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Bioactive Compounds, Medicinal Properties and Applications of *Aloe vera*

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ABSTRACT

Aloe vera is a perennial, drought-tolerant succulent that belongs to the family Liliaceae, widely valued for its therapeutic, nutritional, and cosmetic properties. The objective of this review is to critically summarize the chemical composition, medicinal properties, and industrial uses of *Aloe vera*, with emphasis on its major bioactive constituents. A systematic review of peer-reviewed literature, books, and authoritative databases was conducted to compile and synthesize information on phytochemistry, pharmacological activities, and commercial utilization of *Aloe vera*.

The analysis shows that *Aloe vera* contains numerous biologically active compounds, including saponins, minerals, enzymes, sugars, vitamins, lignin, amino acids, anthraquinones, fatty acids, and polysaccharides. The leaf pulp comprises a complex mixture of enzymes, proteins, lipids, carbohydrates, and inorganic and organic compounds, which collectively contribute to its broad pharmacological profile. Reported studies demonstrate anti-inflammatory, antimicrobial, antioxidant, anti-diabetic, anti-aging, laxative, antitumor, wound-healing, and immunomodulatory activities. Owing to these properties, *Aloe vera* is extensively incorporated into pharmaceutical formulations, functional foods, nutraceuticals, and cosmetic products for both internal and topical applications.

In conclusion, *Aloe vera* is a multifunctional medicinal plant of considerable therapeutic and commercial significance. Its biological effects are primarily attributed to the synergistic interaction of multiple bioactive compounds rather than a single active principle. However, variability in chemical composition arising from environmental conditions, cultivation practices, and processing methods poses challenges for standardization and quality control. Further well-designed experimental and clinical studies are required to clarify structure–function relationships and to ensure the safe, effective, and standardized utilization of *Aloe vera* in health-related industries worldwide and future applications.

Keywords: *Aloe vera,* bioactive compounds, medicinal properties, pharmacological activity, cosmetic and nutraceutical applications

INTRODUCTION

The genus *Aloe* comprises approximately 500 species belonging to the family Asphodelaceae (Liliaceae), among which *Aloe vera* is the most widely utilized for commercial and medicinal purposes (6, 17, 23). *Aloe vera* contains several biologically active compounds, including enzymes such as carboxypeptidase and bradykinin, which are associated with analgesic effects, as well as anti-inflammatory constituents like aloe resin I and dihydrocoumarins that exhibit immunomodulatory and antioxidative activities (18, 39).

Polysaccharides present in *Aloe vera* play a crucial role in immune stimulation, wound healing, reduction of inflammation, repair of radiation-induced damage, and antimicrobial activity against bacteria, viruses, and fungi (5, 15, 30). Botanically, *Aloe vera* is a perennial succulent xerophyte adapted to arid conditions. Its thick, fleshy leaves store water within large, thin-walled parenchymatous cells, forming a viscous mucilage that enables survival during prolonged droughts [26].

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Aloe vera (*Aloe barbadensis Miller)* is a green perennial herb with bright yellow tubular flowers that is extensively distributed in hot and dry areas. *"Aloe vera"* originates from the Arabic term "Allaeh," meaning "shining bitter substances," and the term "vera," meaning "true." *Aloe vera* is the most commercially exploited species of the genus, and large-scale processing of its leaf pulp has developed into a global industry. Aloe vera is a nutraceutical that has been utilized predominantly for decades. It is offered in various health drinks and wellness beverages, as well as in capsules/tablets and in gels and creams for external use. In the food sector, it is widely used in functional foods and health beverages, while in cosmetics and toiletries, it serves as a base ingredient in creams, lotions, soaps, shampoos, and facial cleansers.

Despite the identification of more than 75 biologically active compounds in *Aloe vera* gel, the precise medicinal role of each component remains unclear (21). Most therapeutic effects are attributed to polysaccharides in the inner leaf gel; however, current evidence suggests that the biological activities result from a synergistic interaction among multiple compounds rather than a single active principle [14, 27, 28].

Fresh *Aloe vera* pulp contains approximately 98.5% water, while the gel or mucilage contains nearly 99.5% water (17). The remaining solid fraction includes vitamins, minerals, enzymes, sugars, lignin, phenolic compounds, and organic acids (8, 19, 24). Nutritionally, *Aloe vera* leaves are composed of carbohydrates (56.27%), protein (10.50%), fat (1.83%), ash (19.50%), and essential minerals, yielding approximately 290.08 kcal of energy. Aloe vera powder, rich in dietary fiber, antioxidants, and iron, is widely incorporated into Ayurvedic formulations and functional foods (24).

The World Health Organization recognizes medicinal plants such as *Aloe vera* as vital resources for drug development. High-quality *Aloe vera* is cultivated in desert regions such as Southern California, where the plant tolerates extreme temperatures while maintaining medicinal value (4, 12, 20).

Chemical Characteristics of *Aloe vera*

Aloe vera contains nearly 75 biologically active compounds categorized into anthraquinones, amino acids, saponins, enzymes, vitamins, salicylic acid, sugars, minerals, lignin, sterols, and polysaccharides (33).

Anthraquinones

Aloe species contain free anthraquinones and their derivatives, including aloin, aloe-emodin, barbaloin, anthracene, emodin, anthranol, and aloetic acid. These compounds primarily act as natural purgatives and exhibit antiviral, antibacterial, and analgesic activities (25).

Amino Acids

Aloe vera provides all essential amino acids—such as isoleucine, leucine, lysine, methionine, phenylalanine, threonine, valine, and tryptophan—along with several non-essential amino acids including alanine, arginine, cysteine, glutamic acid, glycine, histidine, and proline (.22).

Saponins and Sterols

Saponins present in *Aloe vera* gel possess cleansing and antiseptic properties and demonstrate strong antimicrobial activity against bacteria, fungi, viruses, and yeasts [25]. Plant sterols such as campesterol, lupeol, cholesterol, and β-sitosterol contribute to anti-inflammatory, analgesic, and antiseptic effects (36).

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Enzymes

Aloe vera contains enzymes such as amylase, lipase, bradykinase, carboxypeptidase, catalase, peroxidase, cellulase, and alkaline phosphatase. Bradykinase reduces inflammation, while carboxypeptidase deactivates bradykinin, thereby alleviating pain and swelling (3, 35).

Vitamins

The gel contains vitamins A, C, and E, which function as antioxidants, along with B-complex vitamins such as niacin, riboflavin, choline, and folic acid. These vitamins enhance immune function and protect against oxidative stress (13).

Salicylic Acid

Salicylic acid, an aspirin-like compound present in *Aloe vera*, exhibits anti-inflammatory, analgesic, antibacterial, and antipyretic activities. Other associated compounds include prostaglandins, tannins, resins, lectins, mannins, and gibberellins.

Sugars

Aloe vera contains monosaccharides (glucose and fructose) and polysaccharides such as glucomannans, which act as immune modulators and moisturizing agents (34, 37).

Minerals

The plant is rich in calcium, magnesium, manganese, chromium, copper, potassium, zinc, sodium, and iron, which are essential for enzyme activation, insulin function, oxygen transport, bone health, and metabolic regulation (11). Trace elements such as rhodium and iridium are also present and are under investigation for anticancer potential.

Lignin

Lignin in Aloe vera gel serves largely as a penetration enhancer, facilitating the deeper and more effective transport of medicinal chemicals into the skin. Lignin, although pharmacologically inactive independently, markedly improves the medicinal and cosmetic efficacy of Aloe vera preparations, especially in wound healing, burn therapy, and skincare formulations (10).

Medicinal Significance of *Aloe Vera*

Antitumor Activity

Aloe vera gel exhibits chemopreventive effects and anti-hepatocarcinogenic activity by modulating apoptosis pathways (29).

Anticancer Properties

Aloe extracts have shown positive effects in cancer treatment, particularly glycoproteins (lectins) and polysaccharides like acemannan. Studies highlight their impact on tumor burden reduction, shrinkage, necrosis, and increased survival rates across various in vitro models and animal species. Anthraquinones and

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aloe-emodin suppress malignant cell proliferation. Aloe-based topical formulations have also reduced radiation-induced dermatitis in cancer patients (32).

Antibacterial Activity

Aloe vera contains significant antibacterial characteristics due to substances such as anthraquinones, saponins, and polysaccharides, which effectively inhibit prevalent pathogens including Staphylococcus aureus, Pseudomonas aeruginosa, and Escherichia coli (E. coli).The gel inhibits bacterial growth, including *Streptococcus pyogenes* and *Streptococcus faecalis* (7).

Anti-Inflammatory Activity

The body's reaction to injury is termed inflammation, and it manifests as swelling, discomfort, redness, heat, and loss of function. Bradykinase, C-glucosyl chromone, and sterols in *Aloe vera* gel extract contribute to its potent anti-inflammatory and analgesic effects (9).

Anti-Aging Property

Mucopolysaccharides in *Aloe vera* enhance skin hydration, elasticity, and collagen synthesis, reducing erythema and wrinkles (38).

Antiseptic Property

Compounds such as cinnamic acid, phenols, salicylic acid, lupeol, sulfur, nitrogen, and urea provide broad antiseptic action against microbes (16).

Anti-Diabetic Activity

Phytosterols and polysaccharides exhibit hypoglycemic activity by enhancing insulin secretion and sensitivity (29).

Laxative Effect

Anthraquinones stimulate intestinal peristalsis and mucus secretion, promoting bowel movement. Aloin A and B are metabolized into aloe-emodin anthrone, the active laxative principle (25).

Cosmetic Applications of Aloe Vera

Aloe vera is extensively used in cosmetic formulations due to its antioxidant content, including vitamins C and E, flavonoids, and phenolic compounds. These constituents neutralize free radicals responsible for skin aging and damage (31). Aloe vera-based products provide soothing, moisturizing, toning, protective, and healing effects and are effective in managing skin disorders such as psoriasis, shingles, burns, wounds, and itching (1).

CONCLUSIONS

Aloe vera has been used for centuries as a medicinal plant with extensive therapeutic applications. Although many of its biological activities are attributed to polysaccharides in the leaf gel, the precise association between individual compounds and specific therapeutic effects remains unclear. Variations in plant composition due to environmental factors, extraction methods, and processing techniques contribute to inconsistencies in reported chemical profiles and biological activities.

Nevertheless, *Aloe vera* remains a potent natural resource, rich in enzymes, sugars, fatty acids, amino acids, minerals, and bioactive compounds. Its diverse pharmacological properties include anti-inflammatory, antioxidant, antimicrobial, anti-diabetic, antitumor, laxative, hepatoprotective, analgesic, and anti-aging effects. Due to this multifaceted therapeutic potential, *Aloe vera* continues to play a vital role in pharmaceuticals, nutraceuticals, cosmetics, and traditional medicine.

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