

REVIEW

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Recent progress in research on ethnobotany, phytochemistry, pharmacology, and toxicology of some wild plants of family Amaranthaceae: an updated review

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Abstract

Background The Amaranthaceae family, belonging to the order Caryophyllales, represents one of the most morphologically and ecologically diversified plant families. It comprises approximately 175 genera and over 2000 species. Members of this family exhibit a broad range of adaptations and hold significant economic, ecological, and medicinal importance. Several wild species within this family have been traditionally employed in ethnomedicine across diverse cultures for the treatment of various ailments.

Aim This review aims to comprehensively summarize the botanical characteristics, ethnobotanical relevance, phytochemical constituents, and pharmacological activities of eight medicinally important wild herbs from the Amaranthaceae family. The selected species include *Amaranthus viridis*, *Chenopodium album*, *Achyranthes aspera*, *Alternanthera sessilis*, *Digera muricata*, *Celosia argentea*, *Gomphrena celosioides*, and *Cyathula prostrata*. The review further elucidates their antioxidant, anti-inflammatory, antimicrobial, and antidiabetic properties along with their proposed mechanisms of action, thereby validating traditional claims with scientific evidence.

Methods A systematic literature review was conducted using reputable scientific databases such as PubMed, Scopus, ScienceDirect, and Google Scholar. Information was gathered from peer-reviewed articles, ethnobotanical surveys, pharmacological reports, and toxicological studies. Each plant was evaluated based on its traditional uses, major bioactive compounds, in vitro and in vivo pharmacological assessments, and safety profile.

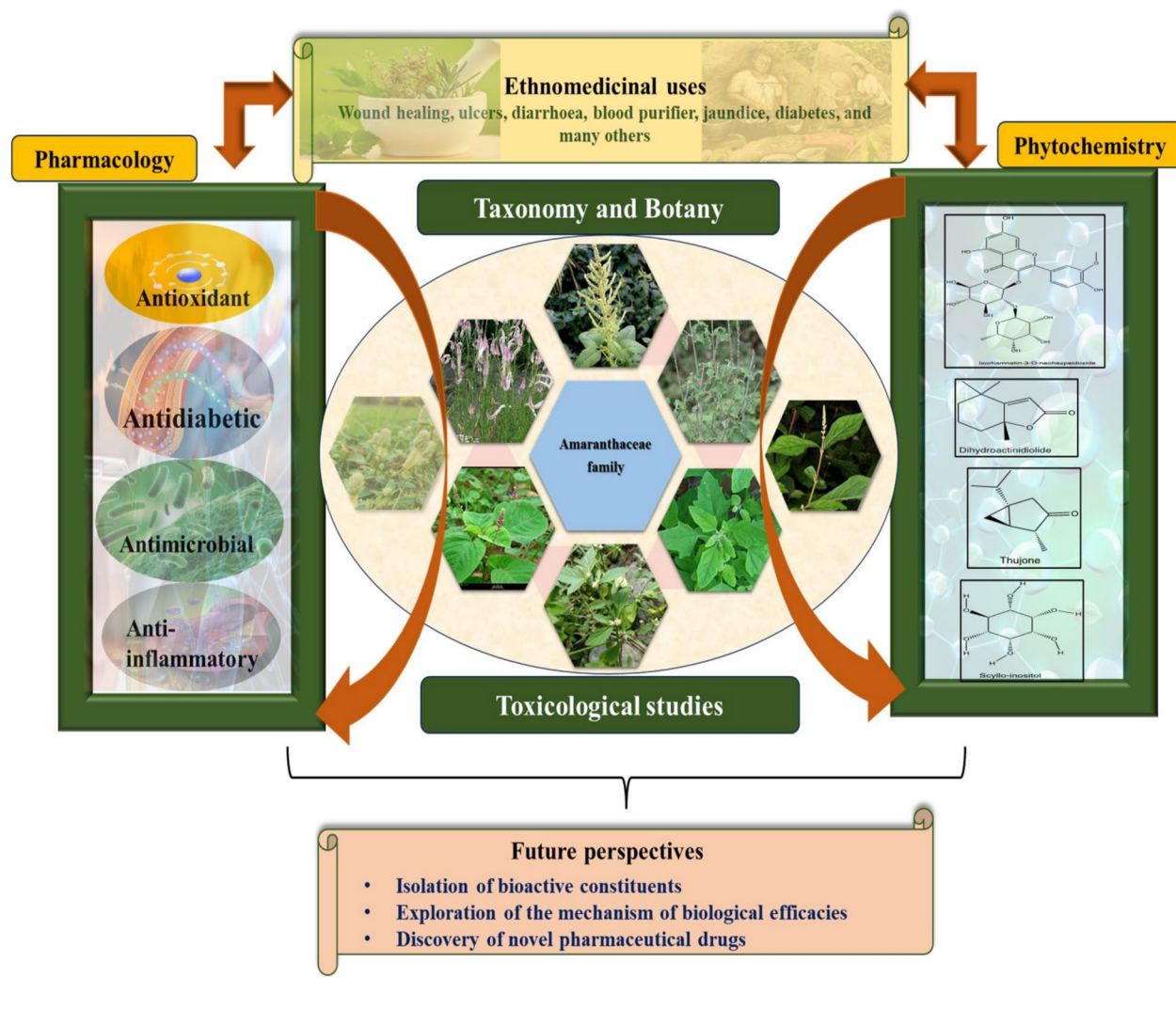
Conclusion The compiled data underscore the immense therapeutic potential of wild herbs within the Amaranthaceae family. These plants are rich sources of diverse phytochemicals, including flavonoids, alkaloids, saponins, terpenoids, and phenolic compounds, which are primarily responsible for their observed bioactivities. The documented antioxidant, anti-inflammatory, antimicrobial, and antidiabetic effects support their ethnopharmacological usage and warrant further exploration. The findings of this review advocate for intensified pharmacological and molecular research on these underutilized species to facilitate the development of novel natural therapeutic agents. Promoting scientific validation and sustainable utilization of these plants could significantly contribute to drug discovery and the development of plant-based pharmaceuticals.

Keywords Antidiabetic, Antioxidant, Anti-inflammatory, Caryophyllales, Ethnobotany, Herbal medicine, Phytochemistry

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Graphical abstract

This review comprehensively summarizes botanical description, ethnobotanical uses, phytochemistry, pharmacology, and toxicology of some wild plants of the Amaranthaceae family.



1 Introduction

India has an ancient heritage of traditional herbal medicine [1]. Early people who used to dwell in forests were highly reliant on plants for their healthcare because of their unique curative effects. The utilization of herbs for medicinal purposes is documented in various traditional systems of medicine like Siddha, Ayurveda, and Unani [2]. The most prevailing Ayurvedic system was discovered about 5000 years ago in India [3]. Ayurveda, derived from the Sanskrit words "Ayur" (life) and "Veda" (knowledge or science), translates to "the science of life." It is one of the world's oldest and most comprehensive systems of natural medicine. Developed through centuries of empirical

observation, spiritual insight, and philosophical reflection, Ayurveda is documented in classical texts such as the *Charaka Samhita* (emphasizing internal medicine) and the *Sushruta Samhita* (highlighting surgery). The comprehensive details of *Charaka Samhita* and *Sushruta Samhita* were updated in *Astanga Sangraha* and *Astanga Hridaya*, which together form the foundation of Ayurvedic knowledge and practice. It was historically classified into eight major clinical branches, collectively known as *Ashtanga Ayurveda* (the eight limbs of Ayurveda). The eight divisions include Kayachikitsa (internal medicine), Salya Tantra (surgery), Salakya (diseases of supra-clavicular origin), Kaumarabhrtya (paediatrics, obstetrics and

gynaecology), Bhutavidya (psychiatry), Agada Tantra (toxicology), Rasayana Tantra (rejuvenation and geriatrics), and Vajikarana (aphrodisiology and eugenics) [4]. For thousands of years, the traditional knowledge of the therapeutic potential of plants has been continuously passed from one generation to the next [5]. Technological advancement and pharmaceuticals have provided society with a wide range of synthetic medicines. These orthodox medicines also come along with negative side effects. According to reports, approximately 5% of the global population has experienced some harmful side effects with the use of synthetic drugs [6]. Herbal remedies are regaining popularity in the modern world due to their affordability, ease of access, and fewer adverse effects [7]. India is the world's greatest medicinal plant producer and is aptly called the world's botanical paradise [8]. It is interesting to note that approximately 25% of today's pharmaceuticals have been directly or indirectly obtained from plants [9]. The World Health Organization (WHO) has made a major effort to discover the medicinal plants being utilized worldwide and documented around 20,000 species with medicinal value [10]. The Botanical Survey of India (BSI) reports that of the 45,000 known plant species, at least 30,000 possess significant medicinal value [11]. It is quite interesting to know that even during the twenty-first century, 70% of people in rural areas use herbal remedies to treat their health issues, and the Ayurvedic system is still proving effective for people who are in need.

Medicinal plants have been well known for their healing properties since ancient times, but several plants grow in the wild and are generally thought to be of no significance. These wild plants are called “weeds”. While the term “weed” generally has a negative connotation, they are also reported to possess some beneficial properties [12]. Such wild plants survive under highly adverse conditions by producing resistant bioactive compounds, which are of good therapeutic value. Novel medicinal compounds with unique properties can be isolated from these wild plants. It has been documented that almost 35,000 wild plants are being utilized in developing nations for therapeutic purposes [13]. In addition to their medicinal value, they are also used as raw materials for crafts and household industries. Numerous investigations have been carried out to explore the chemical composition and pharmacological application of weeds. However, there is still a requirement for more studies, as there are a lot of wild plants that are still less explored. The aim of this study is to present a critical overview of the ethnobotany, phytochemistry, and pharmacology of eight wild species of the family Amaranthaceae (*Amaranthus viridis*, *Chenopodium album*, *Achyranthes aspera*, *Alternanthera sessilis*, *Digera muricata*, *Celosia argentea*,

Gomphrena celosioides, and *Cyathula prostrata*). In addition to documenting the traditional uses and botanical characteristics of these plants, the review delves into their bioactive compounds, highlighting those responsible for antioxidant, anti-inflammatory, antimicrobial, and antidiabetic activities. Where available, mechanisms of action are discussed to provide scientific validation for traditional medicinal claims. Furthermore, the article includes a critical examination of toxicological studies to ensure safety considerations in future therapeutic applications. The novelty of this work lies in its comprehensive focus on eight underexplored wild medicinal herbs from the Amaranthaceae family, emphasizing their pharmacological significance beyond traditional usage. Unlike previous fragmented studies, this review consolidates ethnobotanical knowledge with updated insights into phytochemistry, mechanisms of action, and toxicological profiles. It uniquely bridges traditional claims with modern pharmacological evidence, aiming to validate and promote the use of wild species in drug discovery. This holistic approach not only strengthens the scientific foundation for therapeutic applications but also encourages further exploration at the molecular and clinical levels. Additionally, this article will draw the attention of researchers towards potent therapeutic plant species and provide a lead for the discovery of new drugs and pharmaceuticals.

Amaranthaceae family—Amaranthaceae and Chenopodiaceae have been combined into a single family, i.e., the “Amaranthaceae” family [14]. These two families have been combined based on similarities in morphology, anatomy, and phytochemistry. At present, the Amaranthaceae family consists of 175 genera and 2000 species. Among the order Caryophyllales, this family is considered the most diversified in species richness. This family is indigenous to tropical and subtropical areas of Australia, Africa, and Central America [15]. The family's characteristic feature is diverse bioactive compounds, including a variety of betalains, phenolic compounds, terpenoids, essential oils, alkaloids, and flavonoids. It is mainly comprised of annual or perennial plants, primarily herbs and some forms of shrubs, small trees, and vines. This family is quite interesting in photosynthetic variations, as some members prefer the C_3 or C_4 cycle, while some are C_3 – C_4 intermediates [16].

The Amaranthaceae family possesses plants with good economic importance (Fig. 1). Some plants, including seeds of *Amaranthus caudatus*, are edible, *A. cruentus* and *A. frumentacea* are grown as cereals in Tropical Asia [17]. Due to the bright colours of inflorescence, many plants are cultivated as ornamentals, including *Celosia cristata*, *Gomphrena globosa*, and *Iresine herbstii* are grown in gardens [18]. Some

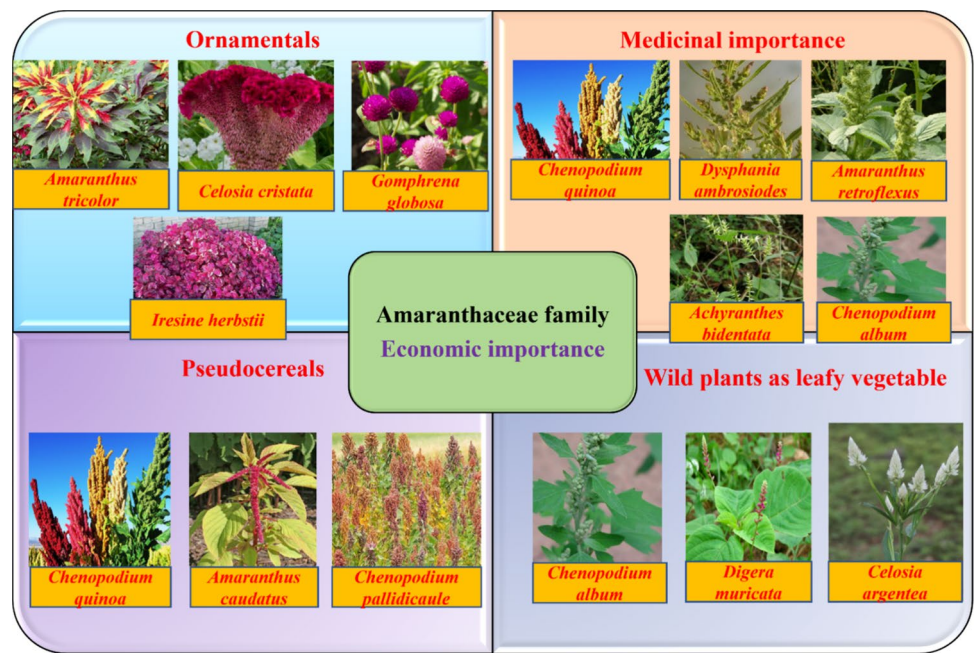


Fig. 1 An overview of the economic importance of plants belonging to the family Amaranthaceae (this figure was made using Canva software)

grow as wild plants, like *Amaranthus viridis*, *Digera muricata*, *Chenopodium album*, and *Celosia argentea*, and are considered leafy vegetables. Weeds, including *Alternanthera sessilis*, *Achyranthes aspera*, *Digera muricata*, and *Amaranthus viridis*, possess good medicinal potential and are traditionally used to treat various health disorders [19, 20].

2 Methodology

The previously published articles were searched via Scopus, ScienceDirect, Google Scholar, Elsevier, and Web of Science databases. An extensive literature survey has been conducted from the year 2000 to 2025 to extract the medicinal potential of some wild plants of the family Amaranthaceae. A bibliographic analysis of the ScienceDirect database was done to analyse the paper publishing trend of selected plants from the Amaranthaceae family from year 2000 till now, as depicted in Fig. 2. The

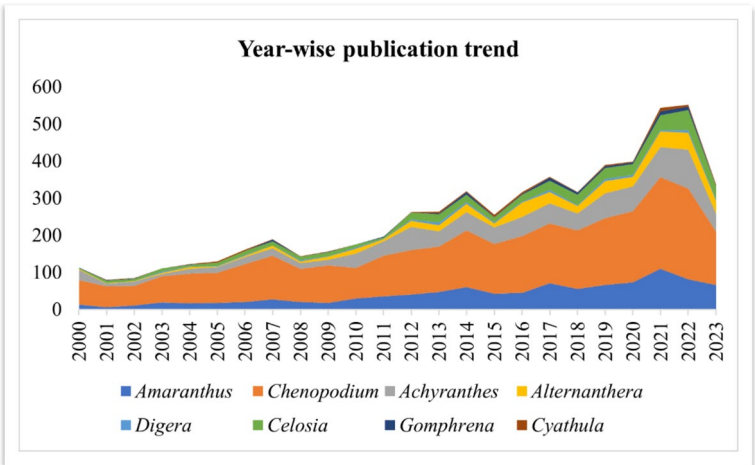


Fig. 2 Graph showing publication trend of selected plants showing the magnitude of change in trend over time (the graph was created in MS-Excel)

keywords used to search the databases were ‘Ethnobotany’, ‘Amaranthaceae’, ‘Antioxidant’, ‘Phytochemistry’, ‘Antidiabetic’, ‘Antimicrobial’, ‘*Achyranthes aspera*’, ‘*Amaranthus viridis*’, etc. The articles selected were on the basis of exclusion and inclusion criteria.

Inclusion criteria: Published articles that involved ethnobotanical uses, phytochemistry, antioxidant, and antimicrobial studies of eight selected wild plants were included in this study.

Exclusion criteria: However, the articles published before 2000 and from other domains like nanoparticle synthesis and phytotoxicity were excluded from the study. A total of 223 articles have been cited in the present study.

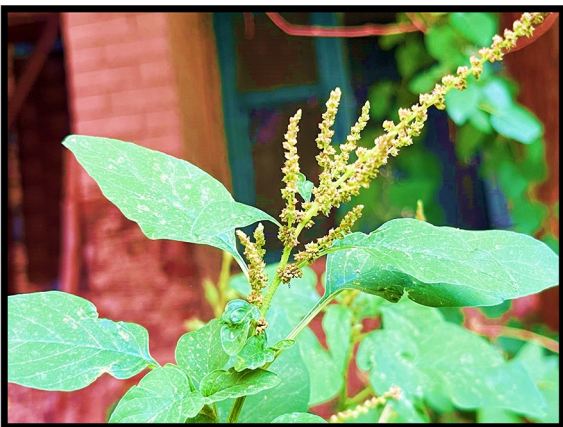


Fig. 3 *Amaranthus viridis*: morphology

3 Botanical description (Table 1)

3.1 *Amaranthus viridis* L.

This plant is locally called “Chowlai” and is considered a wild leafy vegetable. It is distributed worldwide in tropical and subtropical regions and is believed to be of Asian origin. It is an erect, annual herb having branches up to a height of 1 meter (Fig. 3). The stem is generally slender to sparsely pubescent with multicellular hairs. Leaves are alternate, with varying shapes from ovate to rhomboid, petioled, and cuneate base [21]. Green, unisexual, and sessile flowers are accompanied by lanceolate, ovate bracts and bracteoles. In male flowers, tepals possess 3 stamens, and the superior midrib is curved along the fruit in female flowers. The fruit of this plant is a sub-globose capsule type (1.5 mm in diameter), indehiscent and one-seeded [22]. Traditionally, this plant was used to relieve pain and reduce fever due to its analgesic and antipyretic properties [23]. Additionally, it also possesses antifungal, antiproliferative, and lectin antiviral

potential, along with ribosome-inactivating protein antiviral [24].

3.2 *Chenopodium album* L.

Chenopodium album L., locally known as “Bathua,” is an edible leafy vegetable. This is a wild plant that originated from Western Asia and is found widely across the world. It is an erect, annual plant with a height from 20 cm to 1.5 m (Fig. 4) [25]. Leaves are alternate, ovate, and glabrous with hairs. It consists of inflorescences arranged in the form of irregular spikes grouped into panicles. Flowers are bisexual, small, approximately 3 mm in diameter, green, with 5 sepals, 5 stamens, and no petals. The fruit is of achene type, and the seeds possess a thin covering called a pericarp. Seeds are small in size (1.5 × 1.4 mm diameter), oval in shape, and black-coloured [26]. The medicinal properties of this plant are mainly associated with its leaves and seeds. This plant treats several disorders, including skin disorders, rheumatism, urinary disorders, bug bites, etc. [27].

Table 1 Taxonomical classification of the selected eight plants of family Amaranthaceae

Plant	Genus	Species	Family	Order	Class	Kingdom
<i>Amaranthus viridis</i>	<i>Amaranthus</i>	<i>viridis</i>	Amaranthaceae	Caryophyllales	Magnoliopsida	Plantae
<i>Chenopodium album</i>	<i>Chenopodium</i>	<i>album</i>	Amaranthaceae	Caryophyllales	Magnoliopsida	Plantae
<i>Achyranthes aspera</i>	<i>Achyranthes</i>	<i>aspera</i>	Amaranthaceae	Caryophyllales	Magnoliopsida	Plantae
<i>Alternanthera sessilis</i>	<i>Alternanthera</i>	<i>sessilis</i>	Amaranthaceae	Caryophyllales	Magnoliopsida	Plantae
<i>Digera muricata</i>	<i>Digera</i>	<i>muricata</i>	Amaranthaceae	Caryophyllales	Magnoliopsida	Plantae
<i>Celosia argentea</i>	<i>Celosia</i>	<i>argentea</i>	Amaranthaceae	Caryophyllales	Magnoliopsida	Plantae
<i>Gomphrena celosioides</i>	<i>Gomphrena</i>	<i>celosioides</i>	Amaranthaceae	Caryophyllales	Magnoliopsida	Plantae
<i>Cyathula prostrata</i>	<i>Cyathula</i>	<i>prostrata</i>	Amaranthaceae	Caryophyllales	Magnoliopsida	Plantae



Fig. 4 *Chenopodium album*; morphology



Fig. 5 *Achyranthes aspera*; morphology

3.3 *Achyranthes aspera* L.

Achyranthes aspera L., commonly known as “Latjeera,” is a wild plant distributed mostly along roadsides and in waste areas; it also grows as a weed in fields throughout India and in the South Andaman Islands [28]. It is native to Africa and mainly distributed in Tropical Asia, Africa, America, and Baluchistan. It is an erect, annual, or perennial herb having a woody base of 1–2 m in height (Fig. 5). Leaves are thick, ovate to elliptical, or may be rounded and petiolate. Flowers are greenish white in colour, present terminally or axillary in spike form up to 75 cm long. Seeds are reddish brown in colour, subcylindrical in shape, and rounded at the basal region [29]. Traditionally, it was used to treat cough, asthma, and many other diseases like oedema, piles, boils, skin eruptions, and as a diuretic and antiperiodic. However, the plant possesses many therapeutic potentials but is mainly used as an antipyretic [30], cardiovascular agent, and spermicidal [31].

3.4 *Alternanthera sessilis* (L.) DC.

Alternanthera sessilis L., commonly known as “stalkless joyweed,” is an edible leafy medicinal herb [32]. It originated in tropical America and is now widespread in tropical and subtropical regions of the world [33]. The stem is greenish or pink to purple in colour, with a cylindrical shape, generally prostrate, or may sometimes be erect (Fig. 6). Leaves are simple, but the shapes of leaves may vary from linear-lanceolate to obovate. The inflorescence is sessile, axillary, and grouped mainly in clustered form [34]. Locally, it is consumed as a leafy vegetable and is also utilized for medicinal purposes in various regions of Asia [35]. Young aerial parts of this plant are considered edible in India [32]. It was also utilized to treat fever, ulcers, hepatitis, malaria, and diarrhoea. It is also used as a histaminergic and is potent in stopping bleeding.

3.5 *Digera muricata* (L.) Mart.

The *Digera* genus of the family Amaranthaceae has only one species, *D. muricata* (L.) Mart. commonly known as “Kanejaro”. It may be seen as a weed in disturbed lands, waste habitats, and agricultural crops. It is known to have originated from Eastern tropical Africa and is widely distributed in Tropical Africa, Madagascar, India, and Malaysia [36]. It is an annual herb having spreading branches growing up to 45–50 cm in height (Fig. 7). Leaves are alternate, membranous, hairy, and glabrous. Stems may be simple or branched and hairless. The inflorescence of the plant is long, pedunculate, axillary, and spike-like, with bracteate racemes. Each bract possesses a subsessile partial inflorescence having a central fertile flower and 2 lateral sterile flowers. The flowers are hairless, white-pinkish to carmine red in colour, which produces greenish-white fruit [37]. It is considered a famine food [38] because of its rich source of nutrients. Traditionally, it was used to treat renal disorders, bowel complaints, diabetes, and root infusions for lactation purposes. In India, it is also used for gastrointestinal and urinary disorders [39].

3.6 *Celosia argentea* L.

Celosia argentea L., commonly known as “survali” in local regions, is a leafy vegetable, edible in some regions. It also grows as a wild plant during the rainy season in India [40]. It is native to tropical Africa and is also found widely in tropical and subtropical regions, including South Asia, Africa, and Sri Lanka [41]. The plant is annual, mostly erect, but may be branched from its upper regions (Fig. 8). Leaves are simple, alternate, and lanceolate. Flowers are clustered in terminal dense spikes of white to pinkish silvery white colour [42]. It is also an edible weed considered a green leafy vegetable with both nutritional and medicinal potential. In India, whole

plants are used as an antidote against snake venom. Flowers and seeds decoction treats several disorders, including diarrhoea, haemorrhoidal bleeding, and leucorrhoea. In Sri Lanka, leaves were applied for itching, fever, and inflammations. In China, seeds and flowers are used to treat gastroenteritis and leucorrhoea [43].

3.7 *Gomphrena celosioides* Mart.

Gomphrena celosioides Mart. is an annual herb locally called “Bachelor’s button.” This plant is native to South America and widely distributed in Argentina, Bolivia, Brazil, Paraguay, and Indomalaysia [44]. It is a troublesome weed of some crops in tropical, subtropical regions and is found mainly on fallow lands, along roadsides, riverbanks, etc. The plant is much-branched, prostrate up to 50 cm in height, with a deep taproot system (Fig. 9). Leaves are opposite, elliptical, with short and hairy petioles. Flowers are arranged in dense terminal or axillary spikes growing on woolly receptacles having whitish to pink colour with 2 stigmas and 5 stamens. Seeds are lentil-shaped, very small, generally 1.5 mm, brown in colour [45]. It is documented to be used for a variety of therapeutic applications in traditional medication systems. In Nigeria, it is used for skin diseases and worm infections. In South America, it is used as an abortifacient. There are several other medicinal uses of *G. celosioides*, including dysmenorrhea, hepatic disorders, bronchial infections, and renal disorders [46].

3.8 *Cyathula prostrata* (L.) Blume

Cyathula prostrata is an annual to perennial plant locally called “pasture weed.” It is native to Africa and Asia but is now found widely in Oceania and South and Central America [47]. It naturally grows as a weed in cultivated areas, along seashores and roadsides, and is categorized as an invasive species in Pacific lands. It grows as an erect or ascending herb with a 30–50 cm height, having a quadrangular stem covered with hairs (Fig. 10). The leaves are opposite, rhomboid-ovate to oblong in shape, with rounded or narrowed bases and short petioles. Inflorescence is erect and terminal in the form of a raceme with flowers arranged in small groups in the lower part of the raceme. At lower clusters, 2–3 bisexual flowers are there, with several sterile ones, but at the apex region, only solitary bisexual flowers are present. Flowers are quite small, dull pale green with 5 tepals, with a superior ovary. Fruit is an ellipsoid utricle, glabrous, and one-seeded, covered by a perianth. Seeds may be ovoid or ellipsoidal, having a shiny brown colour [48]. The plant has been used for medicinal purposes since ancient times and as a food source. Traditionally, different parts of plants were used for various ailments, including scabies, skin infections,

dysentery, nausea, articular rheumatism, and many others [47]. Various investigations reported that it possesses anti-inflammatory, analgesic [48], antioxidant [49], cardioprotective [50], anticancer [51], and antimicrobial properties [52].

4 Ethnobotanical uses

Traditional knowledge is abundant among the indigenous people and local groups that occupy more than 25% of the world’s total area [53]. One such knowledge is ethnomedicine, which indigenous people have utilized to cure a wide range of ailments and illnesses from the dawn of human civilization. The knowledge obtained via the interaction of humans with the surrounding ecosystem may become a better source for discovering novel therapeutic agents [54]. The cultural knowledge, beliefs, and perceptions of local people, passed from generation to generation, become the basis for collecting information regarding the medicinal uses of a particular plant. Medicinal herbs were utilized in traditional healthcare systems because of their better efficiency, fewer side effects, ease of availability, and cost-effectiveness as compared to synthetic medicines [55]. Since ancient times, plants belonging to the Amaranthaceae family have been utilized for medicinal purposes.

Amaranthus viridis has been documented for eczema, inflammation, and respiratory diseases and is a good source to be used as antiulcer, analgesic, etc. [21]. *A. aspera*, has been well known to have good medicinal properties being used to cure asthma, skin rashes, gastrointestinal problems, snake bites, and many others [30]. Traditionally, *C. album* was used for burns, peptic ulcers, jaundice, gastric and intestinal disorders, influenza, swelling, dysentery, etc. [56, 57]. *A. sessilis* has been



Fig. 6 *Alternanthera sessilis*: morphology



Fig. 7 *Digera muricata*: morphology

used for healthcare since antiquity. In India, it was used to cure fever, eyesight, headache, and gastrointestinal disorders [58]. In Indonesia, it was traditionally used to treat diarrhoea, dysentery, and stomach disorders [59]. *D. muricata* is a wild herbal plant utilized by local people from ancient times for different purposes such as diabetes, urinary disorders, lactation purposes, fever, kidney stone treatment, bowel complaints, etc. [60, 61]. *C. argentea* has been reported to be used traditionally for various ailments, including skin eruptions, wound healing, diarrhoea, eczema, gonorrhoea, bloody stools, fever, jaundice, piles, diabetes, eye disorders, inflammation, ulcers, antidote for snake poison, etc. [43, 62]. *G. celosioides* has been employed to treat various skin disorders in South America, renal disorders, gastrointestinal disorders in Brazil [63], diarrhoea, fever, analgesic, diuretic, bronchial disorders, etc. [64]. *C. prostrata* is documented to treat sores, used as ear drops for otitis, headache in

Ivory Coast, dysentery, articular rheumatism in Nigeria, wounds, urethral discharges in Gabon, etc. [48].

The information on the traditional uses of plants will serve as the basis for further exploration of plants to develop novel potent drugs against several disorders. Several studies have been reported regarding the traditional uses of selected plants of the Amaranthaceae family, which are well summarized in Table 2.

5 Phytochemical constituents

Phytochemicals are a potent class of molecules that are secondary metabolic products of plants. They comprise various compounds with therapeutic potential, including flavonoids, phenolic compounds, alkaloids, tannins, steroids, organosulfur compounds, and vitamins [81]. These secondary metabolites are synthesized in plants to withstand adverse biotic and abiotic conditions. The phytochemicals, including alkaloids, tannins, and flavonoids, are more likely to possess antimicrobial defence properties. At the same time, most commonly, the phenolic compounds are known to exhibit antioxidant activities because of their free radical scavenging capability [82]. Every part of a plant possesses its own significance of having unique therapeutic potential, so it can be utilized in preparing herbal formulations [83]. The Amaranthaceae family is a repository of diverse phytochemical constituents, including flavonoids, alkaloids, fatty acids, phenols, essential oils, terpenoids, sterols, and various hydrocarbons. Isolated compounds from the selected eight plants are summarized in Table 3 with their respective structures. From various studies reported, it can be concluded that most of these wild plants possess a good number of flavonoids, phenols, terpenoids, and alkaloids, which contribute to the medicinal value of plants.

Amaranthus viridis has been reported to possess various bioactive classes of compounds, including flavonoids,



Fig. 8 *Celosia argentea*: morphology



Fig. 9 *Gomphrena celosioides*: morphology



Fig. 10 *Cyathula prostrata*: morphology (attribution: by Franz Xaver—Own work, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=65845962>)

steroids, tannins, cardiac glycosides, saponins, and terpenoids [84]. The study also reported total phenolic content (TPC) (16.4 ± 0.45 mg catechin/g dry weight) and total flavonoid content (TFC) (5.28 ± 0.33 mg quercetin/g dry weight). Ahmed et al. [85] analysed the phytochemical composition of methanolic leaf and seed extract of *A. viridis* and reported that the plant contains a significant quantity of tannins (6.07–5.96%), alkaloids (13.14–11.42%), and glycosides (63.2–32.2%). Leaf aqueous extract of *A. viridis* has been documented to possess tannins, alkaloids, saponins, phenolics, and steroids [86]. Similarly, Pichaivel et al. [87] confirmed the presence of glycosides, alkaloids, saponins, phenols, tannins, and flavonoids in hydro-alcoholic leaf extract of *A. viridis*. The isolated bioactive compounds from *A. viridis* are depicted in Table 3.

Qualitative phytochemical screening of *C. album* has depicted the presence of diverse active components. Saini et al. [88] reported the phytochemical composition of aqueous leaf extract of *C. album* and depicted amino acids, cardiac glycosides, proteins, saponins, flavonoids,

tannins, and phenolics. Similarly, Kunwar et al. [89] conducted qualitative phytochemical screening of *C. album* methanolic leaf extract and reported that phenol, flavonoid, tannins, terpenoids, cardiac glycosides, and steroids were present. Vinita et al. [90] depicted the presence of terpenoids, alkaloids, tannins, flavonoids, and saponins in *C. album* extract. Thus, *C. album* is a great reservoir of phenolic compounds, like gallic acid, vanillic acid, syringic acid, etc., along with some varieties of fatty acids, phytosterols, and terpenoids shown in Table 3.

Achyranthes aspera, a potent medicinal herb, is a rich source of terpenoids, aliphatic hydrocarbons, and some phthalic acid. In a study [91], phytochemical screening of *A. aspera* leaf and stem was performed in different solvents (petroleum ether, chloroform, benzene, ethanolic, ethyl acetate, and water). The results depicted that the stem ethyl acetate extract and leaf chloroform extract showed maximum phytochemicals, including terpenoids, alkaloids, reducing sugar, and saponins. According to Hossain et al. [92], crude methanolic leaf extract depicted the presence of alkaloids, cardiac glycosides, flavonoids, steroids, tannins, and saponins. Similarly, Neupane et al. [93] reported tannins, alkaloids, phenolics, flavonoids, saponins, and phytosterols in the whole plant ethyl acetate extract of *A. aspera*. In quantitative analysis, the dichloromethane extract of *A. aspera* depicted the highest TFC (38.48 ± 1.48 mgQE/g).

Similarly, *A. sessilis* has been reported to show vast bioactive compounds with diversity in a class of compounds. It includes phenols, flavonoids, vitamins, amino acids, silane compounds, and fatty acids. According to Sivakumar and Sunmathi [94], ethanolic leaf extract of *A. sessilis* showed the presence of flavonoids, alkaloids, phenols, steroids, terpenoids, and glycosides. Kota et al. [95] reported the phytochemical constituents of the leaf extract of *A. sessilis* in distinct solvents (ethyl acetate, acetone, methanol, chloroform, and petroleum ether). The methanolic extract showed maximum phytochemicals, including tannins, flavonoids, saponins, terpenoids, cardiac glycosides, phenols, phytosterols, and reducing sugars. Isolated bioactive compounds of *A. sessilis* are presented in Table 3.

Phytochemical screening of different extract fractions of *D. muricata* has depicted various bioactive components (secondary metabolites), including flavonoids, alkaloids, saponins, phenols, cardiac glycosides, terpenoids, tannins, coumarins, and primary metabolites, including amino acids, reducing sugars, lipids, prolines, carbohydrates, and proteins [39]. These results have been supported by another study that reported the presence of tannins, flavonoids, and alkaloids in the aerial parts of *D. muricata* [96]. Sultana et al. [97] isolated phenolic glycosides from aerial parts of *D. muricata*, namely

Table 2 A summary of ethnobotanical uses of the selected eight plants of the Amaranthaceae family

Sr. No	Plant species	Plant part used/preparation method	Therapeutic uses	References
1	<i>Amaranthus viridis</i> L.	Root juice	Urinary tract inflammation (UTI)	[65]
		Leaves	Constipation Diuretic Eczema Rashes	[24]
		Leaf sap	Purgative Cure eye infection	[66]
		Whole plant	Dysentery Inflammation	
		Seeds	Labour pain Stomach problems	
2	<i>Amaranthus caudatus</i> L. <i>Chenopodium album</i> L.	Leaf, Seeds (Decoction, cooked, and oral)	Anthelmintic, diuretic, vegetable, herbal tonic	[67]
		Leaf, Seeds (Decoction, cooked, and oral)	Anthelmintic, diuretic, bone disease, vegetable, tonic	[67]
		Aerial parts	Arthritis Rheumatism	[68]
		Leaf juice	Treat burns	[69]
		Leaves	Laxative and aphrodisiac	
		Leaf decoction	Gastrointestinal disorders	
		Seeds	Strengthen urinary tract wall	[70]
3	<i>Achyranthes aspera</i> L.	Whole plant	Constipation, abdominal pain, dysentery, diarrhoea, headache, and hepatic disorder	[71]
		Roots	Whooping cough, Haemorrhage, cough, and hydrophobia	[72]
		Roots paste	Ophthalmia Opacities of cornea	[73]
		Leaf decoction	Dysentery Diarrhoea	
		Fresh leaves paste	Treatment of wasp bites	
		Flowering spikes	Snake bites Night blindness Cutaneous diseases	[74]
		Whole plant	Diuretic and pneumonia, Liver complaints	[75]
4	<i>Alternanthera sessilis</i> (L.) DC.	Young leaves and shoots	Edible	[32]
		Whole plant sap	Relief pain Dysentery	[76]
		Plant infusion	Reduce fever Hypothermia, malaria, asthma	
		Roots	Hepatitis	
		Whole plant decoction	Cure Rickets Apthous ulcer	
5	<i>Digera muricata</i> (L.) Mart.	Flowers and seeds	Treat urinary discharges	[39]
		Whole plant	Inflammation Urination As refrigerant	
		Crushed plant	Biliousness Bowel complaints	[77]
6	<i>Celosia argentea</i> L.	Stem and leaves	Infected sores, wounds, and skin eruptions	[78]
		Leaf concussions	Gastrointestinal disorders	
		Seeds	Antidiarrhoeal	
		Roots	Abdominal colic, gonorrhoea, and eczema	
		Whole plant	Antidote for snake poison	
		Seeds	Menorrhagia, haematuria, haemoptysis, epistaxis	[79]

Table 2 (continued)

Sr. No	Plant species	Plant part used/preparation method	Therapeutic uses	References
7	<i>Gomphrena celosioides</i> Mart.	Roots	Antidiarrhoeic tea for children	[80]
		Plant juice	Urolithiasis	
		Not specified	Skin diseases, abortifacient	
		Whole plant	Gangrenous wounds	
8	<i>Cyathula prostrata</i> (L.) Blume	Plant sap	Applied to sores Eardrop Headache	[48]
		Inflorescence and seeds	Burns, fractures, and sores	

3-isopropanoic acid phenyl 1-O- α -D-glucopyranoside and resorciny 1-O- β -D-glucopyranosyl-(6'→1'')-O- β -D-glucopyranoside. Fatty acid esters isolated from *D. muricata* are depicted in Table 3.

Celosia argentea is reported to contain numerous phytochemical constituents with remarkable medicinal potential. The alcoholic extract of *C. argentea* leaves was analysed for phytochemicals, and the results demonstrated that tannins and flavonoids were present [98]. Usunomena and Samuel [99] reported the presence of active metabolites, i.e., flavonoids, saponins, phenols, alkaloids, and glycosides. According to Urmila et al. [100], methanolic leaf extract of *C. argentea* exhibited the presence of glycosides, saponins, phenolics, flavonoids, and tannins. In quantitative analysis, TPC was reported to be 12.24 mg/g gallic acid equivalent (GAE) and 12.84 mg/g GAE in methanolic and aqueous leaf extracts, respectively [101].

Gomphrena celosioides leaves have been reported to possess hexadecanoic acid, phytol, and octadecadienoic acid [102]. In another study, Dosumu et al. [103], aurantiamides and their acetate were extracted from the whole plant n-hexane extract of *G. celosioides*. Apithanasakulngeon et al. [104] performed a qualitative analysis of phytochemicals of ethanolic aerial parts and flowers of *G. celosioides*. Both flower and aerial part extracts depicted the presence of terpenoids, alkaloids, tannins, flavonoids, and saponins.

Cyathula prostrata has been known to show good diversity of flavonoids, phenols, terpenes, and saponins. According to Uahomo et al. [47], ethanolic leaf and root extract of *C. prostrata* demonstrated the presence of flavonoids, cardiac glycosides, alkaloids, terpenoids, saponins, and tannins. Ojekale et al. [105] performed the gas chromatography–mass spectrometry (GC–MS) phytochemical characterization of *C. prostrata* aqueous extract and reported various chemical compounds, namely phytol, hexadecanoic acid methyl

ester, eicosene, pentatricontane, and cyclohexane, 1-(1,5-dimethylhexyl)-4-(4-methylpentyl).

Plants (*D. muricata*, *G. celosioides*, and *C. prostrata*) have been explored less in terms of their phytochemistry. However, the available literature gives us an idea about their constituents. These findings can be further extended to study and isolate their bioactive compounds.

6 Pharmacological applications

There are a lot of studies regarding the evaluation of the various pharmacological potential of plants. Medicinal herbs have been utilized for healthcare since ancient times, but their applications at the pharmacological level have been validated by scientific research. This article highlights the antioxidant, antimicrobial, anti-inflammatory, and antidiabetic potential of eight selected plants (Fig. 11).

6.1 Antioxidant potential

Free radicals are generally produced as by-products in various metabolic pathways, and their accumulation results in oxidative stress in plants and animals. These free radicals are very reactive and, thus, interfere with the functioning of biomolecules like proteins, lipids, and DNA by disrupting their structure [121], putting the cells at high risk, which can lead to severe cardiovascular and neurological disorders [122]. Some other severe disorders may occur as a result of oxidative stress, including cataracts, cancer, and age-related and immunological disorders. However, these damages can be controlled by a specific class of compounds known as antioxidants, which may be produced naturally inside the body or provided exogenously via food ingredients or herbal products. Antioxidants are specific compounds that play a crucial role in scavenging free radicals by neutralizing or preventing the generation of new radicals. They may also capture free radicals to prevent oxidizing chain events from spreading, thus reducing the impacts of oxidative

Table 3 Diverse phytochemical compounds present in wild plants of the Amaranthaceae family

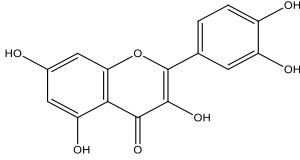
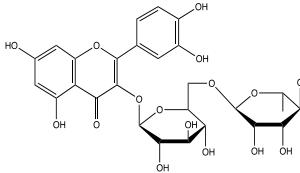
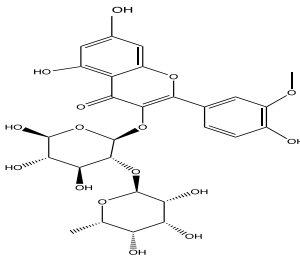
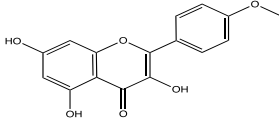
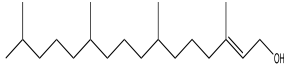
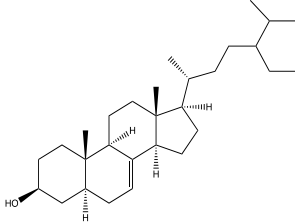
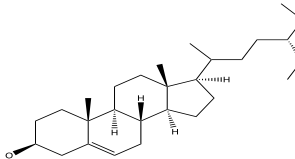
Sr. no	Plant species	Class of compounds	Bioactive compounds	Structure	References
1	<i>Amaranthus viridis</i> L.	Flavonoids	Quercetin (PubChem CID-5280343)		[84]
			Rutin (PubChem CID-5280805)		
			Isorhamnetin-3-O-neohesperidoside (PubChem CID-24204448)		
			Kaempferol (PubChem CID-5280863)		
		Terpenoid	Phytol (PubChem CID-5280435)		[86]
		Sterol	24-ethylthosterol (PubChem CID-157009937)		
2	<i>Chenopodium album</i> L.	Sterol	β-Sitosterol (PubChem CID-222284)		[69]

Table 3 (continued)

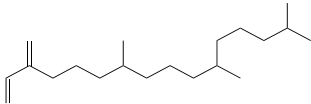
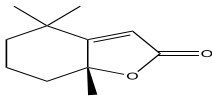
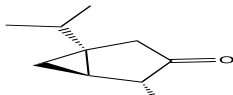
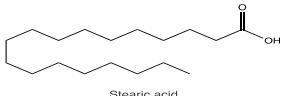
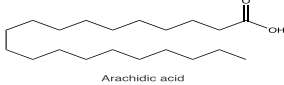
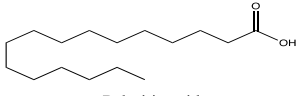
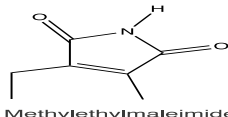
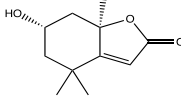
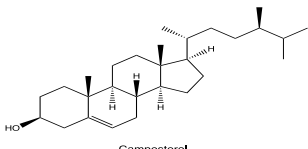
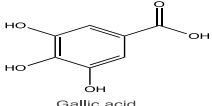
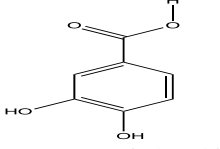
Sr. no	Plant species	Class of compounds	Bioactive compounds	Structure	References
		Terpenoid	Neophytadiene (PubChem CID-10446)	 Neophytadiene	
			Dihydroactinidiolide (PubChem CID-27209)	 Dihydroactinidiolide	
			Thujone (PubChem CID-261491)	 Thujone	[106]
		Fatty acid	Stearic acid (PubChem CID-5281)	 Stearic acid	[69]
			Arachidic acid (PubChem CID-10467)	 Arachidic acid	
			Palmitic acid (PubChem CID-985)	 Palmitic acid	
		Maleimides	Methylethylmaleimide (PubChem CID-29995)	 Methylethylmaleimide	
		Benzofurans	Lololide (PubChem CID-100332)	 Lololide	[106]
		Phytosterol	Campesterol (PubChem CID-173183)	 Campesterol	[107]
		Phenols	Gallic acid (PubChem CID-370)	 Gallic acid	
			Protocatechuic acid (PubChem CID-72)	 protocatechuic acid	

Table 3 (continued)

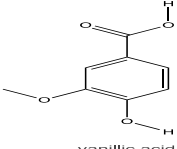
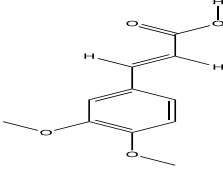
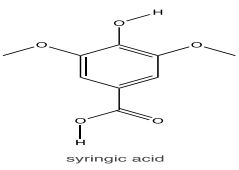
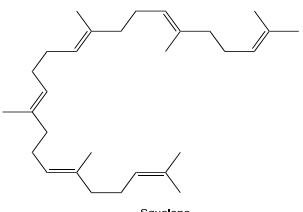
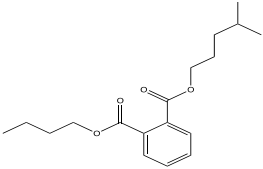
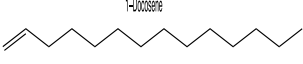
Sr. no	Plant species	Class of compounds	Bioactive compounds	Structure	References
			Vanillic acid (PubChem CID-8468)	 vanillic acid	
			Caffeic acid (PubChem CID-689043)	 caffeic acid	
			Syringic acid (PubChem CID-10742)	 syringic acid	
3	<i>Achyranthes aspera</i> L.	Terpenoids	3,7,11,15-Tetramethyl-2-hexadecen-1-ol (PubChem CID-5280435)	 3,7,11,15-Tetramethyl-2-hexadecen-1-ol	[108]
			Squalene (PubChem CID-638072)	 Squalene	[109]
		Phthalic acid esters	Phthalic acid, butyl isohexyl ester (PubChem CID-6423865)	 Phthalic acid, butyl isohexyl ester	[110]
		Cycloalkanes	Cyclopropane, nonyl (PubChem CID-522556)	 Cyclopropane, nonyl-	[109]
		Aliphatic hydrocarbon	1-Docosene (PubChem CID-74138)	 1-Docosene	[111]
			1-Tetradecene (PubChem CID-14260)	 1-Tetradecene	

Table 3 (continued)

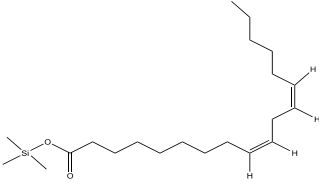
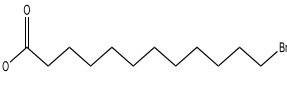
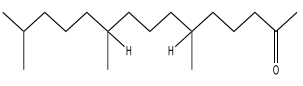
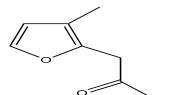
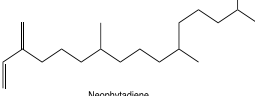
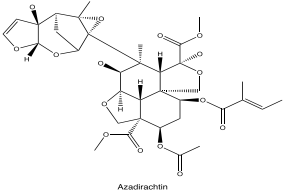
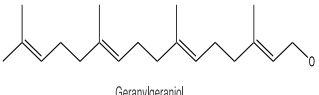
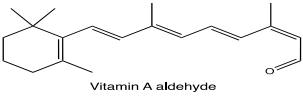
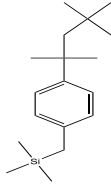
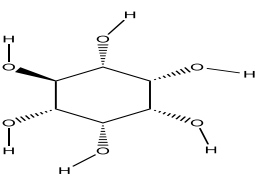
Sr. no	Plant species	Class of compounds	Bioactive compounds	Structure	References
4	<i>Alternanthera sessilis</i> (L.) DC.	Fatty acid	9,12-Octadecadienoic acid (Z, Z) (PubChem CID-5280450)		[112]
			12-Bromododecanoic acid (PubChem CID-175468)		[113]
		Terpenoid	2-Pentadecanone, 6,10,14-trimethyl (PubChem CID-10408)		[112]
			3-Methyl-2-(2-oxopropyl) furan (PubChem CID-545772)		[113]
			Neophytadiene (PubChem CID-10446)		[114]
			Azadirachtin (PubChem CID-5281303)		[115]
			Geranylgeraniol (PubChem CID-5281365)		[116]
		Vitamin	Vitamin-A aldehyde (PubChem CID-638015)		[113]
		Silane compound	Trimethyl [4-(1,1,3,3,-tetramethylbutyl) phenoxy] silane (PubChem CID-528938)		
		Inositol	Scyllo-inositol (PubChem CID-892)		
		Aldehyde	Phenylacetaldehyde (PubChem CID-998)		[114]

Table 3 (continued)

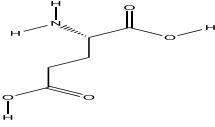
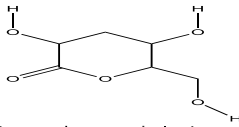
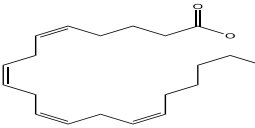
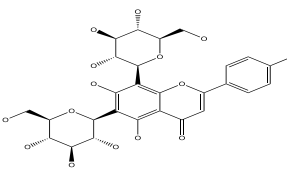
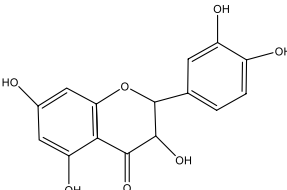
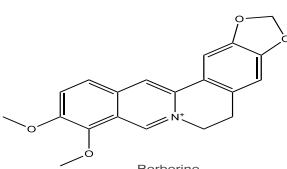
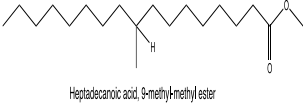
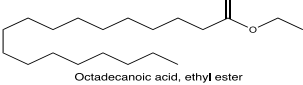
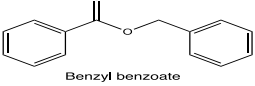
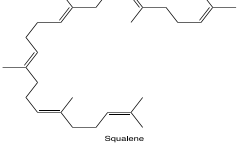
Sr. no	Plant species	Class of compounds	Bioactive compounds	Structure	References
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		Cyclic ester	3-Deoxy-d-mannonic lactone (PubChem CID-541521)	 3-Deoxy-d-mannonic lactone	[115]
		Fatty acid	Arachidonic acid (PubChem CID-444899)	 Arachidonic acid	
		Flavonoids	Vicenin 2 (PubChem CID-442664)	 Vicenin 2	[117]
			Quercetin (PubChem CID-5280343)	 Quercetin	
		Alkaloid	Berberine (PubChem CID-2353)	 Berberine	
5	<i>Digera muricata</i> (L.) Mart.	Esters	Heptadecanoic acid, 9-methyl-methyl ester (PubChem CID-554038)	 Heptadecanoic acid, 9-methyl-methyl ester	[118]
			Octadecanoic acid, ethyl ester (PubChem CID-8122)	 Octadecanoic acid, ethyl ester	
			Benzyl benzoate (PubChem CID-2345)	 Benzyl benzoate	
6	<i>Celosia argentea</i> L.	Terpenoid	Squalene (PubChem CID-638072)	 Squalene	[62]

Table 3 (continued)

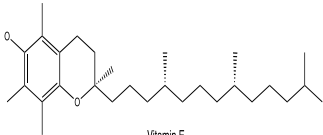
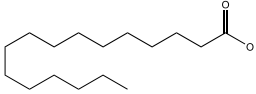
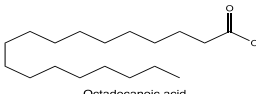
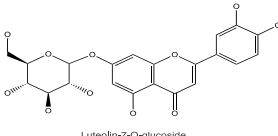
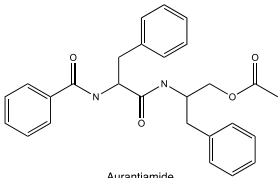
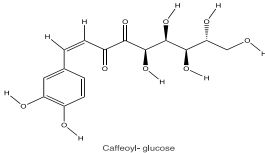
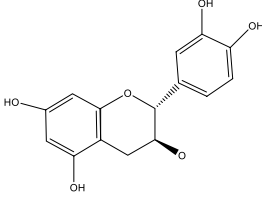
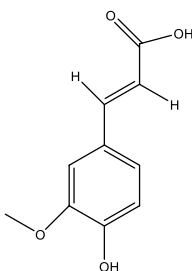
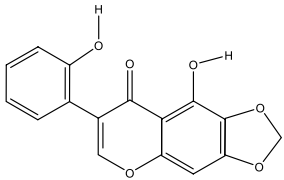
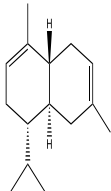
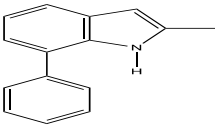
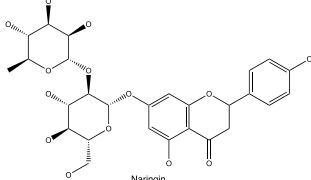
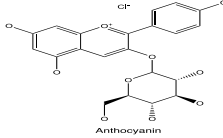
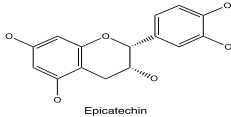
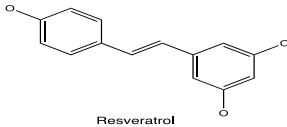
Sr. no	Plant species	Class of compounds	Bioactive compounds	Structure	References
7	<i>Gomphrena celosioides</i> Mart.	Vitamin	Vitamin E (PubChem CID-Not available)	 Vitamin E	[119]
		Fatty acid	Hexadecanoic acid (PubChem CID-985)	 Hexadecanoic acid	[62]
			Octadecanoic acid (PubChem CID-5281)	 Octadecanoic acid	
		Flavonoid	Luteolin-7-O-glucoside (PubChem CID-5280637)	 Luteolin-7-O-glucoside	[120]
		Amino acid	Aurantiamide (PubChem CID-9832120)	 Aurantiamide	
		Phenolic acids	Caffeoyl-glucose (PubChem CID-129669095)	 Caffeoyl- glucose	[64]
			Catechin (PubChem CID-73160)	 Catechin	
			Ferulic acid (PubChem CID-445858)	 Ferulic acid	

Table 3 (continued)

Sr. no	Plant species	Class of compounds	Bioactive compounds	Structure	References
		Flavonoid	Irison B (PubChem CID-5387194)		
8	<i>Cyathula prostrata</i> (L.) Blume	Terpene	1,2,4a,5,8,8a-hexahydro-4,7-dimethyl-1-(1-methylethyl)-naphthalene (PubChem CID-521380)		[105]
		Indole	2-Methyl-7-phenylindole (PubChem CID-610181)		
		Flavonoids	Naringin (PubChem CID-442428)		[47]
			Anthocyanin (PubChem CID-Not available)		
			Epicatechin (PubChem CID-72276)		
		Phenol	Resveratrol (PubChem CID-445154)		

The above structures of chemical compounds were made using the ChemDraw software

stress [123]. This protects plant cells from oxidative stress and cell damage. Plants are rich sources of natural antioxidants due to the presence of a diverse group of bioactive compounds produced under stress conditions [124]. These bioactive compounds include phenols, flavonoids, and tannins, which act as natural antioxidants, protecting plants from harmful oxidative stress effects. The antioxidant action of plants is mainly linked with phenols that

are present in varying concentrations in different plants [125].

The Amaranthaceae family is quite diverse in its bioactive compounds, and the available literature justifies the fact that plants belonging to this family are a good source of natural antioxidants. For in vitro studies, the most commonly used non-enzymatic assays are the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, nitric oxide (NO) scavenging assay, 2,2'-azino-bis

(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) scavenging, hydrogen peroxide (H_2O_2) scavenging assay, and ferric reducing antioxidant power (FRAP) assay.

The different parts (roots, stem, seed, and leaves) of *A. viridis*, in different solvents, exhibited good antioxidant potential. According to Kumari et al. [84], leaves of *A. viridis* were evaluated for antioxidant activity in different solvents, i.e., methanolic, aqueous, chloroform, and n-hexane, and the best antioxidant potential was reported in methanolic extract at various significance levels ($p < 0.01$, $p < 0.05$, $p < 0.001$). Similar results have been reported by Salvamani et al. [126], where the methanolic extract of leaves depicted the best antioxidant potential with a minimum inhibitory concentration (IC_{50}) value of $77.32 \pm 0.96 \mu\text{g/mL}$. Various studies have shown that *A. viridis* leaves possess the best antioxidant activity compared to other parts. Omodamiro et al. [127] assessed the antioxidant activity of *A. viridis* ethanolic leaf extract and reported maximum free radical scavenging activity with $97.6 \pm 0.4\%$ inhibition of radicals.

Chenopodium album plant demonstrated antioxidant activity mainly in aerial parts and as a whole plant. Whole plant aqueous extract demonstrated maximum radical scavenging activity at $300 \mu\text{g/mL}$ concentration with $94 \pm 1.0\%$ inhibition of free radicals [128]. It was further supported by the results of Külcü et al. [129], in which *C. album* ethanolic extract showed maximum inhibition of free radicals' generation. According to Amodio et al. [69], ethyl acetate extract of *C. album* aerial parts exhibited a minimum IC_{50} value of $140.40 \pm 4.3 \mu\text{g/mL}$, showing maximum antioxidant activity.

The plant, *A. aspera*, has also been reported to show antioxidant activity in its different parts. According to Rama et al. [130], the methanolic extract of roots at $200 \mu\text{g/mL}$ concentration was reported to give the maximum radical scavenging activity of 93% with an IC_{50} value ($32.84 \mu\text{g/mL}$). Upadhyaya et al. [131] reported that methanolic leaf extract has been found to depict a significantly ($p < 0.05$) greater antioxidant potential than stem and root extracts. Mishra et al. [132] evaluated the antioxidant properties of *A. aspera* leaf extract in various solvents (petroleum ether and methanol). The methanolic extract exhibited better antioxidant results with a $167.98 \mu\text{g/mL}$ (IC_{50} value). Other parts of this plant also possess antioxidant potential, which can be further explored by different studies to support the present ones.

Alternanthera sessilis has also been documented to exhibit remarkable antioxidant properties. Chai et al. [133] analysed the antioxidant properties of *A. sessilis* leaf and callus in various fractions of methanol extract (hexane, butanol, ethyl acetate, chloroform, and water). The results depicted that the leaf ethyl acetate fraction revealed maximum radical scavenging activity (EC_{50}

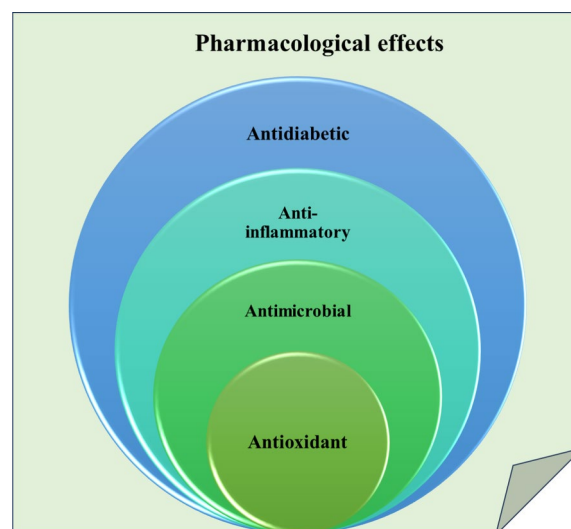


Fig. 11 Different pharmacological effects of selected plants (created using Canva software)

value— $10.81 \mu\text{g/mL}$), while the callus chloroform fraction depicted the highest radical scavenging activity (EC_{50} value— $34.12 \mu\text{g/mL}$). A significant difference of $\alpha = 0.05$ was observed for different values analysed using Fisher's least significant difference (LSD) test. Pathak et al. [134] assessed the antioxidant ability of *A. sessilis* methanol leaf extract via the DPPH assay. The study concluded that the methanolic extract showed maximum radical scavenging (59%) at $110 \mu\text{g/mL}$ concentration. Kota et al. [95] evaluated leaves of *A. sessilis* for antioxidant potential in different solvents (petroleum ether, acetone, ethyl acetate, and chloroform). The results depicted that maximum significant ($p < 0.001$) radical scavenging activity was present in ethyl acetate ($64.73 \pm 0.2\%$), followed by acetone ($57.6 \pm 0.36\%$) and petroleum ether ($20.04 \pm 0.3\%$), respectively.

The plants *G. celosioides*, *D. muricata*, *C. argentea*, and *C. prostrata* have fewer studies regarding antioxidant potential. The present data shows their antioxidant potential, but it needs to be analysed in more detail. Souleymane et al. [135] documented significant ($p < 0.05$ significance level using one-way (analysis of variance) ANOVA at 95% confidence level) antioxidant property of *G. celosioides* aqueous extract and reported IC_{50} — $3.5 \pm 0.5 \mu\text{g/mL}$ at $500 \mu\text{g/mL}$ concentration. An in vivo study [136] studied the antioxidant potential of the whole plant by lipid peroxidation assay in Wistar rats. This study reported that the ethanolic extract of the plant *G. celosioides* reduced the thiobarbituric acid reactive substances (TBARS) (an indicator of oxidative stress) content in carrageenan-treated rats, demonstrating its antioxidant capacity. These are the only studies

available regarding the antioxidant potential of *G. celosioides*, which can serve as the basis for further exploration of its antioxidant properties.

Digera muricata has also been studied for its antioxidant activity. An in vivo study by Khan et al. [137] confirmed the antioxidant potential of aerial part's methanolic extract of *D. muricata*, where TBARS content in the thyroid was decreased by supplementation of plant extract. According to Usmani et al. [138], the methanolic extract of the whole plant exhibited maximum radical scavenging activity, followed by aqueous, ethyl acetate, and chloroform extracts, respectively. These findings were supported by another in vitro study by Aryal et al. [139], which concluded that aerial parts in methanolic extract showed good antioxidant activity by DPPH assay at 100 µg/mL concentration with IC_{50} —29.22 µg/mL.

Celosia argentea was examined for antioxidant activity by DPPH, H_2O_2 , and NO scavenging assays. Urmila et al. [100] studied the antioxidant activity of *C. argentea* via the DPPH assay. It has been reported that at 500 µg/mL concentration, the extract showed the best results with IC_{50} —233.3 ± 20.73 µg/mL and % inhibition—59.73 ± 0.6384. Similarly, the aerial parts of *C. argentea* exhibited radical scavenging activity in various extracts, with the best results observed in methanolic extract [62].

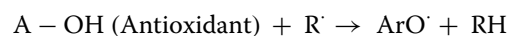
Cyathula prostrata has been less reported for its antioxidant activity. Sonibare and Olatubosun [49] suggested the antioxidant potential of *C. prostrata*. The various parts, including stem, root, leaf, and whole plant, were studied in chloroform and ethyl acetate solvents. It was reported that roots and whole plant were more effective in chloroform extract, while the stem and whole plant showed better results in ethyl acetate extract.

A more detailed summary of antioxidant studies of these plants is presented in Table 4. However, these findings have given the idea of the possibility of applying these plants as a source of antioxidant agents. Still, these studies need to be extended further to validate the available literature because some parts of these plants have not been studied regarding their potential.

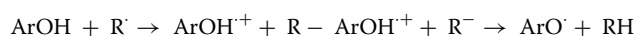
6.1.1 Mechanism of action

Basically, the radical scavenging ability of phenols is due to their potential to inactivate or scavenge free radicals. The number and structural arrangement of hydroxyl groups in the phenol ring determine the level of antioxidant ability. The compounds with more hydroxyl groups tend to possess better antioxidant activity [150]. According to Strmcnik et al. [151], the free radicals scavenging mechanism can be described by the following pathways: (a) proton coupled-electron transfer (PC-ET) and (b) electron transfer-proton transfer (ET-PT)

The PC-ET mechanism involves the hydrogen atom (H-atom) donation to the radical species ($R^\cdot$) to make it stable by the following reaction:



The ET-PT mechanism involves the transfer of electrons (e^-) to free radicals by antioxidants. A cationic radical of an antioxidant is formed, which undergoes a deprotonation reaction ($ArOH^{+\cdot}$), and then the hydrogen cation is transferred to the radical (R):



The free radical species is neutralized by antioxidants by transferring electrons or hydrogen atoms to reactive species, as depicted in Fig. 12.

6.2 Antimicrobial potential

Antimicrobial resistance (AMR) has recently emerged as one of the biggest global public health issues, posing a threat to the ability to effectively prevent and treat infections caused by different pathogens, like bacteria, fungi, and viruses [152]. So, there is an urgent need for new antibiotic agents that inhibit the activity of these resistant organisms. Antibiotic resistance among organisms can be significantly reduced by the use of multiple compounds as an antibiotic agent rather than using similar medicines repeatedly [153]. It has been reported by several previous studies that the use of plant compounds against microbes can significantly reduce the problem of multidrug resistance and give better results instead of pharmaceutical drugs. The presence of various bioactive compounds in plants makes them an efficient source to be used as good antimicrobial agents and found very effective against infectious diseases [9]. Various secondary metabolites present in plants contribute to their therapeutic value. It has been estimated by various studies that the flavonoid class of compounds is probably mainly responsible for the antimicrobial potential of plants [154]. However, some other compounds, like alkaloids and phenols, may also be involved, which have not yet been particularly specified.

Due to various bioactive compounds, plants of the Amaranthaceae family are also known to have remarkable antimicrobial properties. For in vitro studies, the most commonly used assays for evaluating antimicrobial activity include well-diffusion assay, disc diffusion assay, minimum inhibitory concentration (MIC), and minimum bactericidal concentration (MBC) values.

Pichaivel et al. [87] stated that the hydroalcoholic extract of *A. viridis* was most effective against different test bacterial and fungal strains at a 100 µL concentration.

Similarly, Ahmed et al. [85] concluded that 100% methanolic extracts of seeds and leaves of *A. viridis* showed the best activity against test organisms (*Staphylococcus aureus*, *Escherichia coli*, *Fusarium solani*, and *Rhizopus oligosporus*). The best antibacterial activity was in leaf extract against *S. aureus* [zone of inhibition (ZOI)—24 mm] and antifungal activity against *F. solani* (ZOI—17 mm).

Chenopodium album is also reported to show good antimicrobial potential. Lone et al. [128] evaluated the antimicrobial potential of plant methanolic extract against different bacterial and fungal strains. The extract was most effective against *S. aureus* at a 500 µg/mL concentration with a maximum ZOI of 28 ± 0.14 mm. Further study [88] was conducted to analyse the effectiveness of the extract of leaves prepared in different solvents. According to the results, the methanolic extract had the strongest antibacterial activity against *Bacillus subtilis*, among various test strains, followed by chloroform extract. The antifungal activity of methanolic leaf extract was evaluated against soil-borne fungi *Sclerotium rolsfii*, and it restricted the fungal growth in a concentration-dependent manner [155].

Achyranthes aspera has been found to show some antimicrobial potential against test organisms. It has been documented by Ndhlala et al. [156] that the acetone aqueous extract was most effective against gram-negative bacterial strains (*E. coli* and *Klebsiella pneumoniae*), with a minimum inhibitory concentration (MIC) value of 0.78 mg/mL for both bacteria, as compared to the aqueous extract with MIC value of 3.13 and 6.25 mg/mL against the respective bacteria. The statistical analysis was performed using Student's *t* test at a 0.05 significance level. Yadav et al. [157] reported the antibacterial activity of aqueous extracts of the stem and roots of *A. aspera* against *Staphylococcus mutans* using the agar plate method. It has been reported that at 10% concentration and 250 µL volume, both extracts showed maximum ZOI, i.e., 16 mm and 21 mm for stem and root extracts, respectively. The results were compared using Student's *t* test.

Some studies regarding the antimicrobial potential of *A. sessilis* have also been documented. Kumar et al. [158] assessed the ethanolic extract of aerial parts against different test bacterial and fungal strains. The study concluded that the extract was most effective against gram-positive *B. polymexa* with ZOI-23.3 mm, MIC-75 µg/mL, gram-negative *Salmonella typhi* with ZOI-18 mm, MIC-100 µg/mL, and fungal strain *Candida albicans* with ZOI-20 mm, MIC-200 µg/mL at 10 mg/mL concentration. Kumari et al. [159] evaluated the whole plant for antibacterial potential in different solvents (water, ethanol, methanol, ethyl acetate, chloroform,

and petroleum ether). It was reported that the aqueous extract exhibited good antibacterial activity compared to other solvents. Similarly, another study [160] reported the antimicrobial potential of the whole plant using agar well diffusion assay. The whole plant extracts were prepared in different solvents, and ethyl acetate and ethanol extracts were found to show better activity against selected organisms.

Digera muricata, a medicinal wild herb, is known to possess therapeutic value, whose antimicrobial potential has been validated by a few studies. In a study [39], the antimicrobial activity of whole plant was studied in various extracts, including chloroform, petroleum ether, distilled water, and ethanol, against bacterial (*K. pneumoniae*, *E. coli*, *S. aureus*, *S. typhi*, and *Vibrio cholerae*) and fungal strains (*Aspergillus niger*, *A. flavus*, *A. terreus*, and *C. albicans*) by cup diffusion method. The results concluded that petroleum ether extract showed significant ($p < 0.05$) activity against *V. cholerae* (ZOI— 19.13 ± 0.33) and *A. niger* (ZOI— 19.18 ± 1.32) at 400 µg/well concentration.

Celosia argentea has also been known to show good antimicrobial activity. The different parts, including roots, stem, leaf, and inflorescence of this plant, were optimized for antimicrobial activity in different polar solvents (ethyl acetate, ethanol, and water) by disc diffusion assay [79]. The study concluded that ethanol inflorescence extract exhibited maximum ZOI-7–9 mm against different test bacteria and fungi. According to Sreevani et al. [161], it has been documented that the root and stem extracts prepared in chloroform were effective against *S. aureus* and *E. coli* at higher concentrations (1000 µg).

There are fewer studies regarding the antimicrobial potential of *G. celosioides*. In a study [162], leaf and stem were separately studied for their antimicrobial activity in aqueous and alcohol solvents by disc diffusion assay. The aqueous and alcohol extracts showed striking antibacterial activity. Another study [163] included hot water and acetone extracts of leaves, twigs, and flowers to investigate their antimicrobial potential by well diffusion assay. The study concluded that all acetone extracts exhibited better antimicrobial activity, with MIC values of 0.04–0.31 mg/mL. Apithanasakulngeon et al. [104] assessed the antifungal activity of ethanolic crude extracts of *G. celosioides* (aerial parts and flowers) against pathogenic fungi causing chilli diseases (*Cercospora* sp., *C. capsica*, *C. gloeosporioides*, *Fusarium* sp., *Sclerotium* sp.). The flower (ZOI—2.28 cm) and aerial extracts (ZOI—2.18 cm) were most effective against *Sclerotium* sp. at 80 mg/mL concentration. These studies can be further extended to explore the antimicrobial activity of plants and their parts in different solvents against different resistant microorganisms.

Table 4 A summary of different in vitro and in vivo studies of selected plants

Plant	Plant part and extract	Model organism	Concentration	Investigation	Results	References
<i>A. viridis</i>	Leaf (Methanolic extract)	In vitro study	64 µg/mL	ABTS assay	%RSA—60.2 ± 1.17 IC ₅₀ value—47.61 µg/mL	[84]
			64 µg/mL	DPPH assay	%RSA—65.2 ± 1.41 IC ₅₀ value—47.23 µg/mL	
			64 µg/mL	H ₂ O ₂ assay	%RSA—53.43 ± 1.07 IC ₅₀ value—33.21 µg/mL	
			64 µg/mL	NO scavenging assay	%RSA—64.58 ± 1.51 IC ₅₀ value—64.33 µg/mL	
	Leaf (Methanol extract)	In vitro study	100% extract	DPPH assay	IC ₅₀ value—14.27 µg/mL	[85]
	Seed (Methanol extract)		100% extract		IC ₅₀ value—46.55 µg/mL	
	Whole plant (Methanolic extract)	Male Wistar rats	300 mg/kg	SOD activity CAT activity Glutathione peroxidase activity	Antioxidant enzyme activity enhanced by <i>A. viridis</i> plant extract	[140]
	Leaf (Methanolic extract)	In vitro study	300 µg/mL	DPPH assay	70% radical inhibition IC ₅₀ —115.74 µg/mL	
				FRAP assay	85% reducing power IC ₅₀ —77.32 µg/mL	
				NO assay	60% radical inhibition IC ₅₀ —244.36 µg/mL	
<i>C. album</i>	Leaf (Aqueous extract)	In vitro study	40 mg/L	DPPH assay	% radical inhibition—44.26%	[86]
	Seeds (Petroleum ether extract)	In vitro study	100 µg/mL	DPPH assay	% radical inhibition—38.78 ± 1.25	[141]
				ABTS assay	% radical inhibition—63.34 ± 1.43	
				NO scavenging assay	% radical inhibition—35.96 ± 0.74	
	Leaf	In vitro study	20 mg/L	DPPH assay Hydroxyl scavenging assay	%scavenging—83.83 %scavenging—58.64	[107]
	Fruit			DPPH assay Hydroxyl scavenging assay	%scavenging—80.55 %scavenging—52.04	
<i>A. aspera</i>	Leaf (Ethanol)	In vitro study	NR	DPPH assay	IC ₅₀ value—556.07 µg/mL	[75]
	Leaf (Aqueous)			Superoxide scavenging assay	IC ₅₀ value—490.66 µg/mL	
				DPPH assay	IC ₅₀ value—444.69 µg/mL	
				Superoxide scavenging assay	IC ₅₀ value—390.20 µg/mL	
	Whole plant (Ethyl acetate extract)	In vitro study	100 µg/mL	DPPH assay	% scavenging—25.12	[93]
	Leaf (Methanol extract)	In vitro study	250 µg/mL	H ₂ O ₂ scavenging assay DPPH assay	IC ₅₀ value—68.32 µg/mL IC ₅₀ value—62.24 µg/mL	[142]
	Leaf (Methanol extract)	In vitro study	250 µg/mL	DPPH assay	% radical scavenging—33.85 ± 1.66	
	Inflorescence (Methanol extract)	In vitro study	1000 µg/mL	DPPH assay	% radical scavenging—26.89 ± 1.437	[144]
	Roots (Methanol extract)			DPPH assay	% radical scavenging—62.46 ± 5.437	
	Stem (Methanol extract)			DPPH assay	% radical scavenging—62.17 ± 5.394	

Table 4 (continued)

Plant	Plant part and extract	Model organism	Concentration	Investigation	Results	References
<i>A. sessilis</i>	Aerial parts (Ethanol extract)	In vitro study	1000 ppm	DPPH assay	83.3 ± 0.25% RSA	[58]
				ABTS assay	84.19 ± 2.10% RSA	
				Oxygen radical absorbance capacity (ORAC)	13.8 ± 0.73 mmol Trolox equivalent/100 g FW	
	Leaves (Essential oil)	In vitro study	200 µg/mL	DPPH assay	%RSA—179 ± 0.06 µg/mL	[145]
	Flowers (Essential oil)				%RSA—170 ± 0.02 µg/mL	
	Leaf (Petroleum ether)	In vitro study	600 µg/mL	DPPH assay	%RSA—20.04 ± 0.03	[95]
	Leaf (Ethyl acetate)				%RSA—64.73 ± 0.2	
	Leaf (Chloroform)				0	
	Leaf (Acetone)				%RSA—57.6 ± 0.36	
<i>C. muricata</i>	Aerial parts (Methanol)	Male albino rats	200 mg/kg	SOD activity POD activity CAT activity	Activity of anti-oxidants improved by plant extract against CCl ₄ -induced oxidative stress	[146]
<i>C. argentea</i>	Leaves (Aqueous extract)	In vitro study	10 mg/mL	Ammonium thiocyanate assay	67.57% linoleic acid oxidation	[147]
		In vivo study (Male albino rats)	10 mg/mL	Reducing power assay	Reducing power activity increased with an increase in extract concentration	
			400 mg/kg b.w	CAT and SOD activity	Plant extract significantly improved antioxidant enzymes to ameliorate oxidative stress	
	Whole plant	In vitro assay	NR	DPPH assay ABTS assay	IC ₅₀ value—26.25 µg/mL 99.17% radical inhibition	[148]
	Leaves (Aqueous extract)	In vitro assay	300 µg/dL	DPPH assay	IC ₅₀ value—582.75 µg/dL	[149]
				Trolox Equivalent Anti-oxidant Capacity (TEAC) assay	TEAC value—0.45 ± 0.09	

NR—Not reported, SOD—Superoxide dismutase, CAT—catalase, POD—peroxidase

Cyathula prostrata is a wild herbal plant with good therapeutic value. The aerial parts of *C. prostrata* in ethanol solvent demonstrated good antimicrobial activity against different bacterial and fungal strains [164].

The available literature depicts the significant antimicrobial properties of selected wild plants of the Amaranthaceae family (Table 5). However, there is a need to critically evaluate the antimicrobial potential of these plants to isolate novel antibacterial and antifungal compounds.

6.2.1 Mechanism of action

The basic mechanism followed by antimicrobial agents involves several different pathways. Specific mechanisms

are involved when we specify the role of flavonoids against microbial infection, as shown in Fig 13.

- Membrane disruption**—The flavonoids, especially catechin, interact with the membrane by forming H-bonding between polar head groups of lipids and hydrophobic flavonoids. This may lead to alterations in the structure and functioning of the membrane [172].
- Inhibition of DNA synthesis**—There are some flavonoids like quercetin, myricetin, etc., which act as inhibitors of the replication enzyme topoisomerases. Flavonoids generally inhibit the supercoiling of DNA by competitively binding with the ATP binding site of DNA gyrase B subunit (GyrB) and thus result in

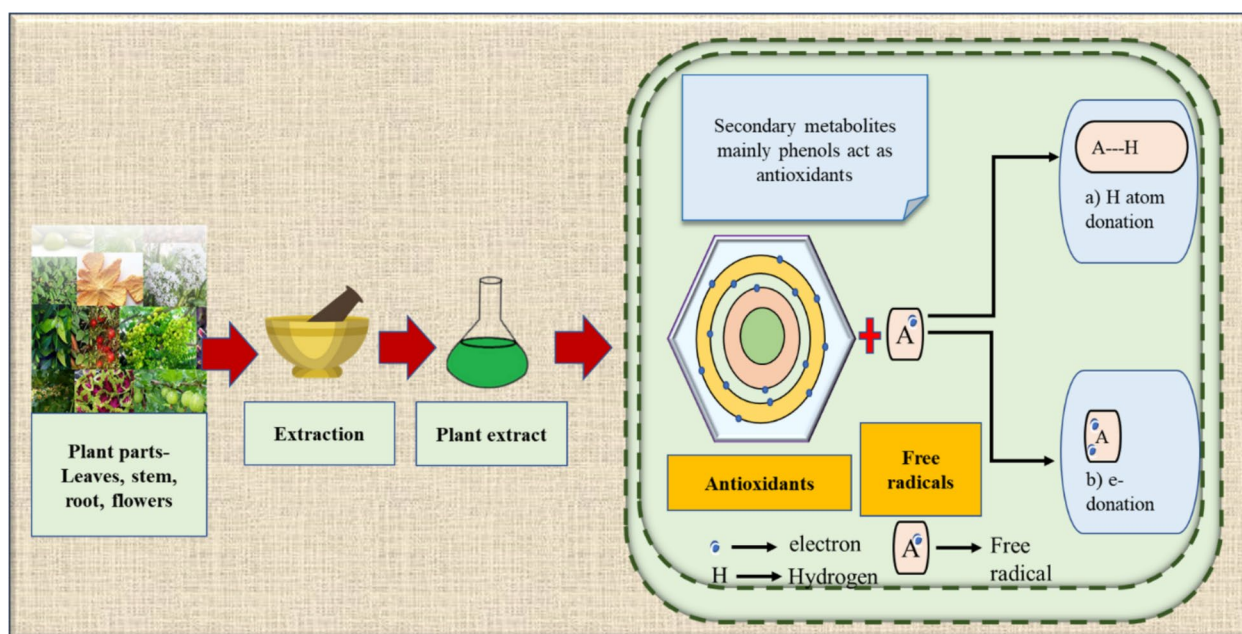


Fig. 12 Diagrammatic representation of the basic mechanism of antioxidants from plants of scavenging free radicals by **a** transfer of hydrogen (H-atom) to free radical and formation of H-bond, **b** donation of free electron to stabilize free radical (this figure was created using Canva software)

the inhibition of the function of the gyrase enzyme, which is quite an important enzyme for the replication of DNA [173]. There is a known flavone, luteolin, and its structurally identical flavonols, such as morin and myricetin, which inhibit the DnaB helicase enzyme of replication and also block the functioning of the RecBCD (helicase/nuclease) enzyme in *E. coli* [174]. Thus, it indirectly affects DNA synthesis and stops the growth of bacteria.

- c. **Inhibiting ATP synthesis**—It has also been reported that some flavonoids, including quercetin, luteolin, and herbacetin, block the F_0F_1 complex of ATPase in *E. coli*. The mechanism involved in this inhibition is binding of flavonoids at the polyphenol binding site of the ATP synthase complex, which further blocks rotation of the c-subunit, resulting in hindrance of ATP synthesis via ATPase [175].

6.3 Anti-inflammatory potential

Inflammation is generally a body's defence mechanism against inflammogens, including infection, allergens, or tissue injury. Normally, it is a physiological process, but it may damage tissues when homeostatic control is lost, leading to severe diseases [176]. Non-steroidal anti-inflammatory medications (NSAIDs) are a class of synthetic bioactive substances employed to treat inflammation, fever, and relieve pain. These synthetic drugs are known to treat various diseases, but they may result in

adverse side effects on living beings. Therefore, herbal extracts and plant-derived drugs are considered safe and efficient as anti-inflammatory agents. Across the world, plant extracts or plant-derived formulations have been used to treat inflammatory disorders since ancient times [177]. Numerous studies have scientifically confirmed that these plants from the Amaranthaceae family have strong anti-inflammatory properties. However, there is a lack of evidence regarding the mechanism of action of particular plant species.

An in vitro study was performed to assess the anti-inflammatory effects of different parts of *A. viridis* by using hyaluronidase and lipoxygenase enzyme inhibition assays [126]. The results depicted that maximum hyaluronidase enzyme inhibition was detected in leaf extract (79%), following seed extract (50%) and stem (35%), respectively. Similarly, the plant extracts inhibited lipoxygenase enzyme in a dose-dependent manner. At 500 $\mu\text{g}/\text{mL}$ concentration, maximum inhibition was found in leaf extract (82%), followed by seed (60%) and stem (35%), respectively. Jin et al. [178] assessed the anti-inflammatory effects of *A. viridis* extracts on lipopolysaccharides (LPS)-stimulated RAW264.7 cells. Upon supplementation of ethyl acetate extract, a significant ($p < 0.05$) reduction in the production of nitric oxide (NO), a key mediator of inflammation in cells, was observed to show good anti-inflammatory potential.

Chenopodium album has been known to exhibit good anti-inflammatory activity. Mushtaq et al. [179]

reported the anti-inflammatory activity of *C. album* aqueous extract at varying concentrations. They showed maximum inhibition of formaldehyde-induced rat paw oedema (an index of acute inflammation) at 400 mg/kg concentration, resembling human inflammation. The results were analysed using one-way ANOVA followed by multiple comparison *t* test at a $p < 0.05$ significance level. Amodeo et al. [69] evaluated this plant for its anti-inflammatory potential by assessing the ability of aerial part extracts to block NO production stimulated by LPS in the murine macrophage RAW264.7 cell line. The best inhibitory activity was reported in the dichloromethane extract of the plant with an IC₅₀ value of 81.7 ± 0.9 µg/mL. Usman et al. [180] studied the anti-inflammatory activity of *C. album* essential oil against 12-O-tetradecanoylphorbol (TPA)-induced ear oedema in mice. It was reported that oil reduced oedema in a concentration-dependent manner.

Achyranthes aspera is another medicinal herb reported to show good anti-inflammatory potential. Aqueous leaf extract of *A. aspera* was effective against carrageenan-induced left hind paw oedema at 800 mg/kg concentration [181]. Samuel and Shabaraya [182] evaluated the leaf anti-inflammatory potential of *A. aspera* in distinct fractions, namely ethyl acetate, ethanol, and hexane, against carrageenan-induced oedema. The results depicted that at 400 mg/kg concentration, ethyl acetate leaf fraction was most effective in reducing oedema volume (0.08 ± 0.01 —86% reduction) after 4 hours of extract induction. Another study [183] explored various leaf fractions (water, chloroform, and n-butanol) for anti-inflammatory potential against carrageenan-induced oedema. The maximum anti-inflammatory effect was observed in the chloroform extract at a 400 mg/kg concentration. Ha et al. [184] assessed the anti-inflammatory potential of *A. aspera* aerial parts via albumin denaturation and lipoxygenase inhibition assay. Methanolic extract depicted remarkable albumin denaturation inhibition (79.35%) and anti-lipoxygenase activity (48.2%) at 1000 µg/mL. A study reported the possible mechanism of the anti-inflammatory potential of *A. aspera* [185], which is depicted in Fig. 14. The (Nuclear factor kappa-light-chain-enhancer of activated B cells) NF-κB signalling pathway is the main signalling pathway involved in inflammation, which involves the activation of transcription of different pro-inflammatory genes, including inducible nitric oxide synthase (iNOS), tumour necrosis factor α (TNF-α), and interleukin-1 (IL-1) [186]. Upon tissue injury, inflammatory pathways are initiated by the activation of some intermediate factors. Src/Syk are tyrosine kinases that regulate the phosphorylation in the NF-κB cascade in early stages. IκBα is an inhibitor of NF-κB. This inhibitor, upon phosphorylation, gets

degraded and regulated by the kinases Src and Syk. Degradation of the inhibitor leads to activation of the NF-κB cascade. The cascade produces NO (pro-inflammatory mediator) and TNF-α, which generates an inflammatory pathway. The anti-inflammatory activity can be linked with downregulation of NF-κB activity [187]. It has been reported that the extract directly targets the Src/Syk kinases, resulting in suppression of phosphorylation of inhibitor of NF-κB (IκBα). Thus, the expression of NF-κB is downregulated, and the inflammatory pathway is blocked. *A. aspera* ethanolic extract decreased the activity of NF-κB luciferase in a dose-dependent manner by up to 71%. Thus, it can be inferred that the ethanolic extract showed anti-inflammatory activity by suppressing NF-κB transcriptional activation.

Alternanthera sessilis also depicted significant anti-inflammatory potential. In a study [188], the Human red blood cells (HRBC) membrane stabilization method was employed to demonstrate the anti-inflammatory activity of ethanolic plant extract of *A. sessilis* because membrane stabilization is considered an important factor in suppressing inflammatory response. The extract was most effective in membrane stabilization at 500 µg/mL concentration. Muniandy et al. [114] explored the anti-inflammatory potential of *A. sessilis* ethanolic stem extract against LPS-stimulated RAW 264.7 macrophage cell line. The anti-inflammatory effect was studied regarding inhibition of NO and cytokine production (key indicators of inflammation). The stem extract significantly ($p < 0.05$) reduced NO production by preventing the degradation of IκBα (inhibitor of NF-κB cascade for NO production) [185]. It inhibited cytokine production at a higher dose of 200 µg/mL.

Digera muricata has been less explored in terms of anti-inflammatory potential. Ravi et al. [189] assessed the anti-inflammatory potential of *D. muricata* leaf methanolic extract using the HRBC membrane stabilization assay. Maximum membrane stability was found at 400 µg/mL concentration, and even at the lowest concentration (25 µg/mL), membrane stabilization was observed. The leaf extract effect was also studied in LPS-stimulated IC-21 macrophages regarding NO production. LPS enhanced the production of NO, while extract treatment significantly ($p < 0.01$) reduced NO generation in a dose-dependent manner.

Celosia argentea has been used traditionally to treat inflammation, and some studies have validated this. Triterpenoid saponins extracted from *C. argentea* seeds were examined for their anti-inflammatory potential [190]. LPS-induced NO production inhibition assay was used to evaluate the anti-inflammatory activity of the compounds extracted. Cell lines treated with extracted compound saponin showed a significant ($p < 0.001$) decrease

Table 5 An overview of different antimicrobial studies of selected plants

Sr. No	Plant species	Plant part and extract	Conc	Assay	Test organisms	Results ZOI (mm) MIC (µg/mL)	References
1	<i>A. viridis</i>	Leaf (methanol)	100% methanol extract (20 µg/mL)	Disc diffusion assay	<i>S. aureus</i>	ZOI—24 ± 1.9 MIC—179 ± 1.28	[165]
					<i>E. coli</i>	ZOI—16 ± 1.4 MIC—398 ± 1.26	
					<i>Fusarium solani</i>	ZOI—17 ± 1.8 MIC—436 ± 1.46	
					<i>Rhizopus oligosporus</i>	ZOI—19 ± 1.4 MIC—302 ± 1.36	
		Seeds (methanol)			<i>S. aureus</i>	ZOI—16 ± 2.1 MIC—428 ± 1.36	
					<i>E. coli</i>	ZOI—11 ± 1.5 MIC—639 ± 1.26	
					<i>F. solani</i>	ZOI—13 ± 1.7 MIC—602 ± 1.89	
					<i>R. oligosporus</i>	ZOI—15 ± 1.0 MIC—482 ± 1.27	
		Whole plant (hexane)	5, 50, and 100 mg/mL	Well diffusion assay	<i>S. aureus</i>	ZOI—16.60–13.80	[166]
					<i>Bacillus cereus</i>	ZOI—13.40–13.60	
					<i>Micrococcus flavus</i>	ZOI—10.80–19.80	
					<i>Bordetella bronchiseptica</i>	ZOI—23.21–35.61	
		Whole plant (ethanol)	1000 µg/mL	Disc diffusion assay	<i>Streptococcus mutans</i>	ZOI—9.05	[167]
					<i>Lactobacillus acidophilus</i>	ZOI—7.86	
2	<i>C. album</i>	Leaves (methanol)	1 mg/mL	Agar well diffusion assay	<i>E. coli</i>	ZOI—25	[88]
					<i>Pseudomonas aeruginosa</i>	ZOI—24	
					<i>Bacillus subtilis</i>	ZOI—31	
					<i>Candida albicans</i>	ZOI—21	
		Leaves (chloroform)			<i>C. glaburata</i>	ZOI—24	
					<i>E. coli</i>	ZOI—21	
					<i>Pseudomonas aeruginosa</i>	ZOI—23	
					<i>Bacillus subtilis</i>	ZOI—28	
		Leaves (hexane)			<i>Candida albicans</i>	ZOI—20	
					<i>C. glaburata</i>	ZOI—23	
					<i>E. coli</i>	No activity	
					<i>Pseudomonas aeruginosa</i>		
		Leaves (acetone)			<i>Bacillus subtilis</i>		
					<i>Candida albicans</i>		
					<i>C. glaburata</i>		
					<i>E. coli</i>	ZOI—15	
					<i>Pseudomonas aeruginosa</i>	ZOI—16	
					<i>Bacillus subtilis</i>	ZOI—0	
<i>Candida albicans</i>	ZOI—15						
<i>C. glaburata</i>	ZOI—15						

Table 5 (continued)

Sr. No	Plant species	Plant part and extract	Conc	Assay	Test organisms	Results ZOI (mm) MIC (µg/mL)	References
		Whole plant (methanol)	500 mg/mL	Agar well diffusion assay	<i>S. aureus</i>	ZOI—20.5	[106]
					<i>S. epidermidis</i>	ZOI—17.5	
					<i>B. subtilis</i>	ZOI—17	
					<i>Proteus mirabilis</i>	ZOI—0	
		Aerial part (ethanol)	50 µg	Agar well diffusion assay	<i>E. coli</i>	ZOI—18	[168]
					<i>S. aureus</i>	ZOI—15.6±0.5	
					<i>B. subtilis</i>	ZOI—12.2±0.7	
					<i>B. cereus</i>	ZOI—14.1±1.1	
					<i>Klebsiella pneumoniae</i>	ZOI—14.6±0.1	
					<i>E. coli</i>	ZOI—20.7±0.8	
					<i>P. aeruginosa</i>	ZOI—20.4±0.5	
		Aerial part (methanol)			<i>S. aureus</i>	ZOI—20.7±0.7	
					<i>B. subtilis</i>	ZOI—20.3±0.9	
					<i>B. cereus</i>	ZOI—26.0±1.0	
					<i>Klebsiella pneumoniae</i>	ZOI—22.2±0.8	
					<i>E. coli</i>	ZOI—24.3±0.8	
					<i>P. aeruginosa</i>	ZOI—24.5±0.8	
		Aerial part (chloroform)			<i>S. aureus</i>	ZOI—20.3±0.8	
					<i>B. subtilis</i>	ZOI—18.3±1.1	
					<i>B. cereus</i>	ZOI—20.9±0.2	
					<i>Klebsiella pneumoniae</i>	ZOI—12.9±0.2	
					<i>E. coli</i>	ZOI—14.2±0.9	
					<i>P. aeruginosa</i>	ZOI—18.2±0.6	
		Aerial part (hexane)			<i>S. aureus</i>	ZOI—20.4±0.9	[169]
					<i>B. subtilis</i>	ZOI—20.3±0.7	
					<i>B. cereus</i>	ZOI—14.3±0.7	
					<i>Klebsiella pneumoniae</i>	ZOI—0	
					<i>E. coli</i>	ZOI—12.3±0.8	
					<i>P. aeruginosa</i>	ZOI—18.4±0.5	
3	<i>A. aspera</i>	Whole plant (methanol extract)	50 µL	Disc diffusion assay	<i>S. aureus</i>	ZOI—9	[169]
					<i>B. subtilis</i>	ZOI—9	
					<i>E. coli</i>	ZOI—0	
					<i>Salmonella typhi</i>	ZOI—7	

Table 5 (continued)

Sr. No	Plant species	Plant part and extract	Conc	Assay	Test organisms	Results ZOI (mm) MIC (µg/mL)	References
4	<i>A. sessilis</i>	Leaf (absolute alcohol extract)	–	Microdilution assay	<i>B. subtilis</i>	MIC—2 mg/mL	[170]
		Callus (absolute alcohol extract)	200 mg/mL	Paper disc diffusion assay	<i>E. coli</i>	MIC—2 mg/mL	
					<i>P. solanacearum</i>	MIC—2 mg/mL	
					<i>Xanthomonas axonopodis</i>	MIC—2 mg/mL	
					<i>X. vesicatoria</i>	MIC—4 mg/mL	
		Leaf (methanol)	200 mg/mL	Paper disc diffusion assay	<i>B. subtilis</i>	MIC—2 mg/mL	[171]
					<i>E. coli</i>	ZOI—8.2 ± 0.12	
					<i>P. aeruginosa</i>	ZOI—8.57 ± 0.57	
					<i>S. aureus</i>	ZOI—8.72 ± 0.18	
					<i>S. typhi</i>	ZOI—8.73 ± 0.18	
					<i>Shigella boydii</i>	ZOI—9.50 ± 0.29	
		Leaf (chloroform)	200 mg/mL	Paper disc diffusion assay	<i>E. coli</i>	ZOI—11.12 ± 0.06	
					<i>P. aeruginosa</i>	ZOI—11.63 ± 0.19	
					<i>S. aureus</i>	ZOI—10.5 ± 0.5	
					<i>S. typhi</i>	ZOI—10.3 ± 0.12	
					<i>Shigella boydii</i>	ZOI—11.83 ± 0.06	
		Leaves (ethanol)	50 µg	Well diffusion assay	<i>B. subtilis</i>	ZOI—1	[94]
					<i>S. aureus</i>	ZOI—1.8	
					<i>S. heamolyticus</i>	ZOI—1.8	
					<i>E. coli</i>	ZOI—1.6	
					<i>K. pneumoniae</i>	ZOI—1.4	
					<i>Proteus vulgaris</i>	ZOI—0.8	[95]
					<i>P. mirabilis</i>	ZOI—1.5	
					<i>Enterococcus faecalis</i>	ZOI—1.3	
					<i>Candida albicans</i>	ZOI—1.5	
		Leaf (acetone)	20 µL	Agar well diffusion method	<i>Pseudomonas sp.</i>	ZOI—10 ± 0.6	
					<i>Cornebacterium glutamicum</i>	ZOI—7 ± 0.6	
		Leaf (ethyl acetate)			<i>E. coli</i> (DH5a)	ZOI—0	
					<i>Pseudomonas sp.</i>	ZOI—7 ± 0.4	
					<i>Cornebacterium glutamicum</i>	ZOI—10 ± 0.5	
		Leaf (chloroform)			<i>E. coli</i> (DH5a)	ZOI—10 ± 0.8	
					<i>Pseudomonas sp.</i>	ZOI—7 ± 0.2	
					<i>Cornebacterium glutamicum</i>	ZOI—10 ± 0.9	
		Leaf (methanol)			<i>E. coli</i> (DH5a)	ZOI—6 ± 0.7	
					<i>Pseudomonas sp.</i>	ZOI—7 ± 0.2	
					<i>Cornebacterium glutamicum</i>	ZOI—10 ± 0.3	
					<i>E. coli</i> (DH5a)	ZOI—0	

Table 5 (continued)

Sr. No	Plant species	Plant part and extract	Conc	Assay	Test organisms	Results ZOI (mm) MIC (µg/mL)	References
5	<i>D. muricata</i>	Leaf (methanol)	NR	Disc diffusion assay	<i>E. coli</i>	ZOI—12 AI—1.19	[37]
					<i>P. aeruginosa</i>	ZOI—8 AI—0.72	
					<i>A. niger</i>	ZOI—0 AI—0.65	
					<i>F. oxysporum</i>	ZOI—7 AI—0.82	
		Stem (methanol)			<i>E. coli</i>	ZOI—11 AI—1.08	
					<i>P. aeruginosa</i>	ZOI—10 AI—0.93	
					<i>A. niger</i>	ZOI—7 AI—0.76	
					<i>F. oxysporum</i>	ZOI—12 AI—1.41	
		Root (methanol)			<i>E. coli</i>	ZOI—10 AI—0.98	
					<i>P. aeruginosa</i>	ZOI—8 AI—0.72	
					<i>A. niger</i>	ZOI—10 AI—1.08	
					<i>F. oxysporum</i>	ZOI—7 AI—0.82	
6	<i>C. argentea</i>	Inflorescence (ethanol)	50 mg/mL	Disc diffusion assay	<i>S. typhi</i>	ZOI—9 MIC—1250 µg/mL MBC—1.25 mg/mL	[79]
					<i>S. aureus</i>	ZOI—9 MIC—1250 µg/mL MBC—1.25 mg/mL	
					<i>P. aeruginosa</i>	ZOI—9 MIC—625 µg/mL MBC—0.625 mg/mL	
					<i>K. pneumoniae</i>	ZOI—0 MIC—625 µg/mL MBC—0.625 mg/mL	
					<i>C. albicans</i>	ZOI—9 MIC—1250 µg/mL MBC—1.25 mg/mL	
		Inflorescence (ethyl acetate)			<i>S. typhi</i>	ZOI—7 MIC—312 µg/mL MBC—1.25 mg/mL	
					<i>S. aureus</i>	ZOI—8 MIC—625 µg/mL MBC—2.5 mg/mL	
					<i>P. aeruginosa</i>	ZOI—8 MIC—625 µg/mL MBC—2.5 mg/mL	
					<i>K. pneumoniae</i>	ZOI—0 MIC—625 µg/mL MBC—1.25 mg/mL	
					<i>C. albicans</i>	ZOI—8 MIC—625 µg/mL MBC—1.25 mg/mL	

Table 5 (continued)

Sr. No	Plant species	Plant part and extract	Conc	Assay	Test organisms	Results ZOI (mm) MIC (µg/mL)	References
7	<i>G. celosioides</i>	Inflorescence (water)	12.5 mg/mL	Agar cup diffusion method	<i>S. typhi</i>	ZOI—0 MIC—625 µg/mL MBC—1.25 mg/mL	[103]
					<i>S. aureus</i>	ZOI—0 MIC—625 µg/mL MBC—1.25 mg/mL	
					<i>P. aeruginosa</i>	ZOI—7 MIC—625 µg/mL MBC—1.25 mg/mL	
					<i>K. pneumoniae</i>	ZOI—0 MIC—0 MBC—0	
					<i>C. albicans</i>	ZOI—7 MIC—625 µg/mL MBC—1.25 mg/mL	
		Whole plant (ethyl acetate)			<i>S. typhi</i>	ZOI—12 ± 0.3	
					<i>E. coli</i>	ZOI—12 ± 0.4	
					<i>P. aeruginosa</i>	ZOI—12 ± 0.7	
					<i>B. subtilis</i>	ZOI—14 ± 0.4	
					<i>S. aureus</i>	ZOI—13 ± 0.7	
8	<i>C. prostrata</i>	Whole plant (methanol)	30 mg/mL		<i>S. typhi</i>	ZOI—12 ± 0.3	[164]
					<i>E. coli</i>	ZOI—12 ± 0.3	
					<i>P. aeruginosa</i>	ZOI—12 ± 0.1	
					<i>B. subtilis</i>	ZOI—13 ± 0.2	
					<i>S. aureus</i>	ZOI—13 ± 0.2	
		Aerial parts (ethanolic extract)			<i>B. subtilis</i>	ZOI—18	
					<i>S. aureus</i>	ZOI—12	
					<i>E. coli</i>	ZOI—5	
					<i>K. pneumoniae</i>	ZOI—5	
					<i>P. aeruginosa</i>	ZOI—5	
					<i>S. typhi</i>	ZOI—5	
					<i>S. dysenteriae</i>	ZOI—5	
					<i>A. niger</i>	ZOI—12	
					<i>C. albicans</i>	ZOI—5	

NR—not reported, MIC—minimum inhibitory concentration, MBC—minimum bactericidal concentration, ZOI—zone of inhibition, AI—activity index

in NO production. These outcomes have been well supported by Kharat et al. [191], stating that methanolic leaf extract of *C. argentea* inhibited carrageenan-induced oedema in Swiss albino mice. Percentage (%) inhibition of paw oedema was observed in a dose-dependent manner, i.e., 18.47% (100 mg/kg p.o.), 26.08% (200 mg/kg p.o.), and 39.13% (400 mg/kg p.o.), respectively. Adegba et al. [192] assessed the anti-inflammatory potential of different extracts of *C. argentea* aerial parts in solvents, namely methanol, aqueous, and acetone, in LPS-induced macrophages (RAW 26.7 cells). The study depicted that methanol extract remarkably inhibited the production of NO in cells, followed by acetone extract and then aqueous extract, respectively. A significant reduction

($p < 0.05$) in NO production was observed using one-way ANOVA followed by the least significant difference (LSD) test.

Gomphrena celosioides is a wild plant with a rich heritage of traditional medicinal uses. It possesses anti-inflammatory potential. Oladele et al. [193] studied the anti-inflammatory efficacy of *G. celosioides* aqueous leaf extract against carrageenan-induced oedema. The results depicted that extract treatment significantly ($p < 0.05$) inhibited oedema (56.14%) at higher concentration (400 mg/kg). In another study [194], the ethanolic and aqueous extract of *G. celosioides* were analysed for anti-inflammatory potential *via* the carrageenan-induced paw oedema model. C-reactive protein (CRP) is

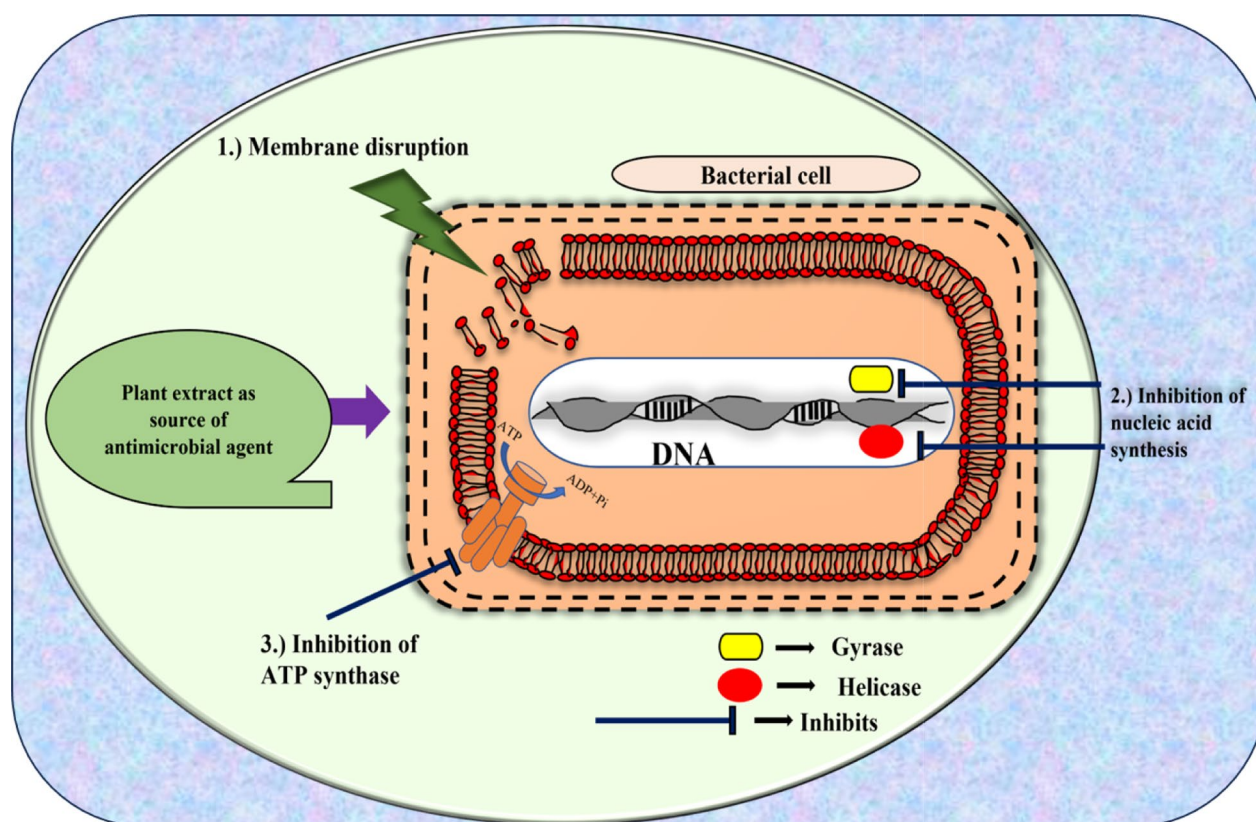


Fig. 13 An overview of the possible mechanism of antibacterial activity of plant extract (mainly flavonoids) 1.) bacterial cell membrane disruption leading to its instability, 2.) inhibiting DNA synthesis by inhibiting the functioning of gyrase and helicase enzymes, 3.) inhibition of ATP synthase, which results in blocking the respiratory chain (this figure was created using Canva software)

a biomarker of inflammation in the serum of a rat model. Treatment of rat models with plant extract significantly reduced CRP levels in serum, indicating anti-inflammatory activity. Isolated compounds (20-hydroxyecdysone, Umbellatosides B, and 20-hydroxyecdysone-20,22-monooacetone) from butanol extract of *G. celosioides* were studied for NO inhibition in RAW264.7 cell line [195]. Maximum inhibitory activity was observed in compound Umbellatosides B with an IC_{50} value of $19.55 \pm 0.61 \mu M$.

Nevertheless, no research on the anti-inflammatory properties of *C. prostrata* plants has been carried out, which can be used for future reference to explore these plants for pharmacological applications.

6.4 Antidiabetic/antihyperglycaemic potential

Diabetes mellitus (DM) is a chronic disease that typically arises when the pancreas is unable to produce a sufficient amount of insulin (hypoglycaemic hormone) or its activity is restricted due to some metabolic changes in the body [196], which results in accumulation of sugar in bloodstream and may lead to increase in toxic advanced glycation end products (AGEs) in chronic hyperglycaemia condition. According to the International Diabetes

Federation (IDF) reports, over 537 million people aged 20–70 years have diabetes globally, and by 2045, this figure might rise to 783 million [197]. The management of this disease is a serious issue across the world. Due to the serious effects of synthetic medications, the need of the hour is to shift towards herbal remedies again. Utilization of herbal plants could be quite effective in treating diabetes because, according to the available literature, more than 400 plant species have been reported with antidiabetic activity [198]. Future drug development programmes must heavily rely on natural compounds, especially those of plant origin, as the primary source for finding attractive lead candidates. Medicinal plants are highly used for diabetes treatment, mainly in developing nations, to relieve the population from the financial burden of the cost of conventional medications [199]. Another main reason for the utilization of plants to treat several diseases is the presence of diverse bioactive constituents like flavonoids, phenols, terpenoids, alkaloids, glycosides, and carotenoids with good antidiabetic potential [200].

Amaranthus viridis, a valuable medicinal herb, has also been reported for antidiabetic potential. Methanolic

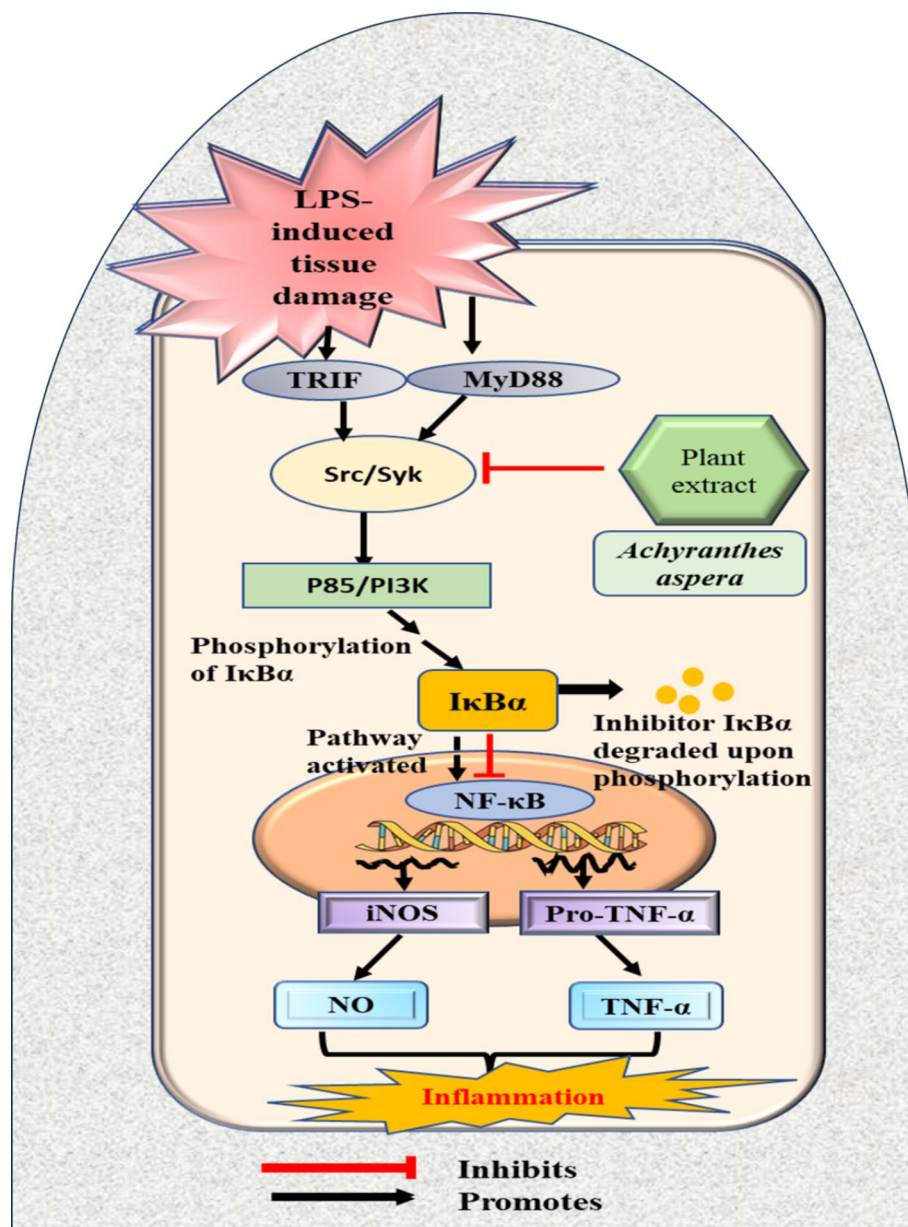


Fig. 14 Anti-inflammatory activity mechanism of ethanolic extract of *Achyranthes aspera*. Plant extract downregulated NF-κB (pro-inflammatory transcription factor) expression by inhibiting the Src/Syk tyrosine kinases, resulting in blockage of inflammation pathway (this figure was created using Canva software)

extract of *A. viridis* was investigated in alloxan-induced diabetic rat models, and blood glucose level (BGL) was highly reduced through the administration of extract in a dose-dependent manner [65]. A reduction in BGL at $p < 0.001$ was considered to be statistically significant. According to Pandhare et al. [201], administration of *A. viridis* aqueous stem extract significantly reduced BGL in streptozotocin (STZ)-induced diabetic rats. Similarly, ethanolic extract of *A. viridis* demonstrated a significant

($p < 0.05$) hypoglycaemic effect in STZ-induced diabetes in rat models by enhancing the uptake of glucose for the formation of glycogen via glycogenesis, as concluded by an in vitro glucose consumption by hemidiaphragm study [202].

Chenopodium album has been reported to have anti-diabetic activity by some studies. Kant [203] investigated *C. album* methanolic root extract for antidiabetic potential in STZ-induced diabetic Wistar albino rats. It

was reported that plant extract significantly decreased BGL and, at higher doses, normalized the insulin levels, depicting its protective action against diabetes. Choudhary et al. [204] assessed the antidiabetic property of *C. album* extracts in various fractions (flavonoid, alkaloid, tannin, and saponin fractions) via in vitro α -amylase inhibition assay and in vivo STZ-induced diabetic models. For in vitro assay, flavonoid fraction showed maximum α -amylase inhibition with an IC_{50} value of 812.83 ± 1.07 . In diabetic rats, flavonoid fraction significantly ($p < 0.05$) reduced glucose levels at a 500 mg/kg dose, showing potent antidiabetic activity.

Various experimental studies were carried out to assess the antidiabetic potential of *A. aspera*. Ethanolic extract of seeds of *A. aspera* has been reported to exhibit a reduction in BGL in STZ-induced diabetic rats at 600 mg/kg concentration [205]. These findings have been supported by Lakshmi and Srivastava [206], who stated that the chloroform fraction of the ethanolic extract of the roots of *A. aspera* was most effective in showing antidiabetic potential in STZ-induced diabetic Sprague Dawley rats. Reedy et al. [207] evaluated the antidiabetic efficacy of *A. aspera* root extracts (methanolic and ethyl acetate extracts) via α -amylase and α -glucosidase enzyme inhibition assays. Methanolic extract demonstrated better enzyme inhibition activity than ethyl acetate extract, with an IC_{50} value (40 ± 2.92) for α -amylase and 38.92 ± 1.93 for α -glucosidase enzyme. Mishra et al. [132] examined methanolic and petroleum ether extracts of *A. aspera* leaves for antidiabetic activity via α -amylase and α -glucosidase enzyme inhibition assays using acarbose as a standard. The study reported that methanolic extract showed significant ($p < 0.05$) inhibitory activity against α -amylase ($55 \pm 0.50\%$) and α -glucosidase ($53.06 \pm 0.23\%$) enzymes, respectively, at 160 μ g/mL concentration.

Alternanthera sessilis is known to possess several therapeutic potentials and, thus, evaluated for antihyperglycaemic potential. Ethyl acetate fractions of leaf and callus cultures were investigated for antidiabetic potential, and it was reported that callus fractions significantly ($p < 0.05$) inhibited α -glucosidase (EC_{50} -0.25 mg/mL) enzyme than leaf fractions [133]. Methanolic extract of *A. sessilis* decreased BGL (46.1% reduction at 400 mg/kg b.w.) in glucose-administered rats, which was measured using the glucose oxidase method [208]. Ethanolic extract from plant was reported to show antihyperglycaemic activity against STZ-induced diabetic Wistar rats, which may be due to its inhibitory effect on structural protein degradation [209].

Digera muricata, a less explored plant with great medicinal value since ancient times. *D. muricata* leaves (methanolic extract) were investigated for antidiabetic

potential in alloxan-induced rats, and it was reported that the extract significantly ($p < 0.05$) reduced blood glucose level, regained insulin level, and body weight in diabetic rats in a dose-dependent manner [61]. Ramalashmi [118] also evaluated the methanolic extract of *D. muricata* for antidiabetic efficacy with an α -amylase enzyme inhibition assay. Maximum inhibition of α -amylase enzyme activity (74.7%) was observed at 100 mg/mL concentration.

Celosia argentea, a wild herbal plant, was traditionally used for diabetes in Indian folk medicine. Hydroalcoholic extracts of *C. argentea* with its different fractions were investigated for antidiabetic potential in an in vitro study using α -glucosidase and α -amylase enzyme inhibition assay [210]. The study reported that the dichloromethane fraction of the extract showed maximum enzyme inhibition to regulate glucose levels. An in vivo study has been reported depicting the antidiabetic potential of root extracts of *C. argentea* in respective solvents (ethanol, petroleum ether, and chloroform) studied against STZ-induced diabetic rats [211]. The key findings of this study were that only ethanolic extract treatment significantly enhanced glucose tolerance in rats at a 500 mg/kg dose. Ethanolic extract reduced glycaemic levels both at 200 mg/kg (75% reduction) and 500 mg/kg (66% reduction) doses, regained body weight, and reduced serum triglycerides more effectively at higher concentration (500 mg/kg) in diabetic rats.

Gomphrena celosioides was studied for its antidiabetic properties. Duc et al. [212] evaluated isolated compounds for hypoglycaemic activity from *G. celosioides* ethanolic leaf extract using the Protein tyrosine phosphatase 1B (PTP1B) inhibition assay and glucose uptake in 3T3-L1 adipocytes. Compound neodactyloquinone demonstrated maximum significant ($p < 0.05$) PTP1B inhibition of $80.39 \pm 6.88\%$ and enhanced glucose uptake at maximum rate.

Kavitha et al. [213] studied the antidiabetic potential of *C. prostrata* extract in alloxan-induced diabetic rats. Treatment of rats with the extract significantly ($p < 0.05$) reduced BGL. Ogbonnia et al. [214] assessed the hypoglycaemic property of *C. prostrata* in alloxan-induced diabetic rats. The administration of extract lowered postprandial plasma sugar.

The present studies validate the antidiabetic potential of these wild plants. However, there is still less information regarding plants like *D. muricata*, *C. prostrata*, and *G. celosioides*. So, there is an urgent need to elaborate on these findings to enhance the application of these herbal plants in the context of diabetes therapy. Available literature serves as the basis for isolating novel compounds from plants to be used as antidiabetic drugs.

6.4.1 Mechanism of action

Though the exact mechanism of action for particular plant species is not well understood, some studies depict possible basic mechanisms that antidiabetic plants may follow to reduce hyperglycaemia. These mechanisms include enhancing glucose metabolism in the liver via glycogenesis. The process of glycogenesis increases glycogen production via glucose molecules, ultimately reducing blood sugar levels [215]. The plant may increase the production of insulin (a hypoglycaemic hormone) from β -cells of pancreatic islets by restoring the structural integrity of pancreatic cells damaged from diabetes-related oxidative stress [216]. In the small intestine, glucose absorption is decreased by blocking the activity of enzymes α -amylase and α -glucosidase, required to digest carbohydrates. Inhibiting these enzymes reduces the conversion of carbohydrates into sugar, which reduces the risk of higher postprandial glucose levels in diabetic patients [217]. Various pathways activated via antidiabetic plants to combat diabetes are well shown in Fig 15.

7 Toxicological studies

Since antiquity, people have harnessed medicinal plants to treat a variety of maladies. Herbal medicines are given preference due to their remarkable efficacy. However, these herbal products must be evaluated for their toxic effects before medicinal use to ensure safety issues. Various studies, including acute toxicity assay, sub-acute toxicity assay, etc., are being conducted to evaluate the toxic effects of crude plant extracts.

Amaranthus viridis aqueous leaf extract was studied for acute toxicity and subacute toxicity assay [218]. In the acute toxicity assay, no toxic symptoms were observed at a 2000 mg/kg dose. From the sub-acute toxicity assay, the extract effect was assessed on rats' body weight, liver, heart, and kidney at varying concentrations (200, 400, and 600 mg/kg b.wt) for 24 days. Histological examination of organs showed no change in the structure of organs, indicating no toxicity. In another study [219], methanolic leaf extract of *A. viridis* was studied for toxicity via acute oral toxicity assay at 2000 mg/kg and 5000 mg/kg doses. It was reported that no toxic symptoms were seen, even at the highest dose (5 g/kg).

Choudhary et al. [204] assessed the toxic effects of aerial extracts of *C. album* in various fractions via an acute toxicity assay. The results indicated that no toxicity symptoms were observed at 2000 mg/kg. The lethal dose (LD_{50}) was considered 2000 mg/kg for *C. album* extract. Nigam and Parakh [220] reported that *C. album* alcoholic and aqueous extract did not exhibit any toxicity symptoms up to a 5000 mg/kg oral dose, assessed by acute oral toxicity assay.

Achyranthes aspera aqueous extract was studied for toxicity via acute oral toxicity assay [182]. No toxicity symptoms were recorded for up to 2000 mg/kg of extract. In another study [221], root methanol extract showed no sign of mortality at up to 100 mg/kg dose and was also found to be free from any neurotoxic-associated effects. Gopal et al. [222] assessed *A. aspera* aqueous extract for a repeated 28-day sub-acute toxicity assay. The study depicted that no mortality or change in normal behaviour like grooming, restlessness, rolling and jumping, twitches, and writhing was observed after administering a 1000 mg/kg oral dose of extract.

Only a few toxicological studies on *A. sessilis* have been reported. Gayathri et al. [223] studied the toxicological effects of *A. sessilis* aqueous leaf extract in Swiss mice at varying concentrations (16.9 mg/mice, 33.8 mg/mice, and 67.6 mg/mice) for 14 consecutive days. The results depicted that no severe toxicity signs were noticed in mice. However, at the highest dose (67.6 mg/mice), one animal developed diarrhoea due to gas accumulation. But no severe damage was reported. Hossain et al. [207] reported that acute toxicity assay results showed no toxicity in mice, even at the highest dose (3000 mg/kg b.wt.) of aqueous extract of *A. sessilis*.

Some studies have assessed the toxicity of *C. argentea* extracts in rat models. Methanolic leaf extract of *C. argentea* was assessed for toxicity via acute oral toxicity assay [192]. There was no toxicity symptoms reported up to a dose of 2000 mg/kg b.wt. These outcomes were validated by another study [209], where the toxicity of *C. argentea* root extract was studied by acute toxicity assay. The results clearly depicted that *C. argentea* extract was non-lethal up to a dose of 2000 mg/kg b.w.

Gomphrena celosioides extract toxicity is documented in some studies. In a study [193], *G. celosioides* leaf extract was screened for toxicity by acute toxicity assay. The results depicted that the extract was safe up to 20–640 mg/kg oral doses in rats. Souleymane et al. [135] reported that intraperitoneal administration of *G. celosioides* aqueous extract was not lethal up to a 100 mg/kg dose, and no toxicity signs were reported. Another study [80] studied the toxicological potential of *G. celosioides* ethanolic extract in acute and sub-acute toxicity models. For the acute toxicity assay, the lethal dose (LD_{50}) was over 2000 mg/kg in male and female Wistar rats. No symptoms of toxicity were seen even in repeated experiments.

The acute toxicity assay results depicted that *C. prostrata* extract showed a (LD_{50}) value up to 20 g/kg b.wt [214]. No toxicity symptoms or death were observed. The mode of administration of the extract is also a major factor in toxicity symptoms. Ibrahim et al. [48] assessed the toxicity of *C. prostrata* extract via oral administration

and intraperitoneal route. The results showed no death or toxicity signs in oral administration, even at higher concentrations (4.0 g/kg). However, 83% mortality (2.2 g/kg conc) and 100% mortality (2.6 g/kg conc) were observed in intraperitoneal administration.

There are no available toxicological studies for *D. muricata* that need to be studied in the future. The present studies can be further extended to understand the toxicological effects of these plants on safety issues. In vivo toxicology will further serve as a basis for clinical evaluation of extracts.

8 Concluding remarks and future directions

Herbs have been widely utilized for medicinal purposes since ancient times, and this has also been proven by various scientific studies. This review presents an overview of the botany, pharmacological effects, and ethnobotanical uses of eight medicinal plants of the Amaranthaceae family, along with the summarized view of their diverse phytochemical compounds, which owe to the therapeutic potential of plants. It could be inferred from the current review that these plants serve as a repository of various bioactive compounds with unique biological efficacies, including flavonoids, alkaloids, sterols, phenols, fatty acids, terpenoids, and some hydrocarbons. Some of these

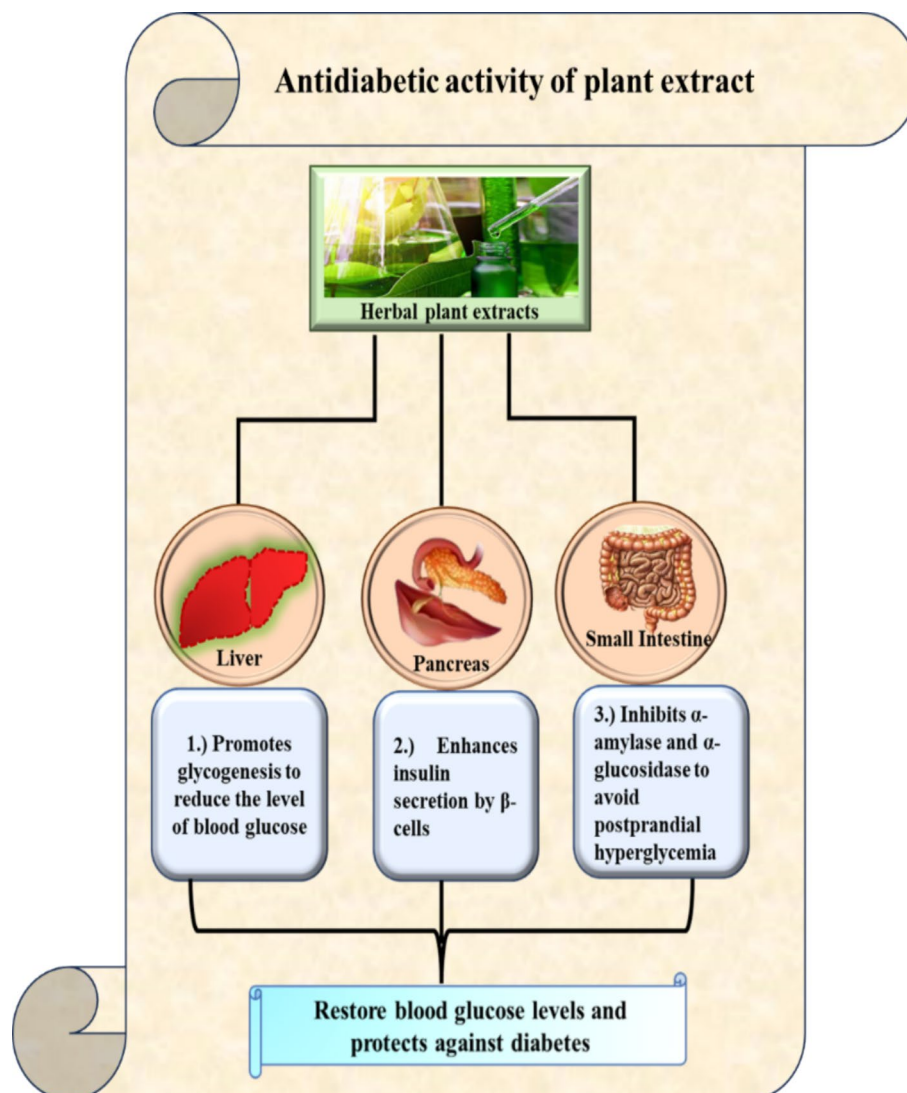


Fig. 15 Possible antidiabetic mechanism of action of herbal antidiabetic plants in different organs. Blood glucose level is maintained by different pathways in organs, including 1) in the liver, glucose metabolism is enhanced, 2) level of insulin hormone, which regulates blood sugar level in body, is maintained in pancreas, 3) a decrease in glucose absorption from the gastrointestinal system (figure created using Canva software)

plants, such as *A. viridis*, *D. muricata*, *C. argentea*, and *C. album*, are edible as leafy vegetables and have therapeutic value. These plants possess good antioxidant, antimicrobial, anti-inflammatory, and antidiabetic potential, summarized in the present article. In contrast, a few plants like *G. celosioides*, *C. prostrata*, *C. argentea*, and *D. muricata* are still less explored for their pharmacological potential, which needs to be extended for further exploration. Therefore, more research is needed to validate some acclaimed pharmacological potentials and determine the mode of action. All the plants discussed in this article are wild plants, generally weeds, which are quite harmful to our crops in agriculture, but their medicinal importance cannot be ignored. With the advancement of science and technology, detailed information regarding the health benefits of wild plants will open up new doors for using weeds in medicine. Not only will this help develop novel drugs, but it will also be one of the better management programmes for weeds in nature. This review highlights the phytochemistry of these plants, which can be further utilized to isolate bioactive compounds from these plants with their unique medicinal value. Thus, the available literature helps us conclude that the Amaranthaceae family comprises valuable medicinal herbs that, on further exploration, can supplement and complement modern medicine better. Despite providing a comprehensive overview of the recent advancements in ethnobotany, phytochemistry, pharmacology, and toxicology of selected wild plants within the Amaranthaceae family, this review also presents the research gap. Firstly, the available data are unevenly distributed across species, with some plants being extensively studied while others remain poorly characterized, leading to potential bias in representation. Secondly, much of the pharmacological evidence is derived from in vitro or animal model studies, which may not directly translate to clinical efficacy in humans. Additionally, many ethnobotanical records lack rigorous scientific validation or standardized documentation, potentially affecting the reliability of traditional use claims. Toxicological data also remain limited or outdated for several species, hindering accurate risk assessment. These limitations highlight the need for more targeted and standardized research to support the therapeutic potential and safety of wild Amaranthaceae species.

Abbreviations

ABTS	2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)
ATPase	ATP synthetase
BGL	Blood glucose levels
CAT	Catalase
CRP	C-reactive protein
DPPH	2,2-Diphenyl-1-picrylhydrazyl
EC ₅₀	Half maximal effective concentration
FRAP	Ferric reducing antioxidant assay
GAE	Gallic acid equivalent

H ₂ O ₂	Hydrogen peroxide
HRBC	Human red blood cells
IC ₅₀	Half maximal inhibitory concentration
IL-1	Interleukin-1
iNOS	Inducible nitric oxide synthase
LPS	Lipopolysaccharides
MBC	Minimum bactericidal concentration
MIC	Minimum inhibitory concentration
NF-κB	Nuclear factor kappa B
NO	Nitric oxide
NSAIDs	Non-steroidal anti-inflammatory drugs
POD	Peroxidase
PTP1B	Human protein tyrosine phosphatase 1B
Src/Syk	Tyrosine kinases
SOD	Superoxide dismutase
STZ	Streptozotocin
TBARS	Thiobarbituric acid reactive substances
TFC	Total flavonoid content
TNF-α	Tumour necrosis factor α
TPC	Total phenol content
TRIF	TIR-domain-containing adapter-inducing interferon-β
ZOI	Zone of inhibition

Author contributions

Conceptualization: Priyanka Sharma, Asha Sharma; Writing original draft: Priyanka Sharma; Investigation, Data curation, and Formal analysis: Priyanka Sharma, Asha Sharma, Sakshi Saini, Pritam Hasanpuri, Naveen Kataria, Vikram Kumar, Pooja Singh. Supervision and Validation: Asha Sharma Writing – review & editing: Priyanka Sharma, Asha Sharma, Sakshi Saini, Pritam Hasanpuri, Naveen Kataria. All authors have read and approved the final manuscript.

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