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Uncovering the Therapeutic Potential of *Aloe vera* in Modern Medicine

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ABSTRACT: This review article presents a comprehensive analysis of *Aloe vera* (*Aloe barbadensis* Miller), concentrating on its morphological characteristics, chemical constituents, historical applications, and therapeutic potentials, with a particular focus on its antifungal properties. *Aloe vera*, a xerophytic succulent belonging to the Xanthorrhoeaceae family, is recognized for its extensive array of bioactive compounds, including vitamins, minerals, enzymes, anthraquinones, and polysaccharides, all of which contribute significantly to its medicinal efficacy. This plant has been employed for over 6,000 years within traditional medicinal frameworks for its wound-healing, digestive, and dermal-soothing properties. The morphological characteristics of the plant, which encompass thick, fleshy leaves containing distinct gel and latex layers, facilitate its adaptation to arid environments through Crassulacean Acid Metabolism (CAM) photosynthesis. The investigation into the chemical composition of *Aloe vera* elucidates its active constituents, such as acemannan, glucomannan, saponins, and anthraquinones, which are known to exhibit anti-inflammatory, antimicrobial, and antifungal properties. This review underscores the multifarious applications of *Aloe vera* within the pharmaceutical, cosmetic, dietary supplement, and food industries, particularly accentuating its potential as a natural antifungal agent. Recent empirical studies have substantiated its efficacy against various fungal pathogens, including *Candida albicans* and Aspergillus species and novel approaches such as the green synthesis of silver nanoparticles utilizing *Aloe vera* are examined. Notwithstanding its promising therapeutic applications, the paper advocates for further investigative efforts to standardize its clinical utilization and ensure safety, particularly concerning oral formulations. *Aloe vera* holds significant promise as an alternative to synthetic antifungal treatments, with its broad-spectrum bioactivity and natural origin offering potential for safer, more sustainable therapeutic strategies.

Keywords: *Aloe vera*, Antifungal activity, Fungi, Disease, Chemical compounds, Plants.

GENERAL INTRODUCTION AND MORPHOLOGY

Aloe vera constitutes a succulent xerophytic plant belonging to the Xanthorrhoeaceae family, recognized for its wide-ranging therapeutic attributes and varied phytochemical composition. Commonly designated as *Aloe barbadensis* Miller, this species is indigenous to dry, tropical, and subtropical locales, especially in North Africa, the Canary Islands, and South Asia. It has been utilized by humans for more than 6,000 years, historically praised for its wound-healing, skin-soothing, and digestive health benefits (Hęś *et al*., 2019; Radha & Laxmipriya 2015).

The name "Aloe" derives from the Arabic word "Alloeh," meaning bitter and shiny substance, reflective of its latex, while "vera" means true in Latin, denoting its authentic medicinal use. *Aloe vera* has been widely integrated into traditional medicine systems in India, China, Egypt, Greece, and Rome (Malik & Zarnigar 2013; Taylor, 1965). Morphologically, *Aloe vera* is characterized by long (40–70 cm), thick, fleshy, lanceolate leaves arranged in a rosette form. Each leaf consists of three distinct layers: the inner gel or pulp (rich in water, glucomannan, and nutrients), a middle latex layer containing anthraquinones (notably aloin), and a thick green outer rind responsible for protection and photosynthesis (Haghani, 2022). The plant typically bears yellow tubular flowers and fruits containing numerous seeds. Morphologically, the plant features triangular, fleshy leaves with serrated edges arranged in a rosette pattern. Each plant bears approximately 20 leaves, which may grow up to 40–50 cm in length and 6–7 cm in width (Ghosh *et al*., 2024).

The leaves contain a gel composed of about 99% water, enriched with bioactive compounds including glucomannan, amino acids, lipids, sterols, and vitamins, which contribute to its therapeutic properties. The outer leaf skin is rich in anthraquinones and polysaccharides, while the latex layer contains tannins, saponins, flavonoids, and anthrone derivatives. These bioactive constituents are linked to *Aloe vera*'s pharmacological activities such as anti-inflammatory, antibacterial, antioxidant, and wound-healing effects (Pradhan, 2023). *Aloe vera* exhibits Crassulacean Acid Metabolism (CAM) photosynthesis, allowing it to conserve water efficiently. It thrives in well-drained, sandy soils and is highly tolerant to drought. The leaves contain vascular bundles essential for water and nutrient transport, with mucilaginous gel promoting wound healing and reducing inflammation (Joseph & Raj 2010; Ni *et al*., 2004; WHO, 1999). It is posited that *Aloe vera* encompasses more than 75 potentially bioactive constituents, which include various vitamins (A, C, E, B12), essential minerals (calcium, magnesium, zinc), a range of enzymes (amylase, lipase), diverse sugars (monosaccharides and polysaccharides like acemannan), anthraquinones (such as aloin and emodin), along with lignin, saponins, sterols, and amino acids (Radha & Laxmipriya 2015; Reynolds & Dweck 1999). These compounds collectively contribute to the plant's antimicrobial, anti-inflammatory, and antifungal activities. Botanical classification according to the ITIS report (Taxonomic Serial No: 182653). This robust succulent is an ornamental perennial with glaucous-green leaves and thorned edges. It is popularly termed "Kanniedood" in Afrikaans, meaning "unkillable," reflecting its hardy nature and adaptive resilience (Bradley, 1992; Newton, 1979).

HISTORY AND ALLOCATION

Aloe vera has been utilized in the field of medical science for over two millennia and has consistently served as a crucial element of therapeutic interventions in regions such as China, India, the West Indies, and Japan (Foster *et al.*, 2011). Historically, scholars have posited that *Aloe vera* originated in the warm, arid environments of Africa. *Aloe vera* thrives in subtropical and tropical regions, encompassing areas such as South America, the Caribbean, and the Mediterranean, as well as in dry forests, urban bushlands, riparian zones, sand dunes, and various other sandy coastal ecosystems (Sowunmi *et al.*, 2022). *Aloe vera* is known by various regional names such as Kalabanda (Telugu), Gheekanwaar (Hindi), Kuwaargandal (Punjabi), Ghrita Kumari, Ghrit Kumaarika (Sanskrit), Indian Aloe (English), GhritKumaari (Bengali), Kumari (Malayalam, Oriya), Katarazhai, Kilimukan, Lolisara (Kannada), Chirukuttali (Tamil), Korepharh (Marathi), and Kumarpathu (Gujarati) and it is also referred to as *Aloe barbadensis* (Malik & Zarnigar 2013).

Aloe vera's therapeutic use dates back around 4,000 years. The potent laxative and purgative properties have been recognized historically. Aloe was referred to as a laxative in the Egyptian Papyrus Ebers as early as 1552 BC (Taylor, 1965). Numerous ancient societies, including those of India, Egypt, China, Rome, and Greece (Marshall, 1990), employed Aloe as a medicinal and cosmetic aid. In the 1st century AD, references to the usage of Aloe in ancient Egypt appear in pharmacopoeia (Castleman, 1991; Steenkamp & Stewart 2007).

In many parts of Himachal Pradesh rural people depends upon plants for treating various ailments (Thakur *et al*., 2023). Medicinal plants such as Aloe, Tulsi, Neem, Turmeric and Ginger cure several common ailments (Singh *et al*., 2018).

The Aloe plant is indigenous to southern Europe and the Canary Islands, *i.e.,* the Mediterranean region. Since the early 1800s, it has been widely cultivated in Mexico and the Caribbean Island. It is harvested all over the world, including Florida, Southern California, South America, Central America, Australia, Pacific Rim nations, Africa, and the Rio Grande valley in South Texas. It typically flourishes in large quantities in hot and dry climates (Newall *et al.*, 1996). Aloe has also been cultivated in India, specifically in the states of Gujarat, Rajasthan, Kerala, Andhra Pradesh, and Tamil Nadu. In addition to Europe, India supplies Aloe to Australia, Malaysia, and Costa Rica.

CHEMICAL COMPOSITION OF *ALOE VERA*

Aloe vera is highly esteemed for its extensive and multifaceted chemical profile, which significantly contributes to its plethora of therapeutic attributes. Contemporary research has discerned in excess of 200 bioactive constituents within *Aloe vera*, with approximately 75 being acknowledged as pivotal nutrients and therapeutic agents (Eshun & He 2004; Radha & Laxmipriya 2015). These constituents encompass vitamins, minerals, enzymes, amino acids, anthraquinones, polysaccharides, and phytosterols. The gel extracted from the leaf of *Aloe vera* predominantly comprises water (96–99%), whereas the residual 0.5–1% consists of a highly advantageous amalgamation of elements such as acemannan (a principal polysaccharide), glucomannan, lignin, saponins, and enzymes including peroxidase and catalase (Boudreau & Beland 2006; Essays, 2018). *Aloe vera* is also rich in essential minerals such as calcium, magnesium, zinc, manganese, iron, and selenium, which are imperative for enzymatic activity, skeletal health, and immune functionality. The vitamin composition includes A, C, E, folic acid, choline, and B-complex vitamins such as B1, B2, B6, and B12, all of which are crucial for metabolic processes and cellular repair (Vázquez *et al*., 1996). Anthraquinones like aloin, aloe-emodin, and barbaloin have demonstrated significant antimicrobial, antifungal, and laxative effects. These compounds are localized in the latex layer of the leaf and are recognized for their ability to induce apoptosis in microbial cells through the disruption of DNA replication (Boudreau & Beland 2006; Subramanian *et al*., 2006). The complex polysaccharides in *Aloe vera*, especially acemannan and glucomannan, are responsible for its immunostimulant and antifungal activities. Acemannan, in particular, enhances macrophage activity and cytokine production, aiding in

the body's defense mechanisms (Davis *et al.*, 1994; Tizard *et al.*, 1989).

Additionally, *Aloe vera* contains sterols like campesterol, beta-sitosterol, and lupeol, which exhibit anti-inflammatory and analgesic effects. Fatty acids such as linoleic acid, caprylic acid, and oleic acid contribute to antimicrobial and skin-healing functions (Reynolds & Dweck 1999). Enzymes present in *Aloe vera*, including amylase, bradykinase, and lipase, support digestive health and help reduce inflammation when applied topically (Boudreau & Beland 2006). Overall, the synergy of these compounds contributes to the plant's broad pharmacological efficacy. The exact composition can vary depending on factors such as soil type, climatic conditions, plant age, and processing techniques (Boudreau *et al.*, 2013; Sowunmi *et al.*, 2022). A breakdown of the key constituents is detailed in Table 1, followed by a diagrammatic representation in Fig. 1 and 2.

Table 1: Key Chemical Components Found in *Aloe vera* Extract (Hęś *et al.*, 2019).

Nutrient Group	Representative Chemical Compounds
Anthraquinones/Anthrones	Anthranol, Aloe-emodin, aloetic acid, emodin, isobarbaloin, aloin A and B (barbaloin), cinnamic acid esters
Carbohydrates	Mannan, acetylated mannan, galactan, glucogalactomannan glucomannan, arabinogalactan, galactoglucoarabinomannan, pectic substances, cellulose
Chromones	Isoaloeresin D, isorabaichromone, neoaloesin A, 8-C-glucosyl derivatives, methylaloediol compounds
Enzymes	Amylase, catalase, carboxypeptidase, lipase, alkaline phosphatase, oxidase, superoxide dismutase, cyclooxygenase
Inorganic Elements	Calcium, magnesium, potassium, zinc, iron, phosphorus, sodium, manganese, copper, chromium, chlorine
Organic Compounds & Lipids	Arachidonic acid, steroids (campesterol, β-sitosterol), γ-linolenic acid, triglycerides, uric acid, lignins, gibberillin, salicylic acid
Amino Acids	Alanine, aspartic acid, arginine, glutamic acid, glycine, histidine, hydroxyproline, leucine, isoleucine, methionine, lysine, phenylalanine, proline, tyrosine, threonine, valine
Proteins	Lectins, lectin-like substances
Vitamins	Vitamin A, C, E, B1, B2, B6, B12, folic acid, choline, β-carotene
Saccharides	Glucose, mannose, L-rhamnose, aldopentose

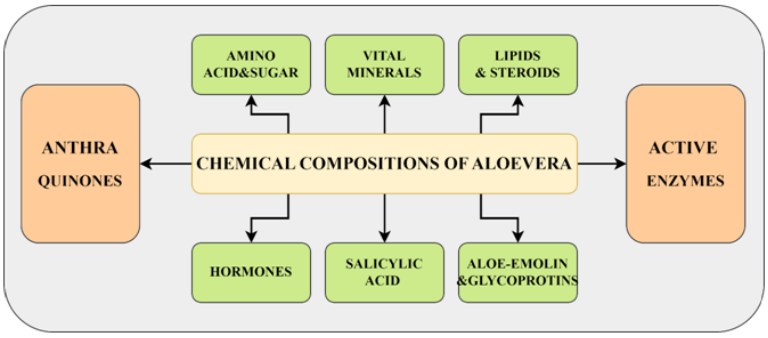

Fig. 1. Chemical Constituents Present in *Aloe vera* Plant (Sharma *et al.*, 2019).

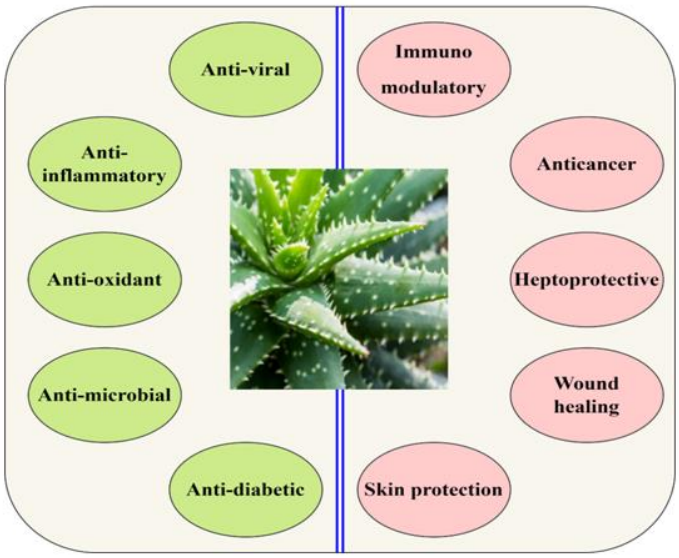

Fig. 2. Applications of *Aloe vera* (Kumar *et al.*, 2019).

UTILIZATION OF *ALOE VERA*

Aloe vera has been used for centuries in various domains such as medicine, cosmetics, and food. Its application is supported by an abundance of bioactive compounds that make it useful for internal and external therapeutic interventions. This section reviews the primary areas where *Aloe vera* demonstrates considerable efficacy.

(i) In Research and Pharmaceutical Development. There is limited yet promising scientific evidence regarding the potency and safety of *Aloe vera* extracts in cosmetics and pharmaceuticals. While some studies have shown beneficial effects, others report inconsistent results. Nonetheless, *Aloe vera* leaf extracts are widely known to be rich in hormones and phytochemicals that function as growth stimulants and wound-healing agents (Hasan *et al.,* 2021). Clinical and preclinical studies elucidate the multifaceted properties of *Aloe vera*, encompassing its roles as an anti-inflammatory, antiviral, antioxidant, antimicrobial, anticancer, antidiabetic, wound-healing, hepatoprotective, and immunomodulatory agent. Notwithstanding certain discrepancies observed in clinical trials, empirical evidence indicates that *Aloe vera* may contribute to the reduction of blood lipid levels in individuals with hyperlipidemia and assist in the regulation of glucose levels in diabetic patients (Sampath Kumar *et al.,* 2010). The topical administration of *Aloe vera* has demonstrated effectiveness in the management of first and second-degree burns, psoriasis, and genital herpes. Nonetheless, rigorously designed clinical trials are requisite to substantiate these purported benefits (Nandlal & Bhardwaj 2012). In commercial applications, *Aloe vera* gel is integrated into yogurts, beverages, and various nutraceutical products. Regulatory agencies have raised concerns regarding the potential toxicological effects of Aloe latex when administered at elevated doses, resulting in its restricted utilization in oral formulations across certain jurisdictions (O'Neil *et al.,* 2006).

(ii) *Aloe vera* as a Dietary Supplement. *Aloe vera* juice, derived from the inner leaf gel, is consumed for its digestive health benefits. It contains vitamins, enzymes, and polysaccharides known to support gastrointestinal functions. However, latex derived from the outer leaf rind contains anthraquinones, which have laxative effects and were once included in over-the-counter purgatives. The FDA banned their use due to insufficient safety data (O'Neil *et al.,* 2006).

(iii) Food Industry Applications. Due to its flavor and bioactive content, *Aloe vera* extract is used in the food industry for manufacturing beverages, candies, jams, yoghurts, instant teas, and ice creams (Ahlawat & Khatkar 2011). Aloe gel is often decolorized and purified before being incorporated into food-grade products to remove latex content and ensure safety.

(iv) Cosmetic and Topical Use. *Aloe vera* gel is a well-established ingredient in cosmetic products such as creams, lotions, shampoos, and sunscreens. It serves as a moisturizing agent and provides relief for sunburns and skin irritations. Its polysaccharides improve skin elasticity and promote wound healing, making it a staple in dermatological formulations (Committee of Experts on Cosmetic Products, 2008).

The cosmetic industry also benefits from *Aloe vera*'s UV-absorbing properties and ability to penetrate the skin, delivering nutrients and enhancing the absorption of other components (Ulbricht *et al*., 2007). It is commonly found in products like lip balms, face masks, shaving gels, and hair conditioners.

(v) Medicinal and Traditional Use. For more than two thousand years, *Aloe vera* has been employed within various traditional medicinal frameworks, encompassing Ayurveda, Traditional Chinese Medicine, and Unani. It has been used to treat burns, frostbite, ulcers, and even X-ray burns. Historical records from the 1930s document its effectiveness in radiation-related skin injuries (Leon, 2003). Aloe latex has been used as a natural purgative for treating constipation, while the gel has shown efficacy in treating minor wounds and inflammatory skin conditions (EMA, 2006). WHO recognizes Aloe latex for occasional use in constipation and Aloe gel for topical wound healing. Aloe gel is also being explored for systemic therapeutic potential through oral administration in managing chronic inflammatory disorders, viral infections, and metabolic syndromes. Several bioactive compounds in Aloe, including bradykinase and plant-derived hormones, modulate pain and inflammation, thus improving post-injury healing and reducing edema (Kumar *et al.,* 2010; Sturm & Hayes 1984). *Aloe vera*-based formulations are being increasingly incorporated in veterinary medicine, topical disinfectants, and antiseptic treatments.

ANTIFUNGAL EFFECT OF *ALOE VERA*

Aloe vera is progressively acknowledged for its antifungal efficacy, which can be ascribed to the synergistic interactions of its multifarious bioactive constituents. Numerous investigations have substantiated *Aloe vera*'s capacity to suppress the proliferation of pathogenic fungi that frequently impact both human health and agricultural yield. One notable application is the use of *Aloe vera* gel as a preharvest treatment to prevent microbial degradation in postharvest fruits, such as table grapes. Aloe gel, when applied to potato dextrose agar (PDA), was shown to inhibit mycelial growth of fungi like *Penicillium digitatum* and *Botrytis cinerea*. Increasing the concentration of Aloe gel resulted in higher inhibition rates, indicating a dose-dependent antifungal activity (Sitara *et al.,* 2011).

Further research confirms *Aloe vera*'s antifungal activity against fungi such as *Aspergillus niger*, *A. flavus*, *Drechslera hawaiiensis*, *Alternaria alternata*, and *Penicillium digitatum* at concentrations ranging from 0.15% to 0.35%. The agar diffusion method revealed that Aloe gel significantly reduced fungal colony development (Sitara *et al.,* 2011). Studies have also highlighted the efficacy of *Aloe vera* ethanolic extracts against *Candida albicans*, a common opportunistic fungus responsible for infections in

immunocompromised individuals. The antifungal activity of the gel was noted to be effective due to glycoproteins that promote cell proliferation and enhance wound healing by improving oxygen availability at the infection site (Shilpa *et al.*, 2020).

Phytochemicals such as saponins, anthraquinones, and polysaccharides in *Aloe vera* contribute significantly to its antifungal activity. These compounds have been tested against a wide array of fungal species, including *Trichophyton mentagrophytes*, *Aspergillus fumigatus*, *Aspergillus glaucus*, *P. notatum*, *R. solani*, and *F. oxysporum* (Zishan & Manzoor 2020). Moreover, green synthesis of silver nanoparticles (AgNPs) using *Aloe vera* aqueous leaf extract has shown antifungal activity against plant pathogenic fungi such as *Rhizopus* and *Aspergillus* species. The nanoparticles synthesized via Aloe-mediated routes were found to be effective in suppressing fungal growth, suggesting an advanced approach for fungal management (Medda *et al*., 2015). Another study on *Aloe megalacantha*, a species of Aloe, confirmed its antifungal potential through agar well diffusion assays. Among tested strains, *Candida krusei* exhibited the highest susceptibility with an average inhibition zone of 22.49 ± 0.47 mm at 400 mg/ml concentration, indicating Aloe's promising use in fungal infection control (Asmerom *et al.*, 2020).

Additionally, *Aloe vera* gel was evaluated against five different fungal species causing postharvest spoilage in fruits and vegetables: *Curvularia hawaiiensis*, *Rhizopus solani*, *Penicillium italicum*, *Botryotinia fuckeliana*, and *Verticillium dahliae*. At concentrations of 100 ml/l and 200 ml/l, *Aloe vera* gel achieved up to 100% inhibition against *V. dahliae* (Sempere Ferre *et al.*, 2022). A recent study also explored the antifungal activity of Aloe-derived silver nanoparticles against multiple clinical isolates of *Candida albicans*. Inhibition zones ranged from 10 to 22 mm, depending on the concentration, with a minimum inhibitory concentration (MIC) reported at 4 µg/ml (Arsène *et al*., 2023). The antifungal mechanism of *Aloe vera* involves disrupting fungal cell membranes, inhibiting ergosterol synthesis, and promoting reactive oxygen species (ROS) accumulation, ultimately leading to fungal apoptosis. Its multifaceted phytochemical profile allows it to act on various fungal targets, making it a suitable alternative or complement to conventional antifungal treatments.

Table 2: Antifungal Activity of *Aloe vera* on Various Fungal Species.

Sample Type	Method	Fungal Species Targeted	Antifungal Outcome	Reference
Aloe vera gel	Agar plate diffusion	*A. niger*, *A. flavus*, *Alternaria*, *Penicillium*	Inhibition at multiple concentrations	Sitara *et al.* (2011)
Aloe vera leaves	Well diffusion	*C. albicans*, *A. niger*	No MIC found	Saniasiaya *et al.* (2017)
Leaf/root extracts	Disc diffusion	*F. oxysporum*, *C. albicans*, *A. fumigatus*, *A. niger*	Inhibition zones up to 19 mm	Mansoor *et al.* (2020)
Aloe vera fruit	Disc diffusion	*C. albicans*	14 mm inhibition at 1000 µg/ml	Shireen *et al.* (2015)
Aloe + ZnO NPs	Agar well diffusion	*A. niger*, *A. oryzae*	Effective antifungal action	Chaudhary *et al.* (2019)
Aloe gel	CLSI Broth dilution	*Candida albicans*	MIC = 6.25%	Vecchione and Celandroni (2018)
Aloe gel NPs	Well diffusion	*A. flavus*, *A. niger*, *P. notatum*	Significant inhibition	Ahmad *et al.* (2022)
Aloe gel	Agar well diffusion	*R. solani*, *C. hawaiiensis*, *P. italicum*, *V. dahliae*	70–100% inhibition of *V. dahliae* at 100–200 ml/l	Sempere Ferre *et al.* (2022)
Crude extracts	Plate hole	*C. paradoxa*, *F. gultiforme*	Inhibition zones: 11 mm, 10 mm	Sales *et al.* (2016)
Leaf extract NPs	Kirby-Bauer/Well diff.	*C. albicans*	MIC = 25 µg/ml, high potency	Arshad *et al*. (2022)

CONCLUSIONS

This review consolidates historical, morphological, and phytochemical evidence showing that *Aloe vera* (*Aloe barbadensis* Miller) possesses a broad therapeutic profile with particular promise as an antifungal agent. Key constituents including acemannan, glucomannan, saponins, chromones, and anthraquinones collectively underpin anti-inflammatory, antimicrobial, antioxidant, wound-healing, and antifungal actions across clinical and agricultural contexts. In vitro and preclinical findings consistently demonstrate growth inhibition of clinically relevant fungi (e.g., *Candida albicans*, *Aspergillus* spp., *Fusarium* spp.) and postharvest pathogens, and emerging nano-enabled formulations further enhance efficacy. However, variability in raw materials and processing, dose–response inconsistency across studies, and safety concerns related to anthraquinone-rich latex (e.g., aloin) limit immediate, standardized clinical translation. Moreover, *Aloe vera* is a strong candidate for integration into modern antifungal strategies, provided its use is guided by rigorous standardization, safety evaluation, and clinical validation.

FUTURE SCOPE

The future of this study lies in translating the antifungal potential of *Aloe vera* into standardized, clinically approved therapies. While laboratory and preclinical studies confirm its efficacy against fungi like *Candida albicans* and *Aspergillus* spp., large-scale clinical trials

are needed to define dosage, safety, and therapeutic indices. Standardization of active compounds and regulatory oversight will ensure consistency and safety. Advances in nanotechnology, including Aloe-based green nanoparticles, may enhance delivery and efficacy. Future work should address pharmacokinetics, long-term safety, and interactions, while also exploring agricultural and food preservation applications, making *Aloe vera* a sustainable alternative to synthetic antifungal agents.

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Conflict of Interest. None.

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