

DEPICTION AND DESIGNING OF PLANT GENOMES
SERIES EDITOR: CHITTARANJAN KOLE AND PHULLARA KOLE

The Aloe Genome Genetics, Genomics and Breeding

Edited by
Vinod Chhokar and Alka Jangra



CRC Press
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The Aloe Genome

The book delves into the intricate world of *Aloe vera*, offering a multidimensional exploration of its biology and genetic makeup. This compilation is meticulously curated, presenting a wide array of topics crucial for understanding and enhancing *Aloe vera*'s agricultural significance. The chapters delve into cutting-edge areas like genomics, transcriptomics, proteomics, metabolomics, and nano-technological advancements specific to *Aloe vera*. It addresses molecular markers, mapping, and genome-wide characterization for breeding, in vitro propagation, and genetic transformation.

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1. Presents authoritative and up-to-date information, empowering with the latest knowledge from leading minds in *Aloe vera* genetics and genomics.
2. Provides exclusive access to groundbreaking insights and advancements in genomics specific to *Aloe vera*, providing readers with a unique and cutting-edge resource.
3. Delves into cutting-edge areas like genomics, transcriptomics, proteomics, metabolomics, and nano-technological advancements specific to *Aloe vera*.
4. Addresses molecular markers, mapping, and genome-wide characterization for breeding, in-vitro propagation, and genetic transformation.
5. Explores physiological responses under abiotic stress, germplasm characterization, gene discovery, and the transformative impact of genomics on plant breeding in *Aloe vera*.

Depiction and Designing of Plant Genomes

Chittaranjan Kole and Phullara Kole

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Genetics, Genomics and Breeding

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Vinod Chhokar and Alka Jangra



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Dedication

*This book series is dedicated to our brothers/brothers-in-law
and sisters/sisters-in-law—*

**Bansi Badan Kole
Niranjan Kole
Bharati Nandi Nee Kole
Arati Kundu Nee Kole
Ram Ranjan Kole**



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Preface to the Series

Genome sequencing of the model plant *Arabidopsis* in 2000 followed by the crop plant rice in 2002 flagged of genome sequencing in an array of plants. As on March 05, 2024, 4604 genomes of 1482 different plant species have been sequenced, and the number has been continuing to grow exponentially. The list includes several crop plants as well as some model plants. Sequencing of the nuclear genomes was followed by sequencing of extranuclear genomes such as mitochondria and chloroplasts, and by several studies on functional genomics. However, detailed reports on them are scattered in the literature, including research articles and reviews. Therefore, a comprehensive compilation of deliberations on the sequences with enumeration of the sequences, annotation, assembly, gene families, and comparative genomics of these useful genomes and elucidation of functional genomics, including transcriptomics, metabolomics, and proteomics in these higher plants, is timely.

A number of higher plants provide the basic F5 – food, feed, fuel, fiber, and furniture – needs, and also, nutraceuticals, beverages, luxury, and aesthetic items. Genetic improvement in these plants with regard to their utilities was being done in the last century, mainly by traditional breeding. The advent of molecular breeding and genetic engineering in the last two decades of the last century strengthened the breeding strategies in the economic plants. Advances in plant genomics have ultimately revolutionized the concepts and strategies of crop improvement. Employment of high-throughput genotyping and phenotyping together with other genomics-assisted breeding tools like gene discovery, allele mining, genome-wide association studies, genomic selection, and genome-wide prediction, etc., has facilitated accelerated and precise plant breeding. Recent emergence of the genome editing technique has enormously supplemented the molecular and genomics tools, making it possible to design and tailor the genomes according to the needs. However, success stories of next-generation breeding techniques need to be compiled for easy access of the readers.

This present book series, entitled *Depiction and Designing Plant Genomes*, includes a number of books each dedicated to the deliberations on genomic attributes and/or genetic improvement of a higher plant, and hopefully will serve as a handy compendium for readers.

The books of this series have been edited by highly reputed scientists, and I remain thankful for their invaluable academic efforts and cooperation. We are also thankful to the publisher and specifically to its Senior Commissioning Editor (Chemistry / Agricultural Sciences), Dr. Renu Upadhyay, and her Editorial Assistant, Tisha Sharma, for their outstanding and timely help and cordial co-operation since the inception of this book series.

Finally, we must express my thanks to our children, Sourav and Devleena, for assisting us in editing the books of this series and also bearing with us for our channelizing the time that should have been kept for them towards editing this book series.

Kolkata, 3rd August 2024
Chittaranjan Kole and Phullara Kole



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About the Editors

Vinod Chhokar, a distinguished Professor of Biotechnology at Guru Jambheshwar University of Science and Technology in Hisar, India, has carved a remarkable career path in the realm of Plant Sciences. His academic journey commenced with a Ph.D. in Biochemistry from CCS Haryana Agricultural University. With a solid educational foundation, he delved into the dynamic field of plant genomics and metabolomics, marking the inception of his illustrious career in 1999. His pioneering research focused on employing molecular approaches for the genetic enhancement of medicinal plants, a field that he has passionately contributed to for over two decades. During his post-doctoral research at Purdue University, West Lafayette, USA, under the prestigious BOYSCAST fellowship of the Department of Science & Technology, Govt. of India, he further honed his expertise in plant genomics. His expertise includes characterizing the genetic makeup and metabolic engineering of medicinal plants such as *Aloe vera*, *Asparagus racemosus*, *Zingiber officinale*, *Bryophyllum pinnatum*, and *Capsicum annuum* L. His contributions to the scientific community are reflected in his extensive publication record, boasting over 100 research papers in highly esteemed journals. A seasoned academician and researcher, he continues to shape the future of plant sciences, leaving an indelible mark on the scientific landscape. His global exposure, membership in professional organizations, and extensive mentorship of students underscore his commitment to advancing knowledge in Functional Genomics, Metabolomics, Biochemistry, and Molecular Biology.

Alka Jangra is an Assistant Professor in Agricultural Biotechnology at the College of Biotechnology, Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, India. She holds a Ph.D. in Biotechnology from Guru Jambheshwar University of Science & Technology. Her research journey is marked by a deep commitment to enhancing the genetic makeup of plants. During her doctoral studies, Alka specialized in the molecular characterization and genetic improvement of *Aloe vera*. Notably, she achieved a breakthrough by developing a highly efficient genetic transformation method for *Aloe vera* using *Agrobacterium tumefaciens*, showcasing her pioneering work in the field. During her postdoctoral work at National Agri-Food Biotechnology Institute (NABI), Mohali, under the Department of Biotechnology (Govt. of India), she played a pivotal role in the biofortification of banana and development of transgene-free genome editing systems. She has published widely in reputed international journals and contributed to several book chapters. She is the co-editor of this volume and a passionate advocate for translational plant science. Her work bridges academic discovery and applied agricultural biotechnology, addressing real-world challenges in sustainable agriculture, food security, and plant-based therapeutics. Her expertise extends to employing advanced techniques like CRISPR/Cas9 for genetic manipulation, reflecting her commitment to cutting-edge research in plant biotechnology.



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1 Exploring *Aloe vera*

Botanical Insights, Medicinal Uses, and Economic Impact

Jyoti Sharma, Shikha Tripathi, Sneha Gupta, and Pooja Garg

1.1 INTRODUCTION

Aloe vera is the oldest known, and the most widely applied medicinal plant worldwide. It is a unique plant with a wealth of historical and cultural value, which is bolstered by its diverse range of applications and vast botanical history (Foster and Hunter, 2009). Its extensive pharmacological characteristics are supported by its varied chemical composition, which includes both gel and latex ingredients. These pharmacological properties have been verified by multiple scientific studies, that confirmed its efficacy in several key areas (Surjushe et al., 2008).

1.1.1 HISTORY

The aloe plant and its derivative products have been integral to medicine and healthcare as far back as the 4th century BC, when ancient Greek doctors sourced aloe from the island of Socotra in the Indian Ocean. In the ancient Nile Valley civilization of Kemet (now referred to as ancient Egypt), aloe was used for medical treatments, beauty care, and embalming. The medicinal use of aloe dates back over 4,000 years, with references found in Sumerian clay tablets from 2100 BC, and it is mentioned as a laxative in the Egyptian Papyrus Ebers from 1552 BC. Through human trade and migration, this plant gained widespread recognition and was used for treating burns and wounds across ancient civilizations (Ni and Tizard, 2004). There are at least 420 different species of aloe, belonging to the family Liliaceae. Among these species, several have been used under the common name of aloe, such as *Aloe vera* Linn., *Aloe barbadensis* Miller, *Aloe ferox* Miller, *Aloe chinensis* Baker, *Aloe. indica* Royle, and *Aloe perryi* Baker (Dagne et al., 2000). Of these, *Aloe vera* Linn., also known as *A. barbadensis* Miller, is unanimously accepted as the correct botanical source of aloe. *Aloe vera* – also referred to as Barbados aloe, *Aloe vulgaris*, *Aloe arborescens*. Cape aloe, and Socotrine or Zanzibar aloe – is the most common form used in aloe-based products (Manvitha et al., 2014). There are over 300 species of aloe, most of which are native to South Africa, Madagascar, and Arabia. These species vary in their concentrations of active ingredients. Originally from South Africa and South America, aloes are currently grown all over the world with the exception of tundra, deserts, and rain forests. In the United States, in southern Texas, aloe is grown commercially (Hossain et al., 2013).

1.1.2 PHENOTYPE OF *ALOE VERA*

Aloe vera is a shrubby or arborescent perennial xerophytic succulent plant with a pea-green tint that is drought-resistant and a member of the Asphodelaceae (Liliaceae) family. The aloe plant has

long, thick, triangular leaves with edges tipped with spikes that can grow up to 20 inches long and five inches wide (Reynolds and Dweck, 1999). It takes four years on average to attain maturity, and its lifespan is roughly twelve years. The clear fresh parenchymal gel found in the leaf center is occasionally dried to make *Aloe vera* concentrate or diluted with water to make goods containing aloe juice. While most reference books regard *A. barbadensis* Miller as the correct name, the WHO monograph accepts *Aloe vera* Linn. as the legitimate name for this species (Das and Chattopadhyay, 2004). *Aloe vera* specifically refers to the *Aloe barbadensis* Miller plant, which is a medicinal plant that grows in hot climates such as California, New Mexico, and the Caribbean (Saeed et al., 2004). The pericyclic tubules, which are greenish-yellow in color, are the source of the sticky latex liquid. The flowers are not utilized medicinally. The Arabic “alloeh” or Hebrew “halal,” which both imply bitter, shining substance, is where the name “aloe” originates (Manvitha and Bidya, 2014).

1.1.3 TRADITIONAL USES OF *ALOE VERA*

In traditional medical systems such as Ayurveda, Siddha, Unani, and homoeopathy, it plays a significant role. *Aloe vera*, or “Ghee kunwar” in Sanskrit. *Aloe vera* grows wild along the southern coast of India. It is grown in a sizable portion of several Indian states, including Tamil Nadu, Gujarat, Maharashtra, and others (Sahu et al., 2013). Aloes may grow in a variety of conditions, including desert, grassland, coastal, and even alpine regions, despite the common misconception that they can only be found in hot, dry climates (Baby and Justin, 2010).

1.1.4 NUTRIENT VALUES OF *ALOE VERA*

Aloe vera leaves are abundant in a variety of minerals, with different proportions of each type present. The fact that calcium makes up about 3.58% of the entire leaf emphasizes how important it is. Following at 1.22%, magnesium adds to the nutritional composition of the plant. Notably, the leaf contains significant amounts of potassium and sodium, which are necessary for cellular activity and electrolyte balance, making about 4.06% and 3.66% of the leaf, respectively (Foster et al., 2011). There are also trace levels of iron, zinc, copper, and phosphorus, with values ranging from 0.02% to 0.1%, which offer extra nutritional assistance. When ingested or applied topically for health advantages, these minerals together increase the nutritional content of *Aloe vera*, perhaps providing it with vital elements. Aloe has traditionally been used as a potent laxative to treat chronic constipation, and many pharmacopoeias still include it as a laxative. It has been mostly replaced, nevertheless, by more moderate laxatives (Mulu et al., 2015). The Aloe plant was first utilized commercially for the manufacture of a substance called Aloin, a yellow sap that was used as a laxative for a long time (Atul et al., 2011).

1.1.5 THERAPEUTICS USES OF *ALOE VERA*

Early in the 20th century, this product was mentioned in commercial, technical, and official literature and came to be associated with the name “Aloe.” Later on, aloe gel, the other key constituent in aloe, started to be recognized as a valuable product in the 1950s and was utilized as a moisturizer, healing agent in cosmetics, and a base for nutritional drinks. However, it caused a great deal of misunderstanding due to the nomenclature (Grace et al., 2008). *Aloe vera* is a multipurpose plant that is mostly utilized as a medication and for food preservation. It is sold commercially in the form of tablets, sprays, ointments, lotions, beverages, jellies, and creams (Tarameshloo et al., 2012). The plant known as “healing aloe,” contains enzymes, amino acids, vitamins, minerals, and other active components, (totaling more than 75), some of which may have therapeutic applications. Around the world, a variety of aloe species are used to treat ailments ranging from cancer to dermatitis (Liu et al., 2010). *Aloe vera* leaf has been shown in numerous studies to have a wide range of medicinal

properties, such as antibacterial, anticancer, antioxidant, antidiabetic, antiulcer, hepatoprotective, immunomodulatory, and many more (Langmead et al., 2004). The polysaccharides included in the gel of the leaves of *Aloe vera* have been linked to numerous health benefits. It has been used for a variety of conditions, including burn wound healing, immune modulation, intestinal absorption, antidiabetic, antioxidant, hepatoprotective, anticancer, antimicrobial, antiviral, antihyperlipidemic, and antiulcer properties (Devaraj et al., 2008).

1.2 CHEMICAL COMPOSITION AND BIOLOGICAL PROPERTIES OF ALOE VERA

Aloe vera is well known for its gel and latex leaf lining, which include chemical components that may be biologically active. A range of polysaccharides, including acemannan and glucomannan, as well as important substances including carboxypeptidase, magnesium, zinc, calcium, glucose, cholesterol, and salicylic acid are present in the gel (Liu et al., 2006). It also includes amino acids, lignins, saponins, plant sterols, vitamins A, C, and E, and prostaglandin precursors like gamma-linolenic acid (GLA) (Hamman, 2008). However, the anthraquinone glycosides found in abundance in the latex leaf lining include barbaloin, aloin, and aloe-emodin. *Aloe barbadensis* contains around 200 chemicals, roughly 75 of which are biologically active (Misra and Dey, 2001). Many different types of chemicals are found in *Aloe vera* leaves, such as anthrones and their glycosides (e.g., 10-(1, 5' anhydroglucosyl)-aloeemodin- 9-anthrone, also known as aloin A and B), chromones, carbohydrates, proteins, glycoproteins, amino acids, organic acids, lipids, sugars, vitamins and minerals (Femenia et al., 1999). *Aloe vera* juice offers a minimal calorie content of ten per 8-ounce serving, making it a low-calorie beverage option. It contains no protein or fat but provides two grams of carbohydrates, including one gram of fiber. The juice is naturally sugar-free. In terms of minerals, a serving typically supplies 74 milligrams of calcium, 60 milligrams of sodium, and 110 milligrams of potassium (Ni et al., 2004). These nutritional components contribute to *Aloe vera*'s appeal as a healthful addition to diets, offering hydration and modest amounts of essential minerals. However, it is essential to note that while *Aloe vera* provides certain nutrients, its consumption should be moderate and ideally discussed with a healthcare provider, given its potential interactions with medications and individual sensitivities. Aloe gel is a popular component of many over-the-counter skin salves and is 99% water with a pH of 4.5. Glucomannan, an emollient polysaccharide, is present in the gel (Saroj et al., 2004). Its use in numerous cosmetics can be attributed to its effectiveness as a moisturizer (Babaei et al., 2012). The primary carbohydrate component of the gel, acemannan, is a water-soluble long-chain mannose polymer that has antiviral and antineoplastic properties as well as the ability to speed up wound healing and modify immunological function, notably macrophage activation and cytokine production (Im et al., 2005). Additionally, the gel contains magnesium lactate, which helps to minimize itching, salicylic acid, and other antiprostaglandin chemicals that reduce inflammation, as well as bradykininase, an anti-inflammatory (Park and Jo, 2006). Strong stimulant laxatives called anthraquinone glycosides, such as aloin, aloe-emodin, and barbaloin, are found in the latex, resin, or sap that lines leaves (Table 1.1).

The chemical composition of *Aloe vera* in detail:

- **Anthraquinones and anthrones**, such as aloe emodin, aloetic acid, anthranol, barbaloin, isobarbaloin, and emodin, along with esters of cinnamic acid, are known for their diverse pharmacological properties. Specifically, compounds like aloin and emodin exhibit analgesic, antibacterial, and antiviral activities (Choi and Chung, 2003). These natural products have been studied for their potential therapeutic applications, contributing to the understanding and development of novel treatments in medicine and healthcare.
- **Carbohydrates** encompass a wide array of compounds such as pure mannan, acetylated mannan, glucogalactomannan, galactan, and others, including pectic substances, xylan, and

TABLE 1.1
Representation of chemical constituents of *Aloe vera*

Aloe vera: Potentially Active

Chemical Constituents	From the Gel	From the Latex Leaf Lining
Polysaccharides	Glucomannan, Acemannan	
Other	Carboxypeptidase, Magnesium, Zinc, Calcium, Glucose, Cholesterol, Salicylic Acid, Prostaglandin Precursors (gamma-linolenic acid [GLA]), Vitamins A, C, E, Lignins, Saponins, Plant Sterols, Amino Acids	
Anthraquinone Glycosides		Aloin, Aloe-Emodin, Barbaloin

cellulose (Femenia et al., 1999). Among these, a glycoprotein known as alprogen exhibits notable antiallergic properties, while novel anti-inflammatory compounds are also identified within this class (Chow et al., 2005). These diverse carbohydrate compounds contribute significantly to various biological activities and applications in pharmaceutical and biomedical research.

- **Chromones** such as 8-C-glucosyl-(2'-O-cinnamoyl)-7-O-methylaloediol A, 8-C-glucosyl-(S)-aloesol, and others like isoaloesin D and nealosin A are notable for their novel anti-inflammatory properties. These compounds have been identified for their potential therapeutic effects in managing inflammation, contributing to ongoing research into new treatments and medications (Hutter et al., 1996). Chromones represent a diverse class of natural products with promising pharmacological activities that continue to be explored for their beneficial impacts on health and well-being.
- **Enzymes** encompass a diverse group of biological catalysts essential for various physiological processes. Examples include alkaline phosphatase, amylase, bradykinase, carboxypeptidase, catalase, cyclooxygenase, lipase, oxidase, phosphoenolpyruvate carboxylase, and superoxide dismutase. Each enzyme serves specific roles: bradykinase, for instance, aids in reducing excessive inflammation when applied topically to the skin, while others play crucial roles in breaking down sugars and fats within the body (O'Brien et al., 2011). These enzymatic activities are integral to maintaining metabolic balance and supporting overall health and wellness.
- **Inorganic compounds** such as calcium, chlorine, chromium, copper, iron, magnesium, manganese, potassium, phosphorus, sodium, and zinc play crucial roles in biological systems. They are essential for the proper functioning of numerous enzyme systems involved in diverse metabolic pathways. Additionally, some of these compounds act as antioxidants, helping to neutralize harmful free radicals and thereby contributing to overall cellular health and longevity (Eshun and He, 2004). Their presence and balance are vital for maintaining physiological processes and supporting optimal bodily functions.
- **Proteins** found in *Aloe vera* gel include lectins and lectin-like substances, which contribute to its bioactive properties. *Aloe vera* also contains salicylic acid, known for its anti-inflammatory and antibacterial effects. Additionally, lignin, though inert itself, enhances the penetration of other active ingredients into the skin when included in topical formulations (Josias, 2008). Saponins, comprising approximately three percent of the gel, provide cleansing and antiseptic benefits due to their soapy nature. These constituents collectively contribute to the therapeutic and cosmetic uses of *Aloe vera*, making it a valuable natural remedy for skincare and health applications (Roy et al., 2012).
- **Vitamins** A, B12, C, E, choline, and folic acid play essential roles in maintaining overall health. Among them, vitamins A, C, and E are known for their antioxidant properties,

which help neutralize free radicals in the body. Antioxidants are crucial for protecting cells from oxidative stress, thereby supporting healthy aging and reducing the risk of chronic diseases (Patidar et al., 2012). These vitamins are obtained through a balanced diet and supplementation, contributing to various physiological functions and promoting well-being.

- **Hormones** such as auxins and gibberellins play important roles in plant growth and development, but they also exhibit therapeutic properties in humans. Auxins, for example, are involved in wound healing processes and have been noted for their anti-inflammatory actions. Gibberellins, similarly, contribute to wound repair and may have additional beneficial effects on inflammation. These natural compounds highlight the potential for plant hormones to be utilized in medicinal contexts, offering insights into novel treatments and therapies for promoting healing and reducing inflammation in various medical applications.

1.3 CULTIVATION

1.3.1 CLIMATE

Aloe vera thrives in tropical, sub-tropical, and arid regions, even under persistent drought conditions due to its low water requirements. It flourishes in hot and dry climates but does not grow well in cold environments (Chandra and Pandey, 1989). However, *Aloe barbadensis*, which is cultivated mainly for its medicinal uses, can grow effectively under irrigated conditions (Saroj and Purohit, 2004).

1.3.2 SOIL

It grows well in marginal to sub-marginal soils with low fertility and can tolerate high pH levels along with elevated sodium and potassium salts. However, it grows more quickly in medium-fertility, heavier soils. For commercial cultivation, well-drained loam to coarse sandy loam soils with moderate fertility and a pH up to 8.5 are preferred, as waterlogged soils are entirely unsuitable.

1.3.3 LAND PREPARATION

The soil should not be disturbed too deeply, as Aloe's root system extends only 20–30 cm below the surface. Depending on soil type and agroclimatic conditions, one or two ploughings followed by leveling may be necessary. Due to Aloe's sensitivity to water stagnation, effective drainage is essential. Fields should be divided into appropriately sized plots, taking into account the slope and available irrigation sources.

1.3.4 PROPAGATION

Propagation is achieved using root suckers or rhizome cuttings. Medium-sized root suckers are selected, carefully extracted without harming the parent plant, and then directly planted in the main field (Rajeswari et al., 2012).

1.3.5 PLANTING TIME

Suckers should be planted in July or August during the monsoon season to enhance field survival and promote healthy plant growth. However, in irrigated conditions, planting can occur throughout the year, except during the winter months from November to February (Rajeswari et al., 2012). *Aloe vera* flowers between October and January, producing long inflorescences with numerous small, bright orange, yellow or coral flowers. The fruits develop from February to April (Manvitha and Bidya, 2014).

1.3.6 MANURING

The crop benefits significantly from the application of farmyard manure (FYM) and compost. In the first year of planting, FYM should be applied at a rate of 20 tons per hectare during land preparation, with the same amount used in subsequent years. Additionally, vermicompost at 2.5 tons per hectare can also be applied (Rajeswari et al., 2012).

1.3.7 SPACING AND PLANTING

Suckers are planted in pits approximately 15 cm deep, created at the time of planting, and spaced 60×60 cm apart. Once the suckers are planted, the soil around the root zone should be compacted firmly, and proper drainage must be ensured to prevent water stagnation (Rajeswari et al., 2012).

1.3.8 IRRIGATION

Aloe is quite resilient to stress, but to achieve optimal yields, irrigation during critical growth stages is essential. It can be effectively grown under both irrigated and rainfed conditions. To ensure good yields, irrigate immediately after planting and provide two to three additional irrigations per week until the plant is established. Typically, two to three irrigations in summer and one to two in winter are sufficient for healthy growth. In semi-arid conditions, once established, Aloe can thrive even without additional irrigation (Saroj et al., 2004).

1.3.9 INTERCROPPING

In the first year after planting, over 40% of the land may remain unused. To make the most of this space, suitable leguminous or low-competition intercrops such as cluster beans, sesame, or coriander can be planted in the gaps, which will also enhance soil conditions. However, from the second year onwards, these intercrops should be avoided as they can interfere with the growth of *Aloe vera* (Maiti and Chandra, 2002).

1.3.10 PLANT PROTECTION

Insect pests and diseases are generally not major issues for this crop. However, problems such as mealy bugs, anthracnose, termites, pad spot disease, leaf spots, and sucker rotting have been reported (Rajeswari et al. 2012). To prevent these issues and enhance crop quality and productivity, maintaining field sanitation is beneficial. Additionally, applying two to three foliar sprays of Dithane M-45 (0.2%) at weekly intervals can help reduce fungal diseases (Saroj et al., 2004).

1.3.11 HARVESTING

An Aloe plantation begins to produce yields approximately six to eight months after planting. However, for commercial yields, it typically takes about a year to achieve, and production can continue for up to five years. After this period, replanting is necessary (Saroj et al., 2004). Typically, older outer leaves are harvested, leaving the fresh and young leaves at the top. Plants can be removed manually or with the aid of a tractor-drawn disc harrow or cultivator. Leaves showing tip necrosis should be avoided as they can be prone to microbial contamination. It is important to minimize juice loss from the cut areas. If harvesting occurs annually, the optimal period is October to November. Post-harvest, the leaves are dried in the shade, followed by sun-drying before storage. Flowers are gathered from December to January and preserved after proper drying. Harvested leaves are carefully stacked and then transported to refrigeration or processing facilities (Manvitha and Bidya, 2014).

1.3.12 PROCESSING

Aloe vera gel is a mucilaginous substance derived from the parenchyma cells of the *Aloe vera* plant. Once exposed to air, the gel quickly oxidizes, decomposes, and loses much of its biological activity. Various researchers have outlined different methods for processing the gel, such as cold processing or heat treatment, to achieve sterilization and stabilization. Despite the differences in techniques, the underlying principle remains similar. Optimal results are achieved when the leaves are processed immediately after harvesting, as natural enzymatic reactions and bacterial growth – triggered by exposure to oxygen – can lead to the degradation of the gel matrix (Ramachandra and Rao, 2008).

The process begins with washing freshly harvested *Aloe vera* leaves in a suitable bactericide. The leaves are then processed to mechanically separate the gel matrix from the outer cortex. The addition of cellulose-dissolving compounds, such as cellulase, can help facilitate this separation. The resulting Aloe liquid is treated with activated carbon to remove color and eliminate aloin and anthraquinones, which have laxative properties, especially if the stabilized gel is intended for internal consumption. The liquid undergoes several steps of filtration, sterilization, and stabilization. The final stabilized liquid can be concentrated to reduce its water content or further processed to remove nearly all the water, resulting in a powder (Ramachandra and Rao, 2008).

In the cold processing method, all steps are carried out without using heat. Coats (1979) described using enzymes such as glucose oxidase and catalase to prevent the growth of aerobic organisms in *Aloe vera* gel, thereby sterilizing it. Additional sterilization steps in cold processing involve exposing the gel to ultraviolet light, followed by micron filtration through a 0.2 µm membrane. In heat treatment processing, sterilization is achieved by pasteurizing the aloe liquid obtained from the activated carbon treatment at high temperatures. According to Aloecorp, the biological activity of *Aloe vera* gel remains largely intact when heated at 65°C for less than 15 minutes. Longer heating periods or higher temperatures significantly reduce the activity levels. They recommend HTST (High Temperature Short Time) pasteurization, followed by rapid cooling to 5°C or below, as the best method. In these processes, stabilization can be achieved by adding preservatives and other additives. The use of sodium benzoate, potassium sorbate, citric acid, and vitamin E in combination has been reported to be effective.

1.4 ECONOMIC IMPORTANCE OF ALOE VERA

The *Aloe vera* plant has been renowned for centuries for its health, beauty, medicinal, and skincare benefits. Its economic importance is derived from its extensive use in agriculture, pharmaceuticals, cosmetics, and health products. *Aloe vera* promotes sustainable farming, particularly in arid areas, offering income and job opportunities. The global trade of *Aloe vera* products significantly boosts export revenues and drives economic growth and innovation across multiple industries. Here, we summarize *Aloe vera*'s applications in various sectors in Figure 1.1.

1.4.1 COSMETIC USES

Aloe vera is extensively utilized in the cosmetic industry, where three distinct forms are used: *Aloe vera* latex, *Aloe vera* gel, and *Aloe vera* whole leaf extract. These preparations contain biological ingredients that may function individually or synergistically (Boudreau and Beland, 2006). Aloe gel is renowned for its ability to retain moisture for long periods and its soothing properties (Gage, 1996). Additionally, *Aloe vera* serves as an astringent, moisturizer, and cleanser (Manvitha and Bidya, 2014). Consequently, it is widely incorporated into various cosmetic and toiletry products, including moisturizers, cleansers, sunscreens, shampoos, conditioners, and serums.

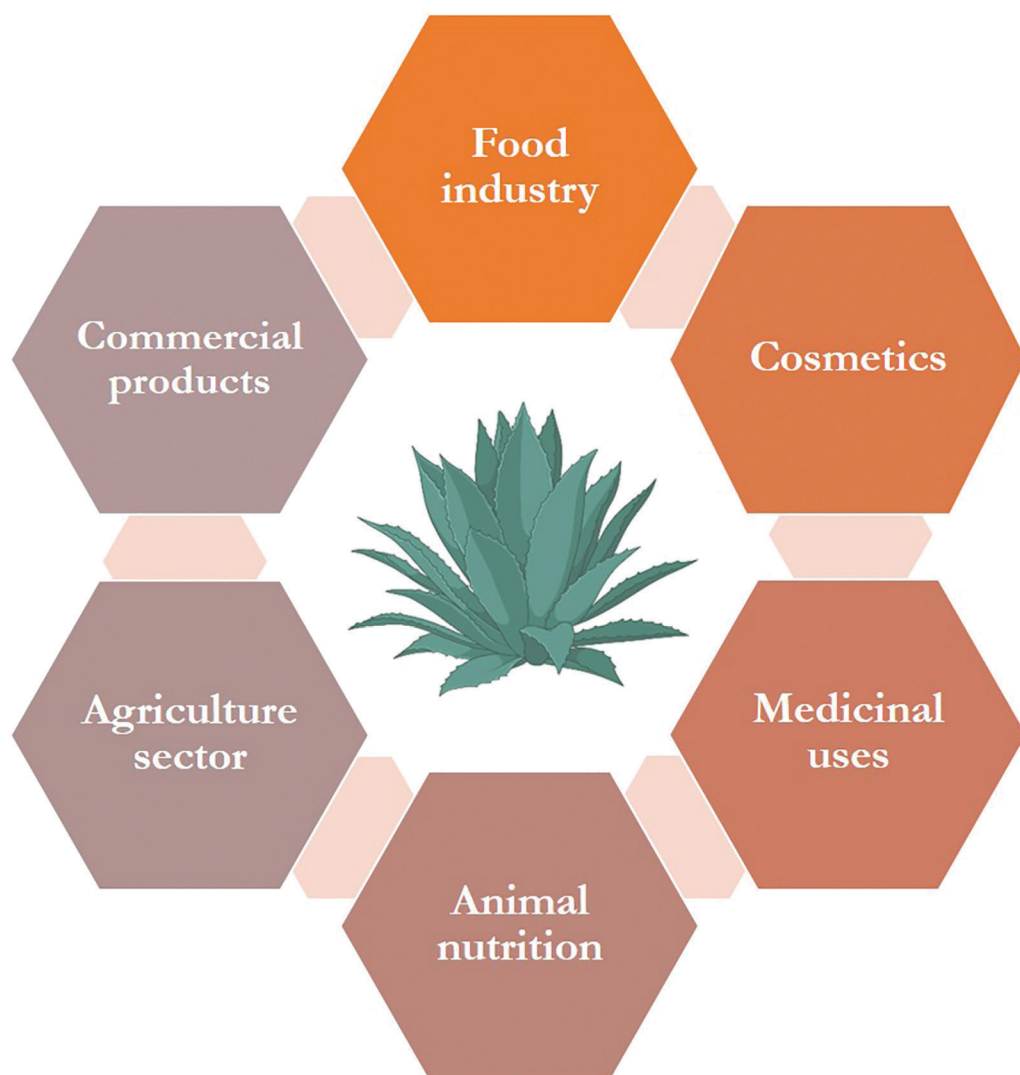


FIGURE 1.1 Representation of the economic importance of *Aloe vera*.

1.4.2 FOOD USES

The food and beverage industry presents a promising opportunity for *Aloe vera*. It has been utilized in functional, such as yogurt and smoothies, and in health drinks, including tea (Eshun and He, 2004). Botanical products are widely recognized for their use as nutritional supplements that promote health and prevent diseases. According to Serrano et al. (2006), *Aloe vera* gel can serve as an edible coating to extend the quality and safety of fresh produce. For instance, aloe-coated table grapes experienced a significant delay in the loss of functional compounds, including total phenolic and ascorbic acid. *Aloe vera* also inhibits the growth of microorganisms that cause foodborne illnesses and spoilage in both humans and animals (Eshun and He, 2004). Moreover, *Aloe vera* does not alter the taste or appearance of food, making it a promising natural, safe, and environmentally friendly alternative to conventional synthetic preservatives (Serrano et al., 2006).

1.4.3 MEDICINAL USES

- **Healing wounds:** The healing properties of *Aloe vera* are due to polysaccharides such as Glucomannan and the growth hormone gibberellins, which boost collagen and elastin production, resulting in reduced wrinkling and improved healing (Reynolds and Dweck, 1999; Surjushe et al., 2008). Furthermore, *Aloe vera* is effective in treating scar tissue and preventing scar formation after skin injuries, likely because of the amino acids necessary for new cell formation and enzymes that promote regeneration of the skin's deepest layers (Choi and Chung, 2003).
- **Anti-inflammatory action and immunity activity:** *Aloe vera* gel not only alleviates pain and discomfort due to its anti-inflammatory properties but also accelerates the healing process. The acetylated mannan in Aloe gel has anti-inflammatory effects similar to mannose-6-phosphate (Hamman, 2008). *Aloe vera* inhibits the cyclooxygenase pathway, reducing prostaglandin production and inflammation, making it useful for arthritis and joint problems (Reynolds and Dweck, 1999; Surjushe et al., 2008; Yu et al., 2009). Its polysaccharides activate macrophage cells to produce nitric oxide, secrete cytokines (like TNF- α , IL-1, IL-6, and INF- γ), and present cell surface markers, showcasing its immunomodulatory activities (Chow et al., 2005). Additionally, some immunomodulatory effects are linked to glycoproteins, such as lectins, found in the gel (Hamman, 2008).
- **Effects on skin exposure to UV and X-radiation:** *Aloe vera* has been noted to shield the skin from radiation damage (Roberts and Travis, 1995). It is believed that applying *Aloe vera* gel generates the antioxidant protein metallothionein, which scavenges hydroxy radicals and protects the skin from oxidative damage. Additionally, it releases the immunosuppressive Interleukin IL-10, preventing UV-induced suppression of delayed-type hypersensitivity (Byeon et al., 1988).
- **Effects on ulcers:** *Aloe vera* gel can treat gastric ulcers or prevent their formation in both animals and humans. Its antiulcer properties are due to several mechanisms, including its anti-inflammatory effects, healing properties, stimulation of mucus production, regulation of gastric secretions, and the presence of lectins (Hamman, 2008).
- **Antidiabetic activities:** Certain inorganic elements such as vanadium, manganese, and copper, along with the polysaccharides in *Aloe vera*, may play a crucial role in its antidiabetic properties (Reynolds and Dweck, 1999; Rajendran et al., 2007). This plant has been associated with reducing blood glucose levels in diabetics and lowering blood lipid or cholesterol levels by approximately 30% in patients with hyperlipidemia (Lim et al., 2003; Geremias et al., 2006).
- **Antioxidant activities:** *Aloe vera* exhibits significant antioxidant properties. Its gel contains glutathione peroxidase activity, superoxide dismutase enzymes, and a phenolic antioxidant, which likely contribute to these effects (Langmead et al., 2004; Hamman, 2008).
- **Laxative effects:** The anthraquinones in *Aloe vera* latex act as a strong laxative, enhancing intestinal peristalsis (Boudreau and Beland, 2006).
- **Antibacterial properties:** Aloe gel inhibits the microorganisms *Streptococcus pyogenes* and *Streptococcus faecalis* (Heggors, Pineless, and Robson, 1979). It is effective against both gram-positive and gram-negative bacteria that cause food poisoning or diseases in humans and animals (Habeeb et al., 2007).
- **Antifungal activity:** *Aloe vera*'s leaf pulp and liquid fraction are effective against plant pathogenic fungi (Joseph and Raj, 2010). It has also been shown to inhibit *Candida* (Feily and Namazi, 2009). Due to its antifungal properties, *Aloe vera* is used as a water conditioner in fish tanks (Shamim et al., 2004).
- **Antiviral and antitumor activity:** These effects might result from both indirect and direct actions: indirectly by stimulating the immune system and directly through anthraquinones (Surjushe et al., 2008). Consequently, clinical trials are underway to gather conclusive evidence for using *Aloe vera* in treating HIV-AIDS and cancer (Eshun and He, 2004).
- **Moisturizing and anti-aging effect:** Aloe is rich in mucopolysaccharides, which help retain moisture in the skin. It stimulates fibroblasts to produce collagen and elastin fibers,

enhancing skin elasticity and reducing wrinkles. Aloe's cohesive effects bind superficial epidermal cells, softening the skin, while its amino acids soften hardened skin cells. Zinc in the gel acts as an astringent, tightening pores. *Aloe vera* gel gloves have been shown to improve skin integrity, reduce fine wrinkles, and decrease erythema in dry skin caused by occupational exposure, highlighting its moisturizing effects (West and Zhu, 2003).

- **High cholesterol and triglyceride levels can be lowered naturally with Aloe vera:** High cholesterol is a risk factor for heart disease and strokes. Medical studies have demonstrated the internal benefits of *Aloe vera* gel. Results showed that administering *Aloe vera* gel to patients with heart disease and high cholesterol reduced their risk levels (Manvitha and Bidya, 2014).
- **Role in dentistry:** *Aloe vera* extracts have proven effective in maintaining oral hygiene, and Wynn (2005) also noted the use of *Aloe vera* gel in dental care.

1.4.4 THE USE OF *ALOE VERA* IN ANIMAL NUTRITION

In addition to its other applications, *Aloe vera* plays a significant role in promoting growth and managing the health of chickens (Bejar and Colapo, 2005; Mwale et al., 2005). For broiler chickens, adding 600 mg/kg of aloe powder, aloe water extract, aloe ethanol extract, or a combination of these to their diet can enhance production performance and immune function, with aloe water extracts showing the most significant improvements. Some studies also found that *Aloe vera* improved the acceptability of broiler meat (Wang et al., 2007).

Broilers fed *Aloe vera* exhibited significantly higher haemagglutination inhibition titres against Newcastle disease. Additionally, *Aloe vera* has been reported to help manage and control coccidiosis in chickens (Mwale et al., 2005; Chandrakesan et al., 2009). Including *Aloe vera* in the diet of laying hens led to a notable increase in egg production per hen, although there was no change in feed consumption or feed conversion ratio. Furthermore, *Aloe vera* extracts in the diet of laying hens may mitigate or treat the effects of lead intoxication in birds (Moorthy et al., 2009). Additionally, *Aloe vera* has been reported as an effective natural phytochemical growth promoter for shrimp, showing promising results.

1.4.5 AGRICULTURE SECTOR

Aloe vera is highly valuable in agriculture due to its numerous benefits. It thrives in arid regions where other crops might struggle, offering a revenue source for farmers in such areas. *Aloe vera* can act as a natural pesticide (Patel, 2017) and fungicide, minimizing the need for chemical treatments and supporting soil health while reducing chemical residues on crops. Its extracts help safeguard plants from pests and diseases, boosting plant resilience and crop yield. Additionally, the vitamins, enzymes, and minerals in *Aloe vera* serve as a biofertilizer, promoting healthy plant growth and enhancing agricultural productivity.

1.4.6 COMMERCIAL PRODUCTS

In addition to its health and beauty applications, *Aloe vera* is used in a wide range of commercial products due to its many benefits. It is found in food and beverages (such as yogurts and jellies), personal care items (including soaps, body washes, hand sanitizers, and deodorants), household products (such as detergents, cleaning sprays, and air fresheners), as well as textiles and other goods (such as wipes and tissues) (Adlakha et al., 2022).

1.4.7 ECONOMIC DEVELOPMENT

Aloe vera plays a pivotal role in economic development by driving growth across various sectors. Its cultivation provides income for farmers, particularly in arid and semi-arid regions where other

crops may not thrive. The growing demand for *Aloe vera* in cosmetics, pharmaceuticals, and health and wellness products generates significant revenue, creating jobs and stimulating economic activity in both rural and urban areas. Additionally, the global trade of *Aloe vera* products boosts export revenues for producing countries, enhancing their economic prospects and contributing to broader economic development. This multifaceted impact underscores *Aloe vera*'s importance as a driver of economic growth and sustainability.

1.5 FUTURE PROSPECTS

1.5.1 EMERGING TRENDS IN *ALOE VERA* RESEARCH AND DEVELOPMENT

Aloe vera, known for its soothing and healing properties, has been a staple in traditional medicine and skincare for centuries. Recent advancements in research and development are unlocking new potentials for this versatile plant, propelling it into emerging fields and industries. The latest trends in *Aloe vera* research in various sectors include:

1.5.2 GENETIC ENGINEERING AND BIOTECHNOLOGY

Recent advancements in genetic engineering and biotechnology are paving the way for new strains of *Aloe vera* with enhanced properties. Researchers are focusing on manipulating the plant's genetic makeup to increase the concentration of beneficial compounds such as polysaccharides, vitamins, and amino acids. The use of CRISPR technology could allow for precise editing of *Aloe vera* genes to enhance desirable traits, such as increased resistance to pests or higher yields of medicinal compounds (Shelake et al., 2023). Additionally, a metabolic engineering approach can optimize the pathways in *Aloe vera* that produce bioactive compounds, making the extraction process more efficient and cost-effective. These genetically modified variants could lead to more effective products for medicinal, cosmetic, and nutritional use.

1.5.3 NANOTECHNOLOGY

Nanotechnology is revolutionizing *Aloe vera* applications with its impressive capabilities and groundbreaking innovations, particularly in the fields of pharmaceuticals and skincare. As a result, the application of *Aloe vera* has expanded significantly in areas such as wound healing, tissue engineering, and drug delivery through its use in hydrogels, nanoparticles, nanocomposites, nanofibers, and bio-inspired sponges (Balaji et al., 2015). Nano-encapsulation of *Aloe vera* extracts can protect its sensitive components from degradation, enhancing the bioavailability and targeted delivery of active compounds to specific tissues or cells, making treatments more effective. This technology also enables controlled release, enhancing the longevity and efficacy of *Aloe vera*-based products. In skincare, topical nanocarriers can help *Aloe vera* penetrate deeper into the skin, maximizing its hydrating and healing effects (Araujo et al., 2022).

1.5.4 SUSTAINABLE CULTIVATION AND PROCESSING

As sustainability becomes a critical concern globally, current research is focused on developing eco-friendly cultivation and processing methods for *Aloe vera*. Innovations in this area focus mainly on reducing the environmental impact of *Aloe vera* farming and production. Implementing organic farming practices, water-efficient irrigation systems (such as drip irrigation and rainwater harvesting), and renewable energy-powered processing plants will help in reducing the environmental footprint of *Aloe vera* production. This trend aligns with the global shift towards green and sustainable practices.

1.5.5 CLINICAL RESEARCH AND EVIDENCE-BASED APPLICATIONS

While *Aloe vera* has been used traditionally for various ailments, the medical community is increasingly interested in validating its health benefits through rigorous clinical research. Conducting randomized controlled trials can provide high-quality evidence regarding the efficacy of *Aloe vera* in treating conditions such as diabetes, inflammatory diseases, and cancer (Samarh et al., 2017). Systematic reviews and meta-analyses suggest that the current shift towards evidence-based applications can facilitate the integration of *Aloe vera* into mainstream medical treatments.

1.5.6 POTENTIAL APPLICATIONS IN NEW INDUSTRIES AND HEALTH SECTORS

As research continues to uncover the myriad benefits of *Aloe vera*, its applications are expanding into new industries and health sectors. Below are some of the promising areas where *Aloe vera* is making a significant impact:

1.5.7 PHARMACEUTICALS

The pharmaceutical industry is poised to harness *Aloe vera*'s therapeutic properties in developing new medications. Its anti-inflammatory, antimicrobial, and immunomodulatory properties make it a promising candidate for a range of treatments, including wound healing, gastrointestinal issues, and autoimmune diseases (Surjushe et al., 2008; Heng et al., 2018; Kumar et al., 2019). Extracts of *Aloe vera* may be formulated into pills, creams, and injectables for chronic conditions like arthritis and inflammatory bowel disease, thereby offering natural alternatives to synthetic drugs.

1.5.8 FUNCTIONAL FOODS AND NUTRACEUTICALS

Several researchers assert that the nutritional and functional benefits of *Aloe vera* are due to its minerals, water-soluble vitamins, and glucomannan (Vega et al., 2005; Hamman, 2008). On account of its chemical composition and structure, *Aloe vera* is considered a significant and natural source of prebiotics. Nowadays, *Aloe vera* is increasingly being incorporated into functional foods and nutraceuticals, which are foods containing prebiotics and probiotics as components with health benefits beyond basic nutrition. *Aloe vera*-based drinks, supplements, and fortified foods are gaining popularity for their potential to improve digestive health, boost immunity, and provide antioxidants (Cuvas-Limon et al., 2015). The demand for natural and health-enhancing food products is driving innovation in this sector.

1.5.9 COSMETICS AND PERSONAL CARE

The cosmetic industry has long utilized *Aloe vera* for its moisturizing and healing properties. Emerging trends are now focusing on developing high-performance, natural skincare products that cater to the growing demand for clean beauty. *Aloe vera* is being used in formulations of sunscreens, anti-aging creams, and hair care products, appealing to consumers seeking effective and natural solutions (Park and Jo 2006; Kumar et al., 2019).

1.5.10 VETERINARY MEDICINE

The benefits of *Aloe vera* are not limited to human health. The veterinary sector is exploring its use in treating animals. Being a natural antioxidant, *Aloe vera* serves as an excellent alternative to synthetic forms, effectively combating cellular and membrane damage caused by pro-oxidants (Sinha et al., 2017). *Aloe vera* based products are being developed for pet skincare, wound healing, and digestive health. This application not only benefits pets but also livestock, potentially improving the health and productivity of farm animals (Ebrahim et al., 2020).

1.5.11 AGRICULTURE AND PLANT HEALTH

Interestingly, *Aloe vera* is finding applications in agriculture as well, where its extracts are being used as natural pesticides and fertilizers. The antimicrobial properties help in protecting crops from diseases, making it an effective natural pesticide, while the nutrient content promotes healthier plant growth, enhancing yield and quality (Ndhlala et al., 2009; Rahmani et al., 2015). Additionally, the use of *Aloe vera* gel coating has generated significant interest due to its potential to extend the shelf life and storage duration of fresh horticultural produce (Hasan et al., 2021). This trend supports sustainable farming practices and reduces the reliance on chemical-based agricultural inputs. *Aloe vera* processing and production provide special agricultural problems as well as substantial economic prospects, especially when sustainable approaches are used. *Aloe vera*'s worldwide market is still expanding, which supports local economies and encourages the creation of numerous commercial goods. *Aloe vera* has bright future possibilities because of new research and possible uses in various businesses and health sectors, which might build on its already remarkable

1.6 CONCLUSION

The future of *Aloe vera* is bright, with ongoing research and development uncovering new potentials for this ancient plant. From genetic engineering to sustainable cultivation, and from pharmaceuticals to agriculture, *Aloe vera* is poised to make significant contributions across various industries. Innovations in biotechnology and nanotechnology will further enhance the efficacy and delivery of *Aloe vera*-based products, opening up new frontiers in personalized medicine and advanced skin-care. As science continues to validate its benefits, *Aloe vera* is set to become an even more integral part of our health and wellness landscape, promising natural and effective solutions for the challenges of tomorrow.

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