, to obtain products with high biological activity from *Aloe vera*, the preservation of its bioactive is extremely important, because of the degradation of bioactive polysaccharides was minor and also could improve functional properties of the juice (Alvarado-Morales et al., 2019).

A study by Kausar (2020) showed that the addition of *Aloe vera* had little effect on the physicochemical characteristics, reduced microbial load, increased total phenolic content, antioxidant activity and reducing capacity. The sensory performance of a sample of orange juice with 5% *Aloe vera* gel was found to be acceptable even after 90 days.

***Aloe vera* in fruit preservation**

Prolongation of shelf life of fresh fruits and vegetables is a matter of great importance because the losses of all fruit and vegetables estimated by Food and Agriculture Organization of the United Nations consists about 50% (Pirog et al., 2022a). Edible coatings are traditionally used to improve food appearance and preservation. Natural biopolymers such as plant or microbial polysaccharides, plant gums, peptides, and lipid-based materials are proposed for development of edible coating (Pirog et al., 2022b). The diluted aqueous extract of *Aloe vera* edible coating could maintain the quality of the tomatoes during storage period

in ambient conditions and slow down ripening. The pure extract of *Aloe vera* could inhibit the growth of fungi *Rhizoctonia solani* and *Alternaria alternata* (García et al., 2014).

In the study of Das et al. (2022), the *Aloe vera* gel and sodium-benzoate were used to increase the shelf life and quality of three tomato varieties. The results showed that the total phenolic content and antioxidant activity were higher than the control in all varieties. The mixture of 3% sodium benzoate and 10% *Aloe vera* gel was used to extend the shelf life of the tomato varieties up to 21 days. The edible films from *Aloe vera* gel and sodium benzoate could provide a better way to expand the safety and shelf-life of tomatoes to help save cost in their preservation (Das et al., 2022).

Aloe vera gel was used as an edible coating in the storage period for the Pisang Awak bananas. The gel could enhance some quality properties compared to the control. Application of the gel in optimal concentration has a positive effect on the ripening process, prevents softening and discoloration, and also improves the quality of bananas (Quoc, 2021).

Aloe vera in dairy industry

In food production, *Aloe vera* has been used as a health-promoting ingredient in gel form (Bahrami et al., 2019). In the dairy industry, *Aloe vera* gel or *Aloe vera* juice is used for incorporation in various dairy products such as flavored milk, ice cream, and yogurt (Srikanth et al., 2016). The adding 3% *Aloe vera* gel to replace milk fat in yogurt formulations showed that *Aloe vera* gel improved the texture of yogurt containing buffalo milk as well as the sensory properties of the product (Ikram et al., 2020). The addition of *Aloe vera* with high aloin content to yogurt helps to stimulate and increase the content of bifidobacterium (Hussain et al., 2017).

Aloe vera contains several ingredients that interact with probiotics, and serve as a source of prebiotics and antioxidants. The addition of 1% *Aloe vera* oil to both non-dairy and dairy products resulted in favourable sensory quality compared to the control samples (Kim et al., 2022). Incorporation of *Aloe vera* gel into non-dairy vegetable cream helped to reduce the melting rate and affected the texture of the cream. The final cream product had a soft, fluffy structure, did not melt quickly when exposed to air, and had a mild, attractive sweet taste (Nguyen and Do, 2023).

Aloe vera in confectionary products

Aloe vera gel is used to produce some products such as candies, bars, chewing gums, gums for sore or bleeding gums, candy type *Aloe* vitamins, and *Aloe vera* fruit smoothies. *Aloe vera* concentrate was collected from the *Aloe vera* juice processing under vacuum (125 mm Hg vacuum, at temperature below 50 °C, and concentration time was less than 2 minutes) to prevent the loss of biological activity. The *Aloe vera* concentrate was used to process various foods such as squash, jam, and jellies. In addition, the concentrate of *Aloe vera* can also be mixed with tea, water or juice. *Aloe vera* powder can be used in curd, lassi, ice-cream, and yoghurt productions (Ahlawat and Khatka, 2011).

Aloe vera in sport nutrition products

Aloe vera contains valuable nutrients needed to provide good nutrition for health and can be used to create functional products to support the body's immunity (Haristy et al., 2021). *Aloe vera* has been used to produce several products such as drinks (health drinks, soft

drinks, laxatives), sports drinks (with electrolytes), diet drinks (with soluble fiber), hangover drink (with B vitamins), vegetable juice mix (Natalia, 2018).

Safety aspects of *Aloe vera*

According to Kumar et al. (2022), scientific reports have agreed that *Aloe vera* is safe for use on external wounds, burns, inflammations, but the safety for use in humans, especially for immunocompromised consumers such as pregnant women, children and patients with gastrointestinal diseases, depends on the usability, dosage and concentration of *Aloe vera* in the food. Determining the safety of *Aloe vera* is quite rigorous due to the lack of standardization in the commercial manufacturing of *Aloe vera* products. The ingestion of *Aloe vera* preparations is associated with diarrhea, hypokalemia, kidney failure (Guo and Mei, 2016).

Conclusions

1. *Aloe vera* is rich in various valuable components, including polysaccharides (55%), sugars (17%), minerals (16%), proteins (7%), lipids (4%), and phenolic compounds (1%). This plant also contains numerous biologically active compounds, providing diverse health benefits such as emollient, purgative, anti-inflammatory, antioxidant, antimicrobial, anti-helminthic, antifungal, antiseptic, and pharmaceutical and cosmetic values.
2. Depending on the purpose of using, leaves of *Aloe vera* could be processed by whole-leaf processing, mechanically filleted or manual filleted processing to obtain *Aloe vera* gel. After that, the gel was used to produce juice, concentrate and powder products.
3. The products of *Aloe vera* are natural functional ingredients or additives for the fortification of food products from vegetable sources to improve food quality, prolong the shelf life of vegetable and fruits, reduce microbial load, increase antioxidant activity, improve acceptability of products, enhance the growth of probiotics cultures, and are also used in the pharmaceutical and cosmetic industries.
4. The main areas of *Aloe vera* applications in the food industry include production of edible coatings, fruits preservation, and beverages, dairy, confectionary, and sport nutrition products processing.
5. Further research into *Aloe vera*'s bioactive compounds will help unlock their health benefits, thereby minimizing and preventing numerous diseases. Safety should be considered when using *Aloe vera* products.

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