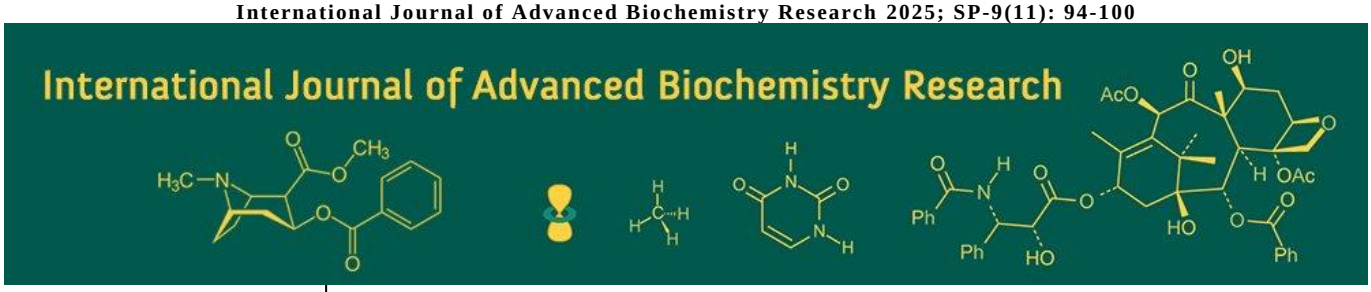


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# Cultivation, processing, nutritional value and phytochemicals in *Aloe vera*

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**Abstract**
*Aloe vera* is a cosmetic, nutraceutical, and medicinal plant of the family Asphodelaceae. The demand for *Aloe vera* gel is increasing day by day, and it is a challenge to optimise quality gel/juice for the public as well as concerned industries for the fulfilment of their requirement. Aloin and Aloe emodin are the main phytochemical that determines gel quality for use in food habits. Cultivation practices, moisture levels, and environmental conditions affect the Aloin and Aloe-emodin content and nutrient composition in the gel of the *Aloe vera*. *Aloe vera* is an important source of vitamins, minerals, enzymes, sugars, phenol compounds, lignin, saponins, and sterols, as well as amino acids, which fulfil the requirements of the human body.
Keeping these facts in view, an effort has been made to compile the work available in the public domain for the development of an efficient protocol for their cultivation, optimisation of the quality of raw materials for humans and industries, their nutritional values, and the phytochemicals of *Aloe vera*.

**Keywords:** *Aloe vera*, aloin, cultivation, nutrition, phytochemicals

## 1. Introduction
*Aloe vera* is derived from the Arabic word "Alloeh," which means "shining bitter substance," and Vera, which means "true" in Latin (Christaki *et al.*, 2010 [14]; Surjushe *et al.*, 2008) [68]. The species was first described by Carl Linnaeus in 1753. It originated in Africa. In the 17th century, it was found to grow in South Africa and Latin America. After that, it was introduced in China, India, and various parts of Southern Europe (Hazrati *et al.*, 2017 [37]; Christaki *et al.*, 2010 [14]; Grindlay *et al.*, 1986 [31]; Akinyele *et al.*, 2007) [6].
*Aloe vera* is a cactus-like plant (Christaki *et al.*, 2010) [14]. The leaves are grey-green to bright green, having small white teeth in the margin (Grindlay *et al.*, 1986) [31]. It has medicinal and cosmetic properties (Christaki *et al.*, 2010 [14]; Eshun *et al*., 2004) [26]. Out of the whole leaf weight, the rind was 20-30%, and the pulp 70-80% (Christaki *et al.*, 2010 [14]; Boudreau and Beland, 2007) [11]. It contains 98.5% water, uronic acid, fructose, hydrolyzable sugars, and enzymes (Christaki *et al.*, 2010) [14]. *Aloe vera* contains vitamins, minerals, enzymes, sugars, phenol compounds, lignin, saponins, and sterols, as well as amino acids (Asghari and Ahmadvand, 2018) [8] and carbohydrates, which are required to improve the immunity of the human body (Surjushe *et al*., 2008) [68].
The *Aloe vera* product market is growing fast in almost all countries in the world and needs to provide varieties and species for a continuous supply of good-quality juice and its products. The global *Aloe vera* market size is expected to reach a growth rate of 6.3 % during 2025-2033. Thailand, Mexico, the Dominican Republic, the United States, and Costa Rica are the leading countries growing *Aloe vera*. Thailand is the dominant country in the world market due to the utilization of *Aloe vera* in various industries. The primary users of *Aloe vera* are the pharmaceutical industry, cosmetic industry, and food industry, which use it as concentrates, gels, drinks, powders, and capsules (*Aloe vera* Market Research Report, 2024).
The Indian *Aloe vera* export industry is booming, and the leading producers of *Aloe vera* are in India. The main reasons for the growing demand for Indian *Aloe vera* are its superior quality and low price. Rajasthan is the largest producer of *Aloe vera* in the country. Other leading states are Gujarat, Madhya Pradesh, Maharashtra, and Karnataka. These five states account for over 80% of India's *Aloe vera* production.

In India, only one species of *Aloe vera* is in cultivation and used by the pharmaceutical industry, cosmetic industry, and food industry. However, other *Aloe* species may also be equally or better nutrient sources.

Keeping the importance and increasing the demand of the *Aloe vera*, a complete package of practices is required for its cultivation. The authors have tried to compile the available and scattered knowledge about *Aloe vera* cultivation, processing, nutritional value, and phytochemicals in *Aloe vera*.

## 2. Cultivation

### 2.1 Climate

It is naturally grown in dry regions of Africa, Asia, Europe, and America. In India, it is cultivated in arid and semi-arid regions, i.e., Rajasthan, Andhra Pradesh, Gujarat, Tamil Nadu, Karnataka, Madhya Pradesh, and Uttar Pradesh (Surjushe *et al.*, 2008) [68]. Water logging may severely affect the *Aloe vera* plants, so proper water drainage management is required for the successful cultivation of the *Aloe vera*. Temperature is phenomenons that indirectly affect plant morphology, growth, root turnover, etc., if it is not within the maximum and minimum range. The mean annual temperatures should be from 10 to 35°C. The low temperature and high humidity increased the disease incidence in the plant (Borekar *et al.*, 2014) [10].

### 2.2 Soil

*Aloe* plants are generally grown in drought regions, barren, salt-affected soil, and less fertile soil; however, well-drained loam to coarse sandy loam soils, black soils, and pH up to 8.5 are suitable for commercial cultivation of *Aloe vera*. *Aloe vera* can be grown in acidic, calcareous, and non-calcareous soils (Chowdhury *et al*., 2018) [13]. The plant does not penetrate deep into the soil as it has a shallow root system. However, water-logged soil is unsuitable (Das *et al*., 2004 [21]; Rajeshwari *et al.*, 2012). Applying organic manure helps improve the soil's physico-chemical properties for the cultivation of *Aloe vera* (Chowdhury *et al*., 2018) [13]. The growth and yield of *Aloe vera* will be affected by soil moisture, salinity, and availability of plant nutrients in the soil (Mohamed *et al*., 2017) [42].

### 2.3 Planting time

The planting time of *Aloe vera* is July-August (Rajeswari *et al.*, 2012) [53] during the monsoon and November-February under irrigated conditions. Under the Indo-Gangetic Plains, from July to August, high rainfall may affect the plants due to waterlogging and increased disease incidences due to high moisture content in the environment. Therefore, under the Indo-Gangetic Plains, the suitable planting time may be September - November and February - March.

### 2.4 Spacing

The plant spacing of 60 cm × 45 cm or 50 cm × 50 cm is required for planting the *Aloe vera*. About 35,000-40,000 suckers are required for the plantation of a one-hectare area (Nematian *et al.*, 2011) [48]. The raised bed planting method was most suitable compared to the ridge and flatbeds (Singh *et al.*, 2021) [65].

### 2.5 Planting

Generally, suckers of the *Aloe vera* are used for plantation. Medium-sized root suckers are required to separate from the mother plant and be planted in the field. About 15 to 25 cm long, 60 days old (Singh *et al.*, 2021) [65], the root suckers of *Aloe vera* are used for plantation. The seed can also be used for growing in a nursery and a plantation. However, due to its self-incompatibility, seed setting is extremely low. The natural hybridisation of *Aloe vera* is very frequent, so it's challenging to maintain the species or variety. The germination of the seeds is about 60-70% (Das *et al.*, 2016) [18].

### 2.6 Tissue culture technique

Tissue culture is also a method for the regeneration of the plantlets of the *Aloe vera*. The homogenous and disease-free plants can also multiply and cultivate *Aloe vera*. Plants regenerated by the tissue culture technique were observed to be more prominent in size and an increase in carbohydrate, protein, chlorophyll, and phenol contents (Saggoo and Kaur, 2010) [58]. Plantlets with developed shoots and roots must be transferred for hardening and acclimatisation under the greenhouse/ poly-tunnels (Das and Bora, 2018) [19]. Suitable media should be used for maximum cell growth and greater nutrient uptake (Das *et al*., 2017) [20]. Differentiation of non-meristematic tissues produces adventitious shoots, which are known as axillary shoots (Gantait *et al*., 2014) [28]. To survive as ex-*vivo* plants, many lateral roots were obtained in IAA and IBA + NAA media (Gupta *et al.*, 2014) [33] and used for plantation. Auxin is the only parameter that improved cell division in root apical meristem, and subsequently, root induction and combination of IAA with cytokinin promoted shoot formation (Molsaghi *et al.*, 2014) [43] and branching of lateral buds due to the cell elongation, cell division, and cell differentiation (Das and Bora, 2018) [19].

### 2.7 Irrigation

Sufficient moisture supplies are required for root development and nutrient uptake, as well as for maintaining cell turgidity and growth by promoting cell elongation and photosynthesis. Cell elongation was not observed in water-deficient conditions due to the obstruction of water flow from the xylem to the developing cell (Ahmad *et al.*, 2018) [4]. The irrigation water supply is equivalent to 80-100% evapotranspiration, which produces maximum biomass and gel with significant water use efficiency (WUE) (Bharadwaj, 2011) [9]. So, proper irrigation is required to replenish the reduced moisture levels. A good yield of *Aloe vera* will be obtained when irrigated immediately as per the requirements of the crops (Rajeswari *et al.*, 2012) [53]. The application of irrigation water @ 15% of the evapotranspiration showed the highest values of WUE due to the highest aerial biomass and gel production (Silva *et al.*, 2010) [64]. The 20% available soil moisture (Singh *et al.*, 2021) [65] and 50% irrigation regimes (Khajeeyan *et al.*, 2019) [41] were found suitable for the cultivation of *Aloe vera*. With increased WUE and water deficit in *Aloe vera*, plants increased the proline synthesis, soluble and total sugars, oligo, and polyfructans for osmotic adjustment. The 75% field capacity or 60% water depletion was optimal for dry mass and gel production (Delatorre-Herrera *et al.*, 2010 [22]; Shams *et al.*, 2015) [65]. Mild salinity improved the synthesis of glucose, xylose, and mannose concentrations in leaf gel up to 9 dS $m^{-1}$ and aloin concentration up to 15 dS $m^{-1}$ (Rahimi-Dehgolan *et al.*, 2012) [52]. When the soil water potential is reduced, all the leaf parameters are affected. This is due to producing a low amount of leaf biomass (Nema *et al*., 2009) [47].

### 2.8 Manures and Fertilizer Application

The application of organic manure with balanced plant nutrients improved cell division and elongation, which increased the plant's height (Hasanuzzaman *et al.*, 2008) [35]. Application of FYM @ 20 t/ ha needs to be applied before planting the *Aloe vera* plants (Rajeswari, 2012) [53]. The leaf, gel, dry weight, glucomannan, antioxidant activity, and anthocyanins of the cortex and flavonoids increased by applying organic matter, such as vermicompost (Yavari *et al.*, 2013) [73]. Combined application of FYM @ 10 t/ ha and vermicompost at 20 t/ ha led to increasing all morphological characters (survival percent, tillers, leaf length and thickness, plant diameter, and fresh weight of leaf/ plant) of *Aloe vera* due to greater nutrient availability in the soil, their uptake by the plant (Guleria, *et al.*, 2013) [32]. The organic source of manure, such as vermicompost and vermiwash, was efficacious compared to inorganic fertilisers for increasing gel and aloin content in *Aloe vera* (Saha *et al.*, 2005) [59]. Application of nitrogen (N) @ 150 kg/ ha increased plant height, gel per leaf, leaf breadth, leaf thickness, leaf volume, the maximum number of leaves, and heavier leaf weight due to increased chlorophyll content and photosynthesis (Rehman *et al.*, 2016) [54]. Application of N @ 150 kg/ ha and P @ 50 kg/ ha improved the plant height, plant spread, leaves/ plant and leaf weight, leaf length, width, thickness, leaf yield/ ha, and sucker/ plant, gel weight/ ha, and chlorophyll content in fresh tissue of *Aloe vera* (Bharadwaj, 2011) [9]. The application of phosphorus (P) and potassium (K) significantly increased the vegetative growth by supporting cell division and the development of meristem tissue. K is involved in the translocation of carbohydrates from the leaves to the root system (Ahmed, 2011) [5]. The highest gel yield was recorded with N (120 kg/ ha), P (120 kg/ ha), and K (60 kg/ ha), however, at an equivalent nutrient level of N (80 kg/ ha), P (40 kg/ ha) and K (80 kg/ ha) through organic sources (FYM or Vermicompost) was superior to the inorganic source (Saha *et al.*, 2005) [59]. Application of 100 t FYM/ ha + 124 kg N/ ha + 54 kg P resulted in a maximum leaf yield of 44 t/ ha with extended leaf thickness, length, number of leaves, and number of suckers/ plant (Pareek *et al.*, 1999) [50]. Spraying of zinc increased chlorophyll, amino acid, and proline content in the leaves of *Aloe vera* (Shams *et al.*, 2015 [65]; Sarmiento *et al.*, 2020) [61].

### 2.9 Abiotic Stress Tolerance

The low soil water potential reduces growth and leaf yield of *Aloe vera* (Rodríguez-García *et al.*, 2007) [56]. The CAM plants have cells with parenchyma, which are used to support the survival of the plants in drought environments (Cristiano *et al.*, 2016) [15]. The transpiration rate attains a maximal peak at midnight and is maintained at minimal rates throughout the daytime, with minimum water loss resulting in accumulation of $CO_2$ by night and malate accumulation in the daytime (Sheteawi *et al.*, 2001) [63]. Sufficient water is required for parenchyma maintenance and stomatal opening (Rodríguez-García *et al.*, 2007) [56]. Under high water stress conditions, a reduction in the opening of stomata was seen, which in turn reduces the yield and growth of the plant, and the sap flow rate decreases, and proline, soluble, and total sugar synthesis occurs for their osmotic adjustment (Delatorre-Herrera *et al.*, 2010 [22]; Cuevas *et al.*, 2016) [17]. Water deficit decreased the growth and leaf yield and chlorophyll concentration, and increased the proline and chloride ions under drought stress (Shams *et al.*, 2015) [65]. Salinity had a significant effect on leaf thickness, leaf width, gel weight, and WUE in *Aloe vera* (Hamidi *et al.*, 2023 [34]; Mota-Ituarte *et al.*, 2023) [44].

Salinity causes an ionic imbalance rather than dehydration and increased aloin concentration in young leaves. *Aloe vera* showed adaptability to osmotic stress and increased active ingredients in leaves (Yin *et al.*, 2016) [74]. Na and Cl increased with the extent of lowering the osmotic potential of plants grown under salt stress. *A. vera* can accumulate $Na^+$ and $Cl^-$ in metabolically inactive cells under saline conditions (Zheng *et al.*, 2004; Zheng *et al.*, 2009) [75, 76]. Increasing the salinity levels in soil, Na and Cl ion concentrations increased in the roots, stems, and leaves of *Aloe vera* (Murillo-Amador *et al.*, 2014) [45], reduced leaf fresh weight without decreasing the dry weight of the leaf and gel content in *Aloe vera* (Murillo-Amador *et al.*, 2015 [46], González-Delgado *et al.*, 2023) [29], but antioxidant enzyme activity, such as ascorbate peroxidase, peroxidase, catalase, superoxide dismutase, and proline content increased. The application of Zn effectively increased *Aloe vera*'s antioxidant enzyme activity (Moghbeli *et al.*, 2012; Kavian *et al.*, 2022) [40]. Under different fertilisation in two *Aloe* species, *Aloe barbadensis* and *Aloe arborescens*, the plant nutrients (N, P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, and B) varied in different amounts. The highest concentration of nutrients was seen in the treatment with no NaCl compared to plants treated with NaCl (Cardarelli *et al.*, 2013) [12]. The plant growth, gel yield, and aloin content increased significantly at 15 ESP (2.5 times) and 30 ESP (1.5 times) compared to the control. N and Ca content decreased, and P, K, and Na contents increased, corresponding to the increasing exchangeable sodium percentage (ESP) levels (Rahi *et al.*, 2013) [51]. Seawater stress decreased N, Ca, and K concentrations but did not affect the P concentration in the leaves of the *Aloe vera*. Seawater stress also increased the aloin concentration in young and middle leaves but was not affected in old leaves of *Aloe vera* (González-Delgado *et al.*, 2023 [29]; Jiang *et al.*, 2014) [38]. The aloin and proline accumulation increased, corresponding to increased water stress and decreased plant growth and leaf yield of *Aloe vera* (Hazrati *et al.*, 2017) [37]. Biochemical parameters (proline, sugars, and polyphenols contents) significantly increased due to salinity stress. *Aloe brevifolia* was the most salinity-tolerant species compared to *Aloe vera* and *Aloe arborescens* (Derouiche *et al.*, 2023) [24]. Under shade, water-stressed plants and irrigation with brackish water resulted in high aloin content in the leaves of *Aloe vera* (Tawfik *et al.*, 2001) [71]. The Aloin concentration increased with salt stress up to 15 dS $m^{-1}$ and decreased at higher salinity levels (Rahimi-Dehgolan *et al.*, 2012) [52].

### 2.10 Intercropping

Less competitive crops can be used as intercrops to utilise the land between the plants. However, in the arid and semi-arid regions, partial shade conditions are beneficial for reducing the field temperature in the summer season, which may be beneficial for *Aloe vera* crops. The *Aloe vera* intercropped under *Melia composite* at closer spacing resulted in higher growth, biomass, and quality of *Aloe vera* gel compared to wider spacing and a sole crop of *Aloe vera* (Jilaria *et al.*, 2017).

### 2.11 Weeding and Cleaning of the field
After plantation, one weeding and hoeing is required each month to reduce the weed density and cleaning in the *Aloe vera* field. Diseased plants and dried flower stalks should be removed regularly from the field.

### 2.12 Harvesting and Yield
The leaf yield is highly correlated with gel yield, fresh weight, and plant spread of *Aloe vera* (Ahmad *et al.*, 2016) [3]. The initial flowering stage might be a better option to harvest leaves to obtain the economic yield of *Aloe vera* (Saeid *et al.*, 2011) [57]. One-year-old and mature leaves are harvested first; the middle and new leaves are kept for maturity (Cristiano *et al.*, 2016) [15]. The leaf should be harvested at 3-4 month intervals (Hazarika *et al.*, 2018) [36]. The yield was 44.5 to 58.5 tons per ha per year, with a density of 10,000 plants per hectare (Cristiano *et al.*, 2016) [15]. The yield was about 12 t $ha^{-1}$ $year^{-1}$ when *Aloe* was grown organically and harvested after 18 months of sowing. The economic yield can be obtained for up to 5 years; after that, it needs replanting (Rajeswari *et al.*, 2012 [53]; Cristiano *et al.*, 2016) [15].

## 3. Processing of *Aloe vera*
More than one-year-old mature leaves should be harvested, put in a refrigerator, and filleted. Proper processing techniques are required to preserve the bioactive chemicals (Eshun and He, 2004) [26]. The hand-filleting method emerged to avoid contamination in the fillets with the yellow sap or latex (Rajeswari *et al.*, 2012) [53]. The hand-filleting method for processing must be finished within 36 hours of harvest (Robert, 1997) [55]. To avoid enzymatic browning, homogenization should be completed within 20 minutes (Gowda *et al*., 1980) [30]. The biological activity of *Aloe vera* gel will not be affected when the gel is heated at 65 °C for 15 minutes (Ahlawat *et al.*, 2011) [2]. The cold processing of *Aloe vera* juice is more effective, including the addition of preservatives, such as sodium benzoate, potassium sorbate, citric acid, and Vitamin E, followed by UV light and micron filtration (Ahlawat *et al.*, 2011) [2].

## 4. Nutrient Composition of *Aloe vera* gel
*Aloe vera* gel is a rich source of nutrients (Talukdar *et al.*, 2023 [69]; Adesuyi *et al.*, 2011) [1]. Primary nutrients, N, P, and K, are the most important for optimal growth, nutrient composition, and quality of *Aloe vera* (Owoade and Adeoye, 2016) [49]. The availability of N increased the auxin activities and ultimately increased the yield-attributing characters and gel yield of *Aloe vera*. P supports growing root tips, which help in cell division and root elongation (Bharadwaj, 2011) [9]. N and P content was found to be highest in gel and juice. The N and P concentrations were reduced, corresponding to an increase in the number of leaves in *Aloe vera*. No trend was noted for K (Cruz *et al.*, 2002) [16]. Colonization with AM enhances nutrient uptake and its growth. Efficient use of P resources was seen with inoculation with mycorrhizal fungi. The N concentration increased from 0.12 per cent to 0.33 per cent, and the P concentration increased from 0.02 per cent to 0.4 per cent by the inoculation of *Gigaspora decipiens* in 12-month-old leaves (Tawaraya *et al.*, 2007) [70]. Higher N (0.95 per cent) and protein (5.93 per cent) content were recorded with 200 kg N and 200 kg K per ha combinations. The highest NPK uptake was recorded with the application of N 75 kg/ ha + 3.75 t/ ha vermicompost and *Azotobacter* treatment. Higher biomass production and the residual effect of vermicompost improved the metabolic activities, resulting in better nutrient uptake by the *Aloe vera* (Ahmad *et al.*, 2016) [3]. The nutrient uptake trend was recorded as high N without K fertilisation, high P without PK, high K without N, and high Ca without S fertilisation in *Aloe vera*. The highest P concentration in gel (0.49%) and leaf (0.94%) was recorded with the highest P dose @ 120 kg/ ha (Owoade and Adeoye, 2016) [49]. Adding a higher dose of P fertiliser releases more P quickly, enhancing P availability and increasing P availability in the plants' root zone (Sultana *et al.*, 2020) [66]. Similarly, the highest concentration of K in gel (0.69%) and leaf (1.73%) was recorded with the highest K dose @ 160 kg/ ha (Sultana *et al.*, 2021) [67]. Applying FYM or Vermicompost showed higher N, P, K, Mg, Zn, Cu, Mn, and Fe content in the gel of *Aloe vera* compared to chemical fertilizers as N, P, K (Saha *et al.*, 2005) [59]. The *Aloe* plants inoculated with AM fungi (*Glomus clarum* or *Gigaspora decipiens*) increased the N and P uptake and growth of A. vera compared to uninoculated ones (Tawaraya *et al.*, 2007) [70].

## 5. Phytochemicals in *Aloe vera*
The different biochemical and medicinal properties due to phytochemicals are found in *Aloe vera*, such as anthraquinones, anthrones, carbohydrates, chromones, enzymes, vitamins, amino acids, proteins, saccharides, miscellaneous organic compounds and lipids, and inorganic minerals (Foster *et al.*, 2011) [27]. Important phytochemicals of *Aloe vera* are Anthraquinone (Aloe emodin, Emodin, Aloin or barbaloin, Chrysophanol, Aloenin), Flavonoid (daidzenin, Genistein, Apigenin), Phenolic acids (Syringic acid, Sinapic acid, Vanillic acid, Homovanillic acid, Protocatechuic Acid). The International *Aloe* Science Council allowed aloin content for oral consumption to be less than 10 mg/ L (Dentali, 2013) [23]. In European countries, the aloin content regulation limit for food and beverages should be 0.1 mg/ L (Shao *et al.*, 2013) [62]. Proline and phosphoenolpyruvate carboxylase (PEP-case) increased as salinity increased total protein in chlorenchyma. The highest amount of the active substances (aloenin, barbaloin) and maleic acid was obtained from the treatment of 150 kg N / ha (Nematian *et al.*, 2011) [48]. The 17 amino acids, D-glucose, and D-mannose were found in the *Aloe barbadensis* Miller (Waller *et al.*, 1978) [72]. Cholesterol, campesterol, *β*-sitosterol, and lupeol were also found in significant quantities in the lipid fraction in the leaf exudates of *Aloe nyeriensis* (Dubey *et al.*, 2017) [25].

## 6. Conclusion
The cultivation practices needed to be appropriately adopted to achieve the optimum gel yield and quality of *Aloe vera*. The moisture level should be less than 50% of the field capacity. Temperatures below 10 °C and more than 35 °C may affect the yield and quality of *Aloe vera*. Proper irrigation and drainage are required in the cultivated field of *Aloe vera*. High temperatures may affect growth and yield, and high moisture, either in soil or in the environment, increases the disease incidence in *Aloe vera*. The future prospects are to standardize the phytochemicals synthesis and nutrient concentrations in *Aloe vera* gel/juice under different cultivation situations, i.e., drought, salinity, and

sodicity stress for human consumption and industries application.

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