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Review article

An overview on pharmacological significance, phytochemical potential, traditional importance and conservation strategies of *Dioscorea deltoidea*: A high valued endangered medicinal plant

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ABSTRACT

Dioscorea deltoidea Wall. ex Griseb. is an endangered species of the Dioscoreaceae family. It is the most commonly consumed wild species as a vegetable due to its high protein, vital amino acid, vitamin, and mineral content. There are approximately 613 species in the genus *Dioscorea* Plum. ex L., which is found in temperate and tropical climates. *Dioscorea deltoidea*, a plant species widespread across tropical and sub-tropical regions, called by different names in different languages. In English, it is commonly referred to as “Wild yam” or “Elephant foot”. The Sanskrit name for this plant is “Varahikand,” while in Hindi, it is known as “Gun” or “Singly-mingly.” The Urdu language refers to it as “Qanis,” and in Nepali, it is called “Tarul,” “Bhyakur,” or “Ghunar.” *Dioscorea deltoidea* has been used to cure a wide range of human ailments for centuries. This plant has nutritional and therapeutic uses and also contains high amounts of steroidal saponins, allantoin, polyphenols, and most notably, polysaccharides and diosgenin. These bioactive chemicals have shown potential in providing protection against a wide spectrum of inflammatory conditions, including enteritis (inflammation of the intestines), arthritis (joint inflammation), dermatitis (skin inflammation), acute pancreatitis (inflammation of the pancreas), and neuro inflammation (inflammation in the nervous system). Furthermore, the valuable bioactive chemicals found in *D. deltoidea* have been associated with a range of beneficial biological activities, such as antibacterial, antioxidant, anti-inflammatory, immunomodulatory, hepatoprotective, and cytotoxic properties. Sapogenin steroidal chemicals are highly valued in the fields of medicine, manufacturing, and commerce. It has both expectorant and sedative properties. It is employed in the treatment of cardiovascular diseases, encompassing various ailments related to the heart and blood vessels, skin disease, cancer, immune deficiencies, and autoimmune diseases. Additionally, it finds application in managing disorders of the central nervous system and dysfunctional changes in the female reproductive system. Furthermore, it is valued for its role in treating bone and joint diseases. Metabolic disorders are also among the ailments for which *D. deltoidea* is employed. It has traditionally been used as a vermifuge, fish poison, and to kill lice. Diosgenin, a

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steroidal compound found in *D. deltoidea*, plays a crucial role as a precursor in the chemical synthesis of various hormones. Due to the presence of valuable bioactive molecule, like corticosterone and sigmasterol, *D. deltoidea* is cultivated specifically for the extraction of these beneficial phytochemicals. The current study aims to assess *D. deltoidea's* medicinal properties, ethnobotanical usage, phytochemicals, pharmacological properties, threats, and conservation techniques.

1. Introduction

The plant known scientifically as *Dioscorea deltoidea* Wall. ex Griseb. is a long-lived herbaceous plant valued for its medicinal properties. It is native to and predominantly found in India and China. This species faces the threat of extinction and is classified as an endangered plant. Taxonomically, it belongs to the Dioscoreaceae family, which falls under the order DioscorealesFig. 1.

Dioscorea deltoidea Wall. ex Griseb. a perennial medicinal plant growing primarily in India and China, is an endangered species belonging to Dioscoreaceae family, which falls under the order Dioscoreales. Many different names have been given to it, including "Wild yam or Elephant's foot" in English, "KildriKreench" in Kashmiri, and "Singly-mingly" in Hindi [1]. It produces rhizomes that are abundant in sapogenin steroidal compounds. These substances are extremely important in the industrial, commercial, and medical fields. The phyto-steroidal-sapogenin "diosgenin" is the most significant bioactive chemical isolated for commercial use [2]. The number of species in this genus has been steadily declining in nature, due to its rising commercial demand and ecological harm. Furthermore, *D. deltoidea* is categorized as an endangered plant species in various Asian countries, including Nepal, Pakistan, and India [3]. The plants exhibit distinctive twining and climbing vines originating from their rhizomes. These rhizomes and tubers primarily function as storage organs for starch and various secondary compounds, serving as photosynthetic sinks [4]. Yam is important for the economics, health care, and food security in developing nations.

Dioscorea Plum. ex L. is a genus of about 633 species that are widely distributed in both temperate and tropical conditions. Seven to ten of these species are currently being intensively farmed in 61 different countries [5] and play a large role in the socioeconomic and cultural life of these nations [6]. Yams belonging to the *Dioscorea* species, which are edible, rank as the third-largest tuber crop globally, contributing to 10 % of the total production of roots and tubers [7]. Bitterness and toxicity have been studied in a number of *Dioscorea* species, including *D. deltoidea* [8]. According to some reports, *D. deltoidea* tubers containe 0.02–0.34 g/kg of the bitter chemicals diosbulbin A and B; yet no harmful toxins were discovered. Various cooking methods were found to influence the bitter components, with research indicating that boiling is the most effective method in reducing bitterness compared to consuming the food in its raw state [9].

Leaf of *D. deltoidea* has historically been used as an anti-rheumatic, to treat eye disorders, eliminating parasites and intestinal worms. The rhizome extract contains anti-rheumatic and roundworm therapy properties, and it has also been used as a source of steroid medications in western India [10]. It has been reported that *D. deltoidea* is utilized in the treatment of various health conditions, including those affecting the central nervous system, diseases of the bones and joints, cardiovascular system, abnormalities in the female reproductive system, immuno-deficiencies, metabolic disorders, autoimmune diseases and skin diseases [11]. Additionally, it has been traditionally used as a vermifuge, lice treatment and fish poison. Commercially, *D. deltoidea* is valued for its bioactive compounds like corticosterone, diosgenin and sigma sterol, with the aglycone of steroidal glycosides serving as a natural source of diosgenin [12]. This compound has been crucial in the pharmaceutical manufacturing of steroid hormones like pregnenolone progesterone and cortisone [13]. Despite the well-established advantages for human health, there are a number of significant restrictions on the usage of *D. deltoidea* plants [14]. The concentration of steroidal glycoside compounds in *D. deltoidea* plants is typically quite low, seldom surpassing 1–2% of the plant's dry weight. The *D. deltoidea* has few natural resources, and the amount of each steroidal

Fig. 1. *Dioscorea deltoidea* Wall. ex Griseb.
a. Field view b. Established in pots.

glycosides in plants varies greatly depending on their age, location, and environmental factors [15]. Furthermore, plants belonging to the Dioscorea genus contain a mixture of two different types of glycosides, known as furostanol and spirostanol glycosides, which makes the process of isolating and purifying individual compounds from these plants quite challenging [16].

2. Geographical distribution

Dioscorea deltoidea is native to a range of countries, including India, Tibet, Pakistan, Nepal, China, Bangladesh, Thailand, Cambodia, Vietnam, Bhutan, Afghanistan, and Laos. It thrives at altitudes ranging from 450 to 3100 m above sea level in these regions [3]. Numerous investigations have revealed that *D. deltoidea* are abundant in the northwestern Himalayan region. The region between the rivers Chenab and Beas produces excellent-quality material, and a significant amount of rhizome can be harvested from this area every year [17]. The highest number of naturally occurring *Dioscorea* plants with massive rhizomes and up to 8 % diosgenin content may be found in Bhadarwah. *D. deltoidea* is extensively distributed from Kashmir and Punjab eastward to Nepal and China at elevations of 300–10,000 feet. In Kashmir, temperatures are mild, the tubers acquire diosgenin at a rate of 3–5 %, but in tropical Bangalore, it is closer to 8 % [18]. The initial recorded specimen of *D. deltoidea* was obtained by Dr. Nathaniel Wolff Wallich, who served as the Superintendent of the Calcutta Botanical Garden in Calcutta, India. This specimen was then deposited in the East India Company's Herbarium in London in the year 1821 (Kew Gardens's Wallich Herbarium 2021).

Taxonomic Classification (Royal Botanic Gardens, Kew, Plants of the world online, https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:317890-1#higher-classification)

Kingdom: Plantae.
Phylum: Streptophyta
Class:Equisetopsida
Subclass: Magnoliidae
Order: Dioscoreales.
Family: Dioscoreaceae.
Genus: *Dioscorea*.
Species: *Dioscorea deltoidea*.

2.1. General morphology

The stems of *D. deltoidea* are characterized as perennial, smooth, left-twining climbers with slender, unarmed branches [1(a, b)]. The leaves are alternate, displaying a variety of shapes and sizes, membranous texture, reticulate veins, acuminate tips, and rounded to sub-angular lobes, featuring a lengthy petiole resembling a blade [9]. Male spikes, ranging from 8 to 40 cm in length, are slender, branched, and form a loose panicle, occasionally occurring in pairs. The flowers are either clustered or solitary, approximately 2 mm in diameter, with six stamens and short, paired anthers. Female spikes are solitary, 8–16 cm long, and bear few, spaced-apart flowers [19]. Seeds exhibit variability in size and shape, often possessing wings on one or both sides. The rhizomes are lengthy, woody, horizontally oriented, cylindrical, branched, and approximately ten cm in diameter, covered with sturdy, elongated filiform roots [9, 20].

2.2. Traditional uses

Numerous ethnomedicinal surveys and studies, as highlighted by Ref. [21], emphasize the notable role of *D. deltoidea* in various traditional healing systems globally. Traditionally, diverse communities have utilized this species to address a broad spectrum of health issues, including gastrointestinal problems, urogenital disorders, diarrhea, respiratory conditions such as abdominal pain, cough and cold, intestinal worms, wounds, joint pain, anemia, irritability and also ophthalmic conditions [22–24].

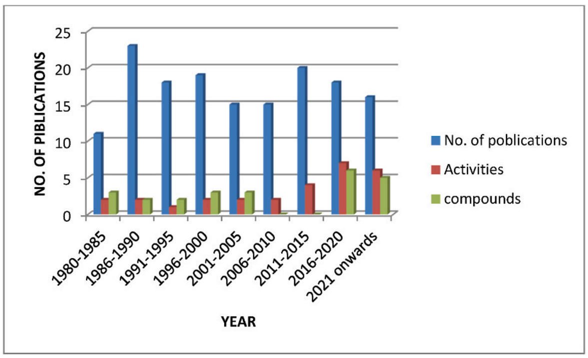
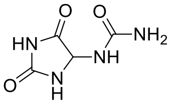
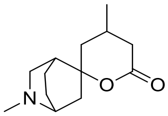
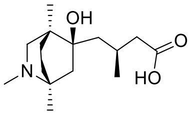
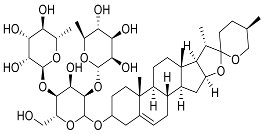
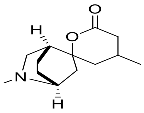
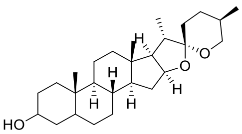
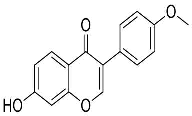
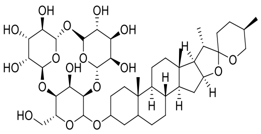
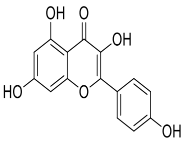
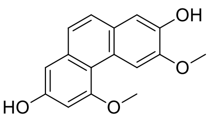
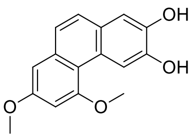


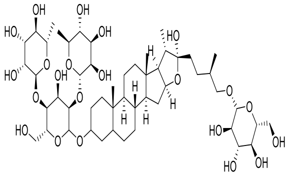
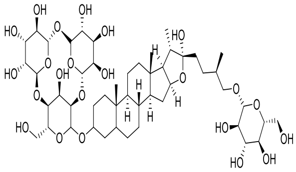
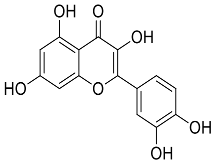
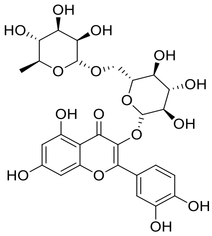
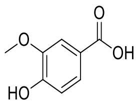
Fig. 2. Rate of compound isolation and biological evaluation from total publications of *D. deltoidea*.

Table 1
The structures of the main bioactive compounds in *Dioscorea deltoidea*.

S. No	Name	Structure	Biological Activity	References
1	Allantoin		Plasma glucose lowering activity	[44]
2	Dihydrodioscorine			
3	Dioscoretine		Hypoglycaemic activity	[45]
4	Dioscin		Antifungal activity, Antitumor activities, Anticancer activities, Antihyperuricemic activity	[46–48]
5	Dioscorine		Antioxidant activity, immunomodulatory activity	[49,50]
6	Diosgenin		Antithrombosis activity, pancreatic lipase inhibitory activity, inhibited catalytic activity, anti-oxidative activity	[51–53]
7	Formononetin			
8	Gracillin		Antiatopic activities, Antiinflammatory activities	[54,55]
9	Kaempferol		Antioxidant activity	[56]
10	Phenanthrene 1		Antifungal phenanthrenes, Antiinflammatory activity	[57,58]
11	Phenanthrene 2		Antioxidant enzyme-inducing activity	[59]

(*continued on next page*)

Table 1 (*continued*)

S. No	Name	Structure	Biological Activity	References
12	Protodioscin		Antiproliferative activity, Antihyperlipidemia, antiosteoporotic activity, Anti-inflammatory	[55, 60–62]
13	Protogracillin		Anti-inflammatory activitiy	[63]
14	Quercetin		Antiobesity, Antioxidant activity, Antimalarial activity	[64,65]
15	Rutin		Antioxidant activity, Anti-diarrheal activity	[56,66]
16	Vanillic acid		Antioxidant and anti-inflammatory properties	[67]

Traditional uses of Dioscorea deltoidea from different places

Uses	Country	References
Muco-active, urinary disorders, antiworms	Pakistan	[25]
Insecticides, Jaundice	–	[26]
Snakebite, Insecticide	–	[27]
Internal injury, Cough and fever, Urogenital disorders	India	[23,28]
Dysentery, Bronchial cough, Urogenital disorders, piles, intestinal worms	–	[19,29]
Ophthalmic conditions, Anti-rheumatic, Gastrointestinal disorders, diarrhea, irritability	–	[30]
Abdominal pain, anemia, wounds, Constipation and urogenital disorders, Respiratory cough and cold, Joint pain, Asthma and as a vegetable	–	[24,31]
Diarrhea, burns, irritability, Digestive disorders, wounds, abdominal pain	–	[32,33]
Constipation, endo-parasites	Nepal	[34]
Constipation, diarrhea, dysentery	–	[35]
Vegetable and livelihood, Insecticidal, oral contraceptives	–	[35,36]
Grinding, hemoptysis, epistaxis, decoction, taken orally for cough,	China	[37]

2.3. Phytochemistry

Dioscoreae deltoidea has a variety of phytochemicals that have been identified by various researchers [38]. These include diosgenin, campastrol, 25-D-spirostan-3,5 diene, stigmasterol, dioscorin, B-sitosterol and dioscin [1]. Roots are a rich source of carbohydrates, tannin, and phytosterols. The phytochemical screening performed by Akalya in 2016 revealed the presence of terpenoids, anthroquinones, polyphenols, phlobatannins, tannin, saponins, and tritepenoids in *D. deltoidea* leaves. A chemical compound called diosgenin, which is present in dioscorea, is employed commercially in the pharmaceutical sector [39]. Steroidal glycosides are well known plant compounds having anticancer, hemolytic, fungicidal, antibacterial and hypocholesterolemic properties [40]. Research findings indicate that the extract of *D. deltoidea* comprises a variety of compounds, including sterols, alkaloids, resins, flavonoids, saponins, unsaturated triterpenoids, tannins, carbohydrates, and glycosides [41]. Additionally, substances such as ascorbic acid, aluminum, riboflavin, beta-carotene, calcium, cobalt, chromium, iron, magnesium, ash, manganese, potassium, phosphorus, proteins, sodium, selenium, tin, thiamine, silicon and zinc have been identified in the plant. Due to the presence of these elements and chemicals this plants is having a great industrial importance [1]. *Dioscorea.* also contains moisture (80.2), crude fat (0.2), crude protein (1.6), crude fiber (1.5), and ash (0.6) [42].

The prevention of several human diseases is greatly aided by plant-based secondary metabolites and bioactive substances [9]. Bioactive substances like polysaccharides, steroidal saponins, polyphenols, and allantoin are abundant in dioscorea. The principal bioactive chemicals in *Dioscorea* are depicted in Table 1 [43] as their structures. It is interesting to note that different cultivated wild plant species have significantly different amounts of intra and interspecies bioactive chemicals.

The prevention of several human diseases is greatly aided by plant-based bioactive substances and secondary metabolites. According to Ref. [68], the environmental factors regulate and control the intricate complex process of producing the bioactive chemicals. Several solvent solutions were used to screen bioactive compounds. *Dioscorea deltoidea* is found to contain tannins, flavonoids, saponins, alkaloids, steroids, terpenoids, triterpenoids, anthraquinone, carbohydrates and proteins, as indicated by studies conducted by Refs. [69,70]. Various parts of *D. deltoidea* were examined, and alkaloids, tannins, saponins, proteins, and carbohydrates were isolated, with concentrations ranging between 0.001 and 0.43, 0.002–0.15, 0.002–0.43, 0.002–0.01, and 0.007–0.98 %, respectively.

The plant's lamina and node were discovered to contain quercetin, cyanidin, kaempferol, as well as synaptic, *p*-coumaric, ferulic acids and caffeic as reported by Ref. [71]. In fresh samples of *D. deltoidea*, the evaluation of total phenolic content, flavonoids, ascorbic acid and flavonol was conducted. The acetone extract from the plant contained the highest levels of flavonoids, flavonols, and ascorbic acid, whereas the water extract exhibited the maximum concentration of total phenolic compounds according to findings by Ref. [72].

The methanol extract of *D. deltoidea,* was found to contain higher levels of total phenolic compounds (402 mg/100 g) and flavonoids (47.5 mg/100 g) compared to 15 other yam species [68]. Additionally, a specific phyto-steroidal-sapogenin called diosgenin, isolated from *D. deltoidea* and other species, plays a crucial role as a precursor in the production of cortisone and other potent corticosteroid drugs [73]. Researchers have explored various potential health benefits of diosgenin, including its anti-inflammatory, anticancer, anti-tuberculosis, immunomodulatory, cardioprotective, memory-enhancing, antifungal, neuroprotective, antiviral, anti-depressant, antidiabetic, and antibacterial properties (Fig. 2) [74–77]. Diosgenin, a significant component of *D. deltoidea*, is present in plants initially at the seedling stage and continues to be present at different growth stages [73].

Sapogenins can be derived from *D. deltoidea* tubers after saponin has been hydrolyzed. Sapogenin concentration and production both increase with tuber aging, dormant tubers containing the largest quantities and being optimal for commercial application. According to Ref. [78] Diosgenins, discovered first time by Ref. [79], could be used for producing cortisone and other drugs.

In the undifferentiated suspension culture of *D. deltoidea*, various compounds were extracted, including diosgenin, campesterol, sitosterol, stigmasterol and 25-*d*-spirostan-3,5-diene. Additionally, the compounds deltoside, deltonine and a trace amount of diosgenine-3-*d*-glucopyranosyl (14)-*d*-glucopyranoside were measured [80].

Researchers have employed advanced analytical techniques to isolate and characterize various bioactive compounds from *D. deltoidea*. Through high-performance liquid chromatography (HPLC), a class of compounds known as oligospirostanosides, accounting for 6.94 % of the total extract, were successfully separated from cell suspension cultures of *D. deltoidea* [81]. In another study, four distinct steroidal saponins, namely tigogenin, hecogenin, diosgenin, and stigmasterol, were isolated and quantified from the same plant source [82]. Additionally, a unique compound called Deltostim, a combination of protodioscin and deltoside, was discovered in suspension cultures derived from *D. deltoidea* bacteria [83].

In separate research studies [84,85], isolated and identified various bioactive compounds like 3-*O*-β-ᴅ-glucopyranosyl-ergost-5-ene-3β,26-diol-26-*O*-β-ᴅ-glucopyranosyl(1 → 3)-(β-ᴅ-glucopyranosyl(1 → 2)-β-ᴅ-glucupyranosyl(1 → 6))-β-ᴅ-glucopyranoside, as well as isonarthogenin-3-*O*-α-ʟ-rhamnopyranosyl-(1 → 2)-(α-ʟ-rhamnopyranosyl-(1 → 4))-β-ᴅ-glucopyranoside, protobioside, and methyl protobioside from the rhizomes of *D. deltoidea*. In another study [86], employed an advanced UHPLC-MS technique to identify and quantify 11 steroidal saponins and 1 sapogenin present in the rhizomes and tubers of 13 different *Dioscorea* species. Specifically, they detected the presence of dioscin (0.77 %), protodioscin (1.78 %), and progenin III (0.01 %) in *D. deltoidea.* Another study by Ref. [87] utilized an ultrasound-aided extraction technique to separate steroidal glycosides from *D. deltoidea cell* suspension culture.

3. Bioactivities

Plant-based secondary metabolites found in Dioscorea, including polysaccharides, steroidal saponins, polyphenols, and allantoin, play a crucial role in avoiding the occurrence of numerous ailments that affect humans as highlighted by Ref. [88]. Due to the concentration of these bioactive components, *Dioscorea* species have been investigated for their medicinal potentials. Bioactive compounds are substances capable of exerting biological effects, triggering reactions, or eliciting responses in living tissues, as defined by Ref. [89]. These substances exhibit a diverse number of effects, like anticancer, antimicrobial, cardiac, and central nervous system effects, among others. Consequently, *Dioscorea* emerges as a potentially valuable medicinal herb for the prevention and treatment of many diseases. The following are some of the important activities associated with Dioscorea.

4. Effect on cardiovascular system

Heart disease can be caused by various conditions, including diabetes, hypertension, and hyper lipidemia. As cardiovascular disease (CVD) accounts for 80 % of deaths in emerging nations, it is anticipated that by 2020, CVDs will overtake all other causes of death [90]. Patients should focus on their dietary habits, level of exercise, blood pressure, and lipid profile in order to lower their risk of heart disease [91]. *Dioscorea* extracts have anti-oxidant, anti-inflammatory, and antiapoptotic properties, which make them beneficial for heart disease [92]. The oxidative damage in the heart and atherosclerosis in hyperlipidemia have been lessened by *Dioscorea* rhizome powder. Numerous studies revealed that diosgenin significantly affects lipid levels by raising the ratio of high density lipoproteins to total cholesterol by increasing cholesterol secretion and decreasing cholesterol absorption. *Dioscorea* exhibits several cardiovascular benefits, including the reduction of total cholesterol levels in plasma and low-density lipoproteins, as demonstrated in studies by Ref. [52]. In experiments using phenylephrine as a reference, diosgenin demonstrated concentration-dependent vasorelaxant effects in superior mesenteric rings. Mesenteric endothelial cells, which were loaded with the calcium-sensitive dye FURA-2, revealed that the compound diosgenin triggered an increase in the levels of calcium within these cells. Additionally, diosgenin increased the production of nitric oxide (NO), as reported by Refs. [93,94]. Furthermore, investigations into the vasodilatory effects of diosgenin on the porcine resistance left anterior descending coronary artery revealed acute endothelium-independent coronary artery relaxation. This effect was attributed to the opening of BK (Ca) channels in arterial smooth muscle cells and the initiation of a protein kinase G signaling cascade [95]. Using myography and confocal imaging, the effects of diosgenin on smooth muscle cell contraction and calcium signaling in the isolated aorta of mice were examined. Diosgenin demonstrated the potential to be therapeutically beneficial for vascular diseases by inhibiting smooth muscle contraction and receptor-mediated calcium signals in the isolated aorta [96].

4.1. Anti-diabetic assay

Numerous studies [97] have shown the anti-diabetic effects of dietary sources including fenugreek seeds and yam tubers containing diosgenin in experimental models. In experiments involving streptozotocin-induced diabetic rats, diosgenin demonstrated a significant reduction in plasma glucose levels compared to other controls. These results are supported by observation that this steroid enhances the activity of crucial glucose-metabolizing enzymes that are impaired in diabetes, as noted in the study by Ref. [98]. Moreover, studies focusing on lipid accumulation in 3T3-L1 preadipocytes in type 2 diabetic rats have revealed that diosgenin, known for its hypolipidemic effects, can stimulate both adipocyte differentiation and the expression of PPAR (peroxisome proliferative-activated receptor gamma). These findings suggest a potential role for diosgenin in regulating lipid metabolism and adipocyte function (the study source for this information was not provided). According to research by Ref. [99], obesity-related insulin resistance and type 2-diabetes are both brought on by persistent inflammation in adipose tissue.

4.2. Antimicrobial assay

Human medicine has advanced significantly over time, but infections brought on by bacteria, viruses, fungi, and parasites continue to be a challenge, particularly in light of the spread of these microbes' drug resistance and the unfavorable side effects of some antibiotics [100]. As part of ongoing research on plant-based antibiotics, particularly yam species *D. deltoidea* have had their antibacterial potentials investigated and reported. Fresh rhizomes (underground stems) of *D. deltoidea* were extracted using methanol, and the resulting extract was evaluated for its antibacterial properties against four bacterial strains: Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli, and Salmonella typhi, as well as one fungal strain, Candida albicans. This evaluation was carried out using an agar diffusion method. The methanol extract from *D. deltoidea* demonstrated significant antibacterial activity against S. aureus and E. coli when tested at two different doses (5 % and 10 %), as reported by Ref. [101]. This highlights the positive antibacterial effects of the plant extract at varying concentrations. Additionally, the antibacterial properties of fresh *D. deltoidea* tubers were investigated using various solvents (petroleum ether, chloroform, pure ethanol, acetone, methanol, ethyl acetate and water) [102]. employed a disk diffusion method with two concentrations (10,000 and 50,000 μg/mL) against a range of microbial strains, including bacteria and fungi. The ethanolic extract demonstrated significant antibacterial activity against P. aeruginosa (17 mm), E. coli (15 mm) and S. aureus (19 mm) surpassing the effects observed with other microorganisms or extracts.

4.3. Antifungal assay

The antifungal activity of compounds methyl protobioside protobioside, and orbiculatosides A and B, isolated from *D. deltoidea*, was tested against Pyricularia oryzae, as reported by Ref. [103]. The antifungal potency of these compounds was assessed by determining the minimal concentration required to induce morphological deformities in fungi, a parameter known as the minimal morphological deformation concentration (MMDC). The MMDC values obtained were 28.0 μM, 28.4 μM, 15.3 μM, and 12.1 μM, respectively, indicating strong antifungal activity across all the compounds tested. Furthermore, the defatted seed extract of *D. deltoidea* was assessed for its ability to inhibit the growth of six microbiological strains, including *Aspergillus fumigatus*, *Aspergillus niger*, *Escherichia coli*, *Penicillium marneffei*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*, as noted by Ref. [9]. The defatted extract demonstrated notable antifungal activity, with inhibitory diameters of 18.6 mm for A. fumigates, 21.0 mm for P. marneffei, and 16.4 mm for A. niger, when compared to the reference drug Nystatin (28.3 mm). Additionally, antifungal activity was observed in both the ethanol (7–9 mm) and aqueous (7–9 mm) extracts. The inhibitory diameters in these trials were within the recommended dosages of erythromycin (10–14 mm) and ketoconazole (8–10 mm), as reported by Ref. [102].

4.4. Anticancer assay

Cancer is any of a broad range of diseases characterized by uncontrolled and abnormal cell proliferation with the ability to enter and kill normal human tissue.The disease has the potential to spread throughout the body.Cancer is the world's second biggest cause of mortality, and it requires effective treatment [104]. Many active molecules have shown this action, and steroidal compounds are increasingly used to treat cancer among medicinal chemists [105,106]. Diosgenin, a potential anticancer medication is also being studied for its potential to have therapeutic and chemo preventive effects against malignancies of many organs [107]. Many tumor cell lines have been utilized to investigate diosgenin's ability to fight cancer, and it has been discovered that anticancer efficacy varies depending on cell type and concentration [108]. Diosgenin is hence antiproliferative for many tumors, specifically for Colon carcinoma (HT-29 and HCT-116 cells), prostate cancer (DU-145 and PC-3 cells) [109], human chronic myeloid leukaemia (CML) (K562 cells) [110] and breast cancer (MCF-7), squamous carcinoma (Hep2, RPMI 2650 and A431, cells), erythroleukemia (HEL cells), gastric cancer (BGC-823 cells), lung cancer (A549 cells) [111], hepatocellular carcinoma (HCC and HepG2cells) [112,113].

Diosgenin, a bioactive compound found in *Dioscorea* species, has been the subject of numerous studies investigating its mechanism of action. Research has shown that the compound diosgenin impacts numerous crucial cellular signaling pathways that regulate vital processes like cell growth, multiplication, specialization, movement during the epithelial-mesenchymal transition (EMT), programmed cell death (apoptosis), as well as the development of cancers (oncogenesis) and the formation of new blood vessels (angiogenesis) [114]. In osteosarcoma cells, diosgenin has been shown to induce apoptosis and cause cell cycle arrest in the G1 phase, effectively inhibiting cell proliferation [115,116]. Additionally, in human breast cancer, diosgenin demonstrates antimetastatic effects by restraining the migration of MDA-MB-231 cells and partially decreasing Vav2 protein activity [117]. These findings collectively underscore the multifaceted impact of diosgenin on cellular processes associated.

All of the aforementioned research has sufficiently shown the potential of diosgenin as a novel therapeutic agent against various cancer types. To inhibit the growth and spread of several types of human cancers, efforts are being made to harness the potential of diosgenin as a solo drug and in combination with a few other bioactive molecules [88]. This can be seen in the synergistic antiproliferative and apoptotic effects of diosgenin and thymoquinone on squamous cell carcinoma (SCC), which may represent a novel strategy for the development of potential antineoplastic therapies for squamous cell carcinoma. To boost bioavailability and cure breast cancer, diosgenin is used as a component of a target drug delivery system enclosed in manganese ferrite nanocarriers [118,119].

4.5. Antioxidant activity

Nature has endowed plants with some specific agents that protect their cells from the damage produced by free radicals. However, in animals, free radicals may have a role in heart disease, stroke, cancer and other aging illnesses [120]. Plants have been identified as good source of antioxidants, and *D. deltoidea* is one of them that has been shown to have excellent antioxidant qualities [121]. [122,123] emphasize the significance of phenol, flavonoids, and vitamins as substantial natural antioxidant sources with the ability to neutralize free radicals [124]. conducted a study using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging experiment, revealing that the antioxidant activity of the aqueous extract from *D. deltoidea* rhizomes and its callus surpassed that of the positive control, ascorbic acid. Another investigation by Ref. [68] utilized DPPH radical scavenging (19.9 %) and reducing power (25 %) assays to assess the antioxidant potential of *D. deltoidea* tubers methanol extract.

Alternatively [72], investigated the antioxidant potential of freshly extracted *D. deltoidea* tubers using both aqueous and acetone solvents. Various techniques, including OH radical scavenging, DPPH, ferric reducing antioxidant power (FRAP), hydrogen peroxide scavenging (H_2O_2), phosphomolybdenum complex assays and ferrous ion chelating (Fe^{2+}) were employed for the assessment. The water extract exhibited significantly higher DPPH radical scavenging (71 %), Fe^{2+} chelating (62 %) and H_2O_2 scavenging (87.5 %), activities compared to the acetone extract.

Furthermore, the analysis of antioxidant activity revealed that the water extract of the plant exhibited higher reducing power, as evidenced by its superior performance in the ferric reducing antioxidant power (FRAP) assay (17 μM ascorbic acid equivalents per 100 g fresh weight) and the phosphomolybdenum complex assay (58 μM ascorbic acid equivalents per 100 g fresh weight). In contrast, the acetone extract exhibited a notably higher capacity for scavenging hydroxyl radicals, with 72.2 % of the radicals being neutralized. Moreover, the water extract showed greater levels of ferric reducing antioxidant power (FRAP) (17 M AAE/100 g fw) and phosphomolybdenum complex (58 M AAE/100 g fw) tests. Conversely, the acetone extract demonstrated notably higher capacity for scavenging hydroxyl radicals, with 72.2 % of the radicals being neutralized.

4.6. Anti-inflammatory and immunological activity

Inflammation occurs when tissues are harmed by infection, trauma, toxins, heat, or any other cause. Chemicals like histamine, bradykinin, and prostaglandins are released by injured cells [125]. These substances induce blood vessels to leak fluid into the tissues, creating swelling; the inflammation can be serious and requires prompt treatment [126]. Chronic inflammation typically involves the deregulation of numerous intracellular signaling pathways, such as transcription factors, kinases, and cell surface receptors [127]. [128] discovered, that pretreatment with diosgenin reduced the production of NO and interleukins 1 and 6, as well as other inflammatory mediators, in lipopolysaccharide/interferon-stimulated murine macrophages. Furthermore, a mouse investigation was done to show that diosgenin inhibits the creation of superoxide in activated neutrophils from the bone marrow. The formation of extracellular and intracellular superoxide anion was found to be effectively inhibited by this steroid in a concentration-dependent manner. In the study conducted by Ref. [129], the signaling pathways associated with cAMP, PKA, cPLA2, PAK, Akt, and MAPKs were found to be interconnected. Specifically, in the context of the anti-inflammatory activity within vascular smooth muscle cells (VSMC), diosgenin demonstrated inhibition of vascular cell adhesion molecule (VCAM-1) in VSMC and TNF-mediated induction of intracellular adhesion molecule (ICAM-1). This inhibitory effect was attributed to the disruption of the mitogen-activated protein kinase (MAPK)/protein kinase B (Akt or PKB) signaling pathway and the reduction of reactive oxygen species (ROS) production. The findings suggest that diosgenin has the potential to modulate immune responses and alleviate inflammation in atherosclerotic lesions, as elucidated by Ref. [130].

4.7. Other activities

Deltostim a metabolites of *D. deltoidea*, have been associated with various pharmacological effects. In studies conducted by Ref. [131], Deltostim demonstrated stimulatory effects on spermatogenesis and ovulation in rabbits and rats. Additionally, it increased fertilization rates by 2.0–2.5 times in cows. The same researchers investigated the immunomodulatory effects of Deltostim, focusing on cell-mediated immunity and various lymphocyte subsets. They observed a dose-dependent immunomodulatory activity in cultured lymphocytes, with the most significant stimulating effects occurring at doses ranging from 0.01 to 0.1 g/mL. In a study by Ref. [132] involving male rats, Deltostim derived from *D. deltoidea* was examined for its anabolic effects. The results showed a significant increase in body weight compared to the control group, with dosages of 5 and 10 mg/kg being the most effective (19 and 22.4 g body weight, respectively). Furthermore, Deltostim significantly influenced nucleic acid and protein synthesis in the liver and muscle tissues. These findings collectively suggest that Deltostim and *D. deltoidea* may have potential applications in reproductive and immunomodulatory contexts, as well as anabolic effects on body weight and tissue synthesis.

A study by Ref. [133] investigated the hepatoprotective abilities of rhizome and callus extracts from the plant *D. deltoidea* in rats with liver injury induced by D-galactosamine. Administration of the aqueous rhizome and callus extracts at a 200 mg/kg oral dose significantly decreased serum levels of the liver enzymes alkaline phosphatase (ALP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), as well as reducing levels of thiobarbituric acid reactive species (TBARS, a marker of oxidative stress) and total bilirubin in the treated rats. Moreover, at that same 200 mg/kg dosage, the plant extracts notably increased levels of the anti-oxidant enzymes superoxide dismutase (SOD) and catalase (CAT), as well as boosting tissue glutathione, serum protein, and serum albumin concentrations in the rats receiving treatment.

In another study [101], researchers examined the anti-inflammatory effects of rhizome extracts from the plant *D. deltoidea* using Wistar rat models. The methanol extract of the rhizomes exhibited anti-inflammatory activity that was dependent on the dosage administered. The highest level of inhibition of inflammation was observed 3 h after intraperitoneal injection of the extract at a dose of 200 mg per kg of body weight. At this dosage, the rhizome extract demonstrated its maximum anti-inflammatory capacity. These findings suggest that *D. deltoidea* rhizomes and their callus exhibit hepatoprotective qualities and anti-inflammatory properties, supporting their potential therapeutic applications in liver disorders and inflammatory conditions.

In a study by Ref. [134], *D. deltoidea* rhizomes were utilized to extract a diosgenin analogue from the tuber using a dichloromethane (DCM): methanol (1:1) ratio. The anti-proliferative properties of diosgenin and its synthesized analogs (Dgn 1 through Dgn 17) were investigated in four different human cell lines: breast (HBL-100), colon (HT-29), lungs (A549), and colon (HCT-116). The results revealed that all synthesized analogs, at dosages ranging from 3 to 50 μM, exhibited broad-spectrum cytotoxic effects. Notably, derivatives such as Dgn-1, Dgn-2, Dgn-5, and Dgn-15 demonstrated potent anti-proliferative activity with IC50 values ranging from 5.16 to 6.33 μM in the tested cell lines. A positive control (Dactolisib-BEZ-235) showed IC50 values ranging from 0.03 to 6.52 μM in all analyzed human cancer cells. These findings suggest the potential of diosgenin analogs and certain chemical components of *D. deltoidea* in exerting cytotoxic effects on different human cancer cell lines, highlighting their potential as candidates for further anti-cancer research.

Conservation methods: There are various methods that can be used to conserve a plant but typically there are two well-known types of conservation techniques: 1. *Ex-situ conservation*. 2. *In-situ conservation.* There are several sets of guidelines for medicinal plant preservation, including those that address in *in situ* and *ex situ conservation*. To guide conservation efforts, it's important to understand the biological features and geographic range of medicinal plants. It involves assessing whether to conserve species in a nursery or in their natural habitat.

In situ conservation: "In-situ conservation of biodiversity involves establishing and managing protected areas with other effective conservation methods. The primary objectives of *in-situ conservation* are twofold: first, to provide ecosystem services, and second, to protect and restore species populations along with their habitats [135]. The success of *in-situ conservation* projects is thought to hinge on two crucial components: the preservation of ecosystems and the implementation of region-specific action strategies. This is being done through recognizing national parks and biosphere reserves [136]. Wild nurseries and natural reserves are common ways of how to preserve plants' medicinal value in their native environments. Since secondary metabolites react to signals in their native habitats and cannot be expressed in culture. We can preserve native flora and natural communities, together with their complex web of interrelationships, by practicing *in situ conservation* of entire communities. Furthermore, by strengthening the connection within the protection of resources and sustainable utilisation, *in situ* conservation raises the diversity that may be preserved. Globally, efforts to conserve *in situ* have focused on developing protected regions and an ecosystem-oriented strategy rather than a species-oriented one [137]. In situ conservation success relies on policies, processes, and adherence of medicinal plants to their growing habitats.

Ex situ Conservation: Involves safeguarding of threatened species while simultaneously developing them outside of their natural habitat. Medicinal plant seedlings and vegetative components are planted on private property to achieve this purpose [138]. D.

deltoidea micro-propagation has been enabled by the rapid multiplication of shoot-tip axillary buds in culture. A variety of elements, according to reports, influence the growth of in vitro produced plants. To duplicate the plant, different researchers use different explants, such as the stem, seed, flower, or tuber. Plant tissue culture has been successful in achieving significant advancements, as highlighted by Ref. [139]. This method has effectively generated high-yielding plantlets, stored in in vitro gene banks, and utilized for rapid multiplication [140]. contributed to this progress by establishing a system for synthetic seed production, employing an complexing agent (calcium chloride) and a artificial coating material (sodium alginate).

In addition to direct methods, indirect approaches like callogenesis and somatic embryogenesis have been applied to produce plantlets, facilitating the establishment of large-scale plant nurseries [141]. For medicinal plants such as Dioscoreae species, synthetic seed technology proves particularly beneficial. Microtubers derived from in vitro plantlets have been suggested as an alternative method for preserving and disseminating genetic material [142]. Furthermore, it has been asserted that artificial (synthetic) seeds are employed for storage and germplasm preservation. These seeds contain a somatic embryo with the potential to develop into a plantlet. Cryopreservation, a process involving the cooling of micropropagules at low to subzero temperatures, such as 77K or $-196\,^{\circ}C$, has also been mentioned as a method for preserving genetic material [143]. These innovative techniques contribute to the conservation and propagation of plant species, offering valuable tools for researchers and conservationists alike.

4.8. Food and economic importance

Yams, which have been shown to contribute energy, have several beneficial nutritional qualities and health effects, including hypoglycemic, hypocholesterolemic, antioxidative, immunomodulatory and antibacterial properties. These wild yam tubers could be used as nutraceuticals and functional foods to treat long-term illnesses. Research should be done to find ways to manufacture new medications to combat various ailments using the bioactive components found in these tubers. When it comes to food value, potatoes come in first place, followed by the edible tubers of various yam species (*Dioscorea* spp.). Indeed, the most widely grown true yams globally include species like *D. bulbifera, D. pentaphylla*, and *D. alata*, whose tubers are high in starch and constitute a vital dietary supplement [144]. In addition to starch, the *Dioscorea* root tubers possess fibers, protein, lipids, and minerals like phosphorus, potassium, sodium, magnesium, calcium, copper, manganese, iron, sulfur and zinc containing amino acids. *Dioscorea* is a steroidal medication that is widely used and somewhat expensive. Its pharmacologically active component, "diosgenin," is extracted from the root and rhizomes of the plant. Plant estrogens (PEs) derived from *Dioscorea* are dietary supplements that offer numerous health advantages. These include prevention of certain cardiovascular disease, osteoporosis, nephritis, diabetes, cancers, asthma in the manufacture of contraceptives and the treatment of a variety of genetic disorders [145].

5. Conclusion

Dioscorea a crucial tuber species in the Himalayan region, serves various purposes. While there have been limited studies on its chemical characterization and pharmacological applications, *D. deltoidea* tubers stand out as an important source of diosgenin. In addition to diosgenin, these tubers are found to be rich in a diverse array of other bioactive chemicals. The presence of these bioactive compounds hints at the potential multifaceted applications and health-related benefits that *D. deltoidea* may offer. Further research and exploration into the chemical composition and pharmacological properties of *D. deltoidea* can provide a more comprehensive understanding of its potential uses and benefits. There aren't many in vivo experiments; the vast majority of research is limited to in vitro testing. For a thorough understanding of the safety profile of any herbal medication, clinical safety and toxicological aspects of D. deltoidea should be investigated, in addition to preclinical studies. Furthermore, *D. deltoidea* is under a lot of pressure in nature due to its multiple uses and the unrestricted collection of diosgenin for extraction. As a result, raising the population of this species and preventing its extinction will surely be made possible by educating the local public on the cultivation, preservation, and sustainable usage of this species. The study indicates that *Dioscorea* contains a variety of phytochemicals, including dioscorin, saponin, flavonoids, diosgenin, and other important components. These compounds possess varied biological activities, like, antimicrobial, anticancer, cardiac, central nervous system (CNS), and potentially other beneficial effects. The presence of these phytochemicals suggests that dioscorea, likely referring to plants of the *Dioscorea* genus, may have potential therapeutic applications across various health domains. However, for a more detailed understanding of the specific mechanisms and applications, further research and exploration would be necessary. As a result, *Dioscorea* is a potentially valuable medicinal plant that can be considered as a packet containing medication for a variety of disorders.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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