REVIEW ARTICLE

A Way Forward in Drug Discovery and Antimicrobial Activities of *Dioscorea* L. Species: A Review

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Abstract

The bulbils (air potatoes) and tubers of *Dioscorea* L. species are huge reservoirs of biomolecules that provide nutrition and healthcare benefits to human beings. After the cereal and pseudocereal, bulbils and tubers are precious sources of nutraceuticals to society, nature and natural systems. *Dioscorea* species commonly known as 'Yams' is a monocotyledonous vine that belongs to the family Dioscoreaceae. The vine has tubers, stems, leaves, inflorescence and bulbils which are organized reservoirs of biofunctional therapeutic biomolecules. These are carotenoids, polyphenols, flavonoids, sapogenins, steroids, phytates, tannins, dioscin, dioscorine, diosgenins, etc. These phytomolecules perform many physiological and pharmacological activities in living organisms, especially human beings. Traditionally, it is used for digestive disorders, pain of the stomach and abdomen, and dysmenorrhea, as an anti-inflammatory, analgesic, antacid, appetizer, reduce weakness, antidiarrheal, contraceptive, antidandruff, wormicide, anthelmintic, antiobesity and antirheumatic. Many antimicrobial properties such as antibacterial (Gram-positive and Gram-negative bacteria), antifungal, antiviral, antiprotozoal and antileishmanial activities were also shown by the potential *Dioscorea* species. They are a source of natural bioenergy that can be explored and utilized by the civilized world for their proper utilization and conservation.

Highlights:

- The ethnomedicinal potential of *Dioscorea* species provides immense capacity for Ethnopharmacology and drug discovery.
- Tubers and bulbils are rich sources of bioactive molecules that provide Nutraceutical values to *Dioscorea* species.
- Bulbils and tubers are also vehicles of food security during adverse conditions as they contain huge amount of imperishable carbohydrates.
- Diosgenin is the key steroidal moiety for steroidal drugs instead of dioscin, dioscorine and protodioscin.
- Phytochemicals of *Dioscorea* species showed effective antimicrobial activities.

Keywords: Ethnopharmacology, Phytochemistry, Drug discovery, *Dioscorea* species, Nutraceuticals.

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Introduction

India possesses a rich heritage of traditional medicinal plants. Traditional plants have been used worldwide as a source of medicine to treat and manage numerous serious diseases (Prajapati *et al.,* 2024). Plants of Indian subcontinents serve as a reservoir of food, medicine, fodder and fuel to the people residing in and around it. Species of *Dioscorea* contain several phytochemicals such as terpenoids, tannins, alkaloids, flavonoids, etc., which possess antioxidant and antimicrobial properties (Talib and Mahasneh, 2010). Herbal medicine is the most ancient form of healthcare known to humanity. Many antimicrobial drugs are available in the market that are being used for curing diseases caused by noxious microbial organisms. These microorganisms develop resistance against used drugs and show side effects when used in the long run. To overcome these problems scientists emphasized the use of alternative herbal medicines as antimicrobial agents with no resistance and side effects. Plants have been processed to develop as new antimicrobial agents for decades (Cowan, 1999). Antimicrobial resistance has become a leading global health problem for human beings. According to the Lancet, 4.71 million deaths were recorded in 2021 due to bacterial antimicrobial resistance (Naghavi *et al.,* 2024). Leaves, stems, inflorescence, aerial bulbils (air potatoes), fruits and tubers (given in Fig. 1) demonstrated the nutritional and various pharmacological potential such as antimicrobial, antidiabetic, anticancer and anti-inflammatory. Among them, antimicrobial activities are important pharmacological activity shown by the species of *Dioscorea*. The *Dioscorea* species showed antimicrobial activities against multidrug-resistant bacteria as antibiotic-sensitive and antibiotic-resistant strains (Shriram *et al.,* 2008; Dahiya, 2017). Hence, the potential of *Dioscorea* species is reviewed for their future drug discovery in the natural way i.e. a way forward in drug discovery and antimicrobial activities.

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Distribution and Botanical Characterization

Dioscorea is a genus of plants with wide distribution, found in various regions across the world. *Dioscorea* L., commonly referred to as Yam, serves as the type genus for the Dioscoreaceae family, encompassing approximately 682 species that are

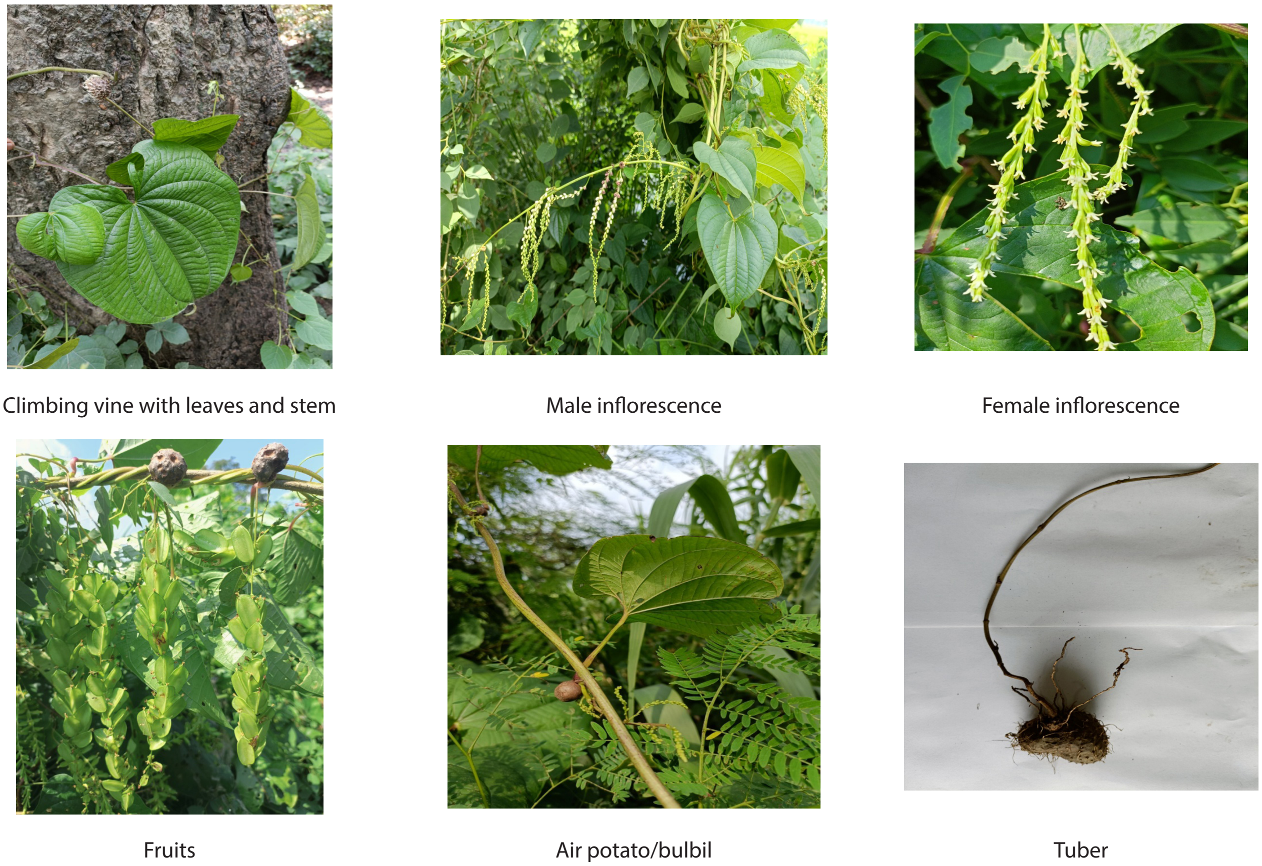


Fig 1: Biofunctional parts of *D. bulbifera*.

dispersed globally. The greatest diversity of these species is observed in Southeast Asia, Africa, Australia, and Tropical America (Mabberley, 2017). In the Indian subcontinent and Southeast Asian countries, there are a total of 150 *Dioscorea* species. The presence of 50 species of *Dioscorea* was recorded from India (Hooker, 1894; Prain and Burkill, 1939). These plants are primarily native to tropical and subtropical areas. It is the monocotyledonous vine and has the ability to climb. The aerial stem twines on the neighboring vegetation and the twining features are often species-specific. The leaves are with variable phyllotaxy and are distinctly petiolate. Bulbils are also present in many of the species like *D. alata, D. bulbifera, D. pentaphylla,* etc. The modified underground stem is called a tuber rich in nutrients. The plants are usually dioecious and the inflorescences are axillary spikes with actinomorphic flowers.

Day To Day Uses, Preparations, Ethnobotany And Ethnopharmacology

Dioscorea species have been traditionally utilized by inhabitants for their food and healthcare since antiquity. Tribal people collected yam tubers robustly for food purposes only because they had very little or no knowledge of therapeutic potentials. Concurrently the people's knowledge gradually increased and came to understand its medicinal importance. Ethnopharmacology provided a gradual transformation in the life of humans due to the gradual exploration of the medicinal properties of the species. The *Dioscorea* has a long history of use in traditional medicine and ethnopharmacology (Kundu, 2021). *Dioscorea* species are known for their starchy tubers, which are a staple food source in many parts of the world. However, various species within *Dioscorea* have been used for medicinal purposes as well. *Dioscorea* species hold significant ethnobotanical importance across tropical regions. Extensive documentation exists regarding the indigenous knowledge and traditional uses of *Dioscorea* species on a global scale. *Dioscorea prazeri* Prain & Burkill is employed in India for its lice-killing properties in the form of soap and shampoo. (Maneenoon *et al.,* 2008). The common medicinal uses of yams are in piles, dysentery, muscular pain, ulcers and inflammation (Kumar *et al.,* 2017a). Detailed Ethnobotanical studies of different *Dioscorea* species are given in Table 1 and Fig 2.

Phytochemicals: Bioactive Biomolecules

Dioscorea species have huge reservoir of bioactive biomolecules and are used to cure various ailments since ancient time. The folkloric medicinal uses of tubers of *D. bulbifera* are more common in tribal peoples because of its potential bioactive compounds as diosgenin, dioscin, polyphenols, steroids, saponins, tannins, alkaloids, flavonoids, terpenoids, volatile oils, fatty acids, phenolics etc. (Shajeela *et al.,* 2011; Padhan and Panda, 2020; Adeosun, 2016; Ezeabara and Anona, 2018; Ayo *et al.,* 2018). Certain studies showed that *D. bulbifera* have rich number of responsible biomolecules which have different biological properties to treat fever, dysentery, headache,

Table 1: Ethnobotanical potential of some *Dioscorea* species in India

S. No	*Plant species*	*Ethnobotanical uses*	*Plant parts used*	*Method of use*	*Preparation / Administration*	*References*
1.	*Dioscorea bulbifera*	Antidiarrhoeal Analgesic for labour pain Antacid	Tubers	As vegetable	Oral	Jadhav *et al.,* 2011 Nayak *et al.,* 2004 Dutta, 2015
		Treating Dysmenorrhoea Anti-inflammatory Ulcer treatment		Vegetable food	Oral	Mehta and Bhatt, 2007 Bhogaonkar and Kadam, 2006 Dutta, 2015
		Used in Skin infection		Vegetable	Oral	Tiwari & Pande, 2006
		As a contraceptive		Tablets	Oral	Kamble *et al.,* 2010
		Used to kill hair lice, treatment of syphilis, piles and dysentery				Abhyankar and Upadhyay, 2011
		Cure cough using with salt and Antipyretic		Food	Oral	Singh *et al.,* 2009
		Appetizer			Oral	Mishra *et al.,* 2008
		Antidandruff	Stem		Body lotion	Dutta, 2015
		Skin diseases	Leaves		Body lotion	Girach *et al.,* 1999
2.	*D. alata*	Treatment of piles Wormicide for stomach worms Reduce weakness		Vegetable	Oral	Jadhav *et al.,* 2011 Kamble *et al.,* 2010 Samanta and Biswas, 2009
3.	*D. esculenta*	Anti-inflammatory, used in chest pain, treatment of swellings, boils and dysentery	Tubers	Boiled tubers	Oral	Edison *et al.,* 2006
4.	*D. deltoida*	Diarrhea Abdominal pain Digestive disorders	Tubers	Boiled tubers	Oral	Dangwal *et al.,* 2015
5.	*D. oppositifolia*	Used as tonic after pregnancy	Tubers	Syrup of tubers	Oral	Mishra *et al.,* 2008
		Improve sperm count	leaves	Vegetable food	Oral	Sharma and Bastakoti, 2009
6.	*D. pentaphylla*	Reduces pain of stomach As a spasmodic and tonic	Tubers	Vegetable Syrup	Oral Oral	Choudhary *et al.,* 2008 Tiwari and Pande, 2006

tumors, rheumatism, abdominal pain, cough, goiter, and remove dandruff (Singh *et al.,* 2009, Abhyankar and Upadhyay, 2011, Gao *et al.,* 2003 and Ghosh *et al.,* 2015a). The potential biomolecules of *Dioscorea* species are given in Table 2.

Alkaloids

Alkaloids are nitrogen-containing natural organic compounds that have pronounced physiological effects on humans, animals, and plants. They are present in different plant parts viz., roots, stems, leaves, tubers, aerial bulbils (air potatoes), flowers, and seeds, and are known for their ethnobotanical and pharmacological properties. Alkaloids are important in plant defense mechanisms and their interaction with the environment. Alkaloids belong to a group of secondary metabolites, mainly obtained from plants (Bhambhani *et al.,* 2021). The tubers of *Dioscorea*, contain many alkaloids such as dihydrodioscorine, dumetorine, dioscoretine and dioscorine. (Nimenibo-Uadia and Oriakhi, 2017). Alkaloid derivatives exhibit pharmacological properties that include pain relief, cough suppression, and antibacterial effects (Padhan *et al.,* 2020). However, yam contains a significant alkaloid called Dioscorine, which is known for its toxicity as an isoquinoline alkaloid. It can be effectively removed by soaking in a 1.0 M NaCl solution for 5 days. This method has proven to be more efficient than the traditional detoxification process (Lebot *et al.,* 2023; Kamaruddin *et al.,* 2020). Moreover, a purification apparatus utilizing a water cycling process has been developed to effectively remove dioscorine (Haji *et al.,* 2011).

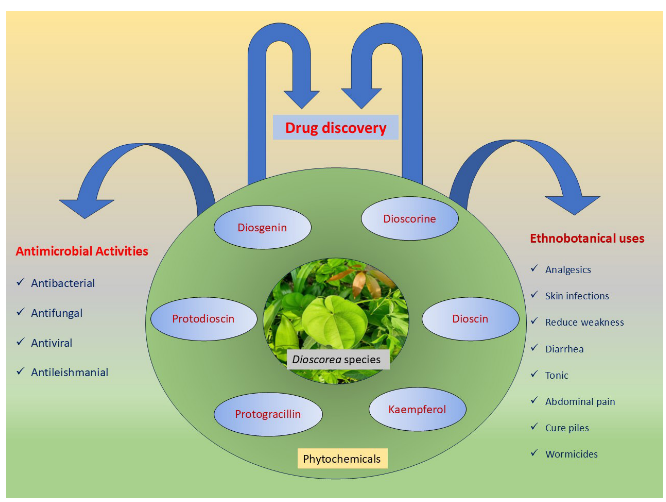


Fig. 2: Graphical representation of *Dioscorea* species

Table 2: Potential Biomolecules of *Dioscorea* species

S. No.	*Dioscorea L. species*	*Biomolecules*	*Parts of plant*	*References*
1.	*D. bulbifera*	Diosgenin	Tubers	Ghosh *et al.,* 2014
		Polyphenols, Organic acids	Tubers	Bhandari and Kawabata, 2004
		Tannins, phytates, Oxalates	Tubers	Polycarp *et al.,* 2012
		Carotenoids, Terpenoids, Phenolics	Tubers	Shajeela *et al.,* 2011
		Saponins, Alkaloids, Phenols	Tubers	Ezeabara and anona, 2018
		Steroids, Diosgenin, Flavonoids	Tubers	Obidiegwu *et al.,* 2020
		Cyanogenic glycosides, tannins, saponins	Tubers	Ifeanacho *et al.,* 2017
2.	*D. alata*	Flavonoids, alkaloids phenols	Tubers	Ezeocha, 2012
		Allantoin		Shajeela *et al.,* 2011
		Phenolics, Tannins, Oxalates, Hydrogen cyanide	Tubers	Ezeabara and anona, 2018
		Phytates/phytic acid, Saponins, Alkaloids	Tubers	Bhat *et al.,* 2022
3.	*D. esculenta*	Phenolics, Tannins, Phytates, Oxalates, Hydrogen cyanide	Tubers	Shajeela *et al.,* 2011 Polycarp *et al.,* 2012
4.	*D. pentaphylla*	Phenolics, Flavonoids, Tannins, Oxalates, Hydrogen cyanides	Tubers	Padhan and Panda, 2020 Shajeela *et al.,* 2011
5.	*D. hispida*	Dioscorine, Phenols, Flavonoids	Tubers	Padhan *et al.,* 2020
6.	*D. deltoida*	Polyphenols	Tubers	Bhandari, 2004

Diosgenin (Steroidal saponins)

Diosgenin is glycosides, containing a sugar moiety (glycone) connected with a non-sugar component (aglycone or sapogenin). In the case of steroidal saponins, the aglycone component is structurally similar to steroids, specifically steroidal hormones, and may have similar properties. Steroidal saponins demonstrate a diverse range of pharmacological activities as anticancer, antifungal, anti-inflammatory, hypolipidemic and cardioprotective effects (Hwang *et al.,* 2019; Okubo *et al.,* 2021, Yang *et al.,* 2018; Xue *et al.,* 2021; Zhao *et al.,* 2019; Wang *et al.,* 2010; Feng *et al.,* 2017). Among the principal saponins are dioscin, gracillin, protogracillin, and protodioscin. Diosgenin is a naturally occurring chemical compound found in several plants. Diosgenin is a crucial source for pharmaceuticals used to derive androgens, estrogens and contraceptives (Yoon and Kim, 2008; Sautour *et al.,* 2007). However, of more than 137 species of *Dioscorea* species that contain diosgenin, 41 species of them contain diosgenin content exceeding 1%, rendering them highly valuable (Shen *et al.,* 2018). An RDA study demonstrated that environmental factors are responsible for 64.67% total variance in the biosynthesis of steroidal saponins, including diosgenin (Hou *et al.,* 2021).

Polyphenols

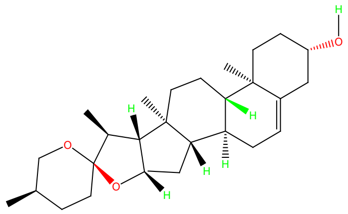
Polyphenols, considered secondary plant metabolites, belong to a class of phytochemicals that have the potential to promote health. They are commonly found in fruits, vegetables, tea, red wine, etc. Polyphenols overcome oxidative stress and have anti-inflammatory and anti-cancer properties. Phenols and phenolic acids represent a class of prevalent secondary compounds that are widely present in *Dioscorea* species. Many polyphenolic compounds such as catechol, phloroglucinol and resorcinol, caffeic acid, ferulic acid, kaempferol, quercetin, and anthocyanins are present in plants (Abbas *et al.,* 2017). Polyphenols act as antioxidants and deactivate or neutralize the free radicals and strengthen the cells from damage. They play several roles in plants, including protection against ultraviolet radiation, pathogens, and herbivores. In addition, polyphenols also provide potential health benefits to humans. These polyphenols are categorized into two main groups: flavonoids and non-flavonoids, specifically phenolic acids (Lorenzo *et al.,* 2021). Furthermore, it was demonstrated that many polyphenolic compounds exist in *Dioscorea pentaphylla*'s leaf extract (Mondal *et al.,* 2019). Another study identified 13 monocyclic phenols with two flavonoids, specifically formononetin and (+)-catechin, in *D. collettii*. Among these compounds, two benzylacetone derivatives, three phenylpropanoids, and formononetin were isolated from the *Dioscorea* genus for the first time (Jing *et al.,* 2017).

Flavonoids

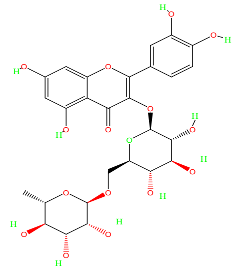
Flavonoids are polyphenolic compounds generally responsible for the various colors in fruits, vegetables and flowers. They serve potential health benefits for humans. Flavonoids, which are commonly found in photosynthesizing cells, naturally exist in different forms including glycosides, aglycones and methylated derivatives (Havsteen, 1983). These compounds hold significant pharmacological potential, demonstrating a wide array of beneficial properties viz., antimicrobial, antiulcerogenic, anti-inflammatory, anticancer, antihypertensive, anticonvulsant, antioxidant, cardioprotective, antidepressant, sedative, anti-proliferative and antidiabetic activities (Sangeetha *et al.,* 2016).

Allantoin

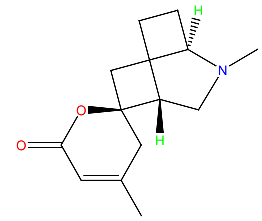
Allantoin is a naturally occurring chemical compound found in some plants and used in the cosmetic, pharmaceutical, and skin care industries. Allantoin exhibits antidiabetic and antioxidant properties and it plays a role in enhancing wound healing (Lebot *et al.,* 2023). Allantoin quantities were measured in six yam species *D. bulbifera, D. esculenta, D. alata, D. dumetorum, D. rotundata,* and *D. cayenensis*. Allantoin quantity ranges from 0.23 mg/g dw - 22.35 mg/g dw (Lebot *et al.,* 2019). *Dioscorea polystachya* tubers revealed



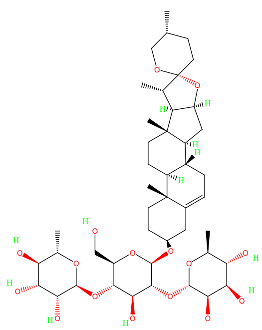
1| Diosgenin



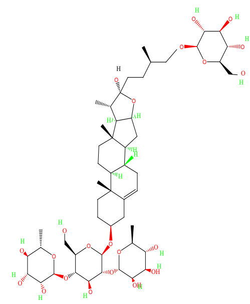
2| Rutin



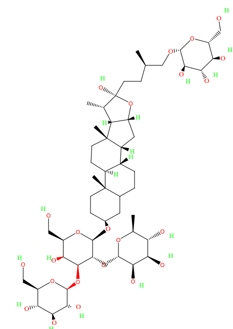
3| Dioscorine



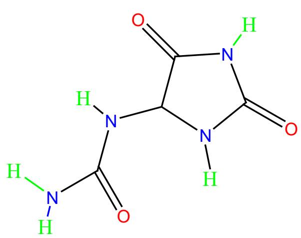
4| Dioscin



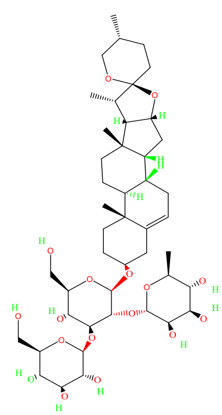
5| Protodioscin



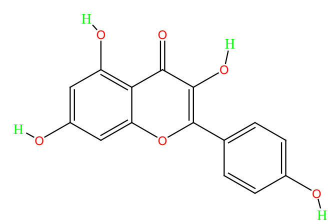
6| Protogracillin



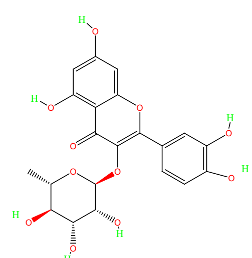
7| Allantoin



8| Gracillin



9| Kaempferol



10| Quercetin

Fig 3: Structures of bioactive biomolecules

that four-year-old tuber had the highest quantity of allantoin and was found to be the best for industrial-scale production of allantoin (Yu *et al.,* 2021). Furthermore, investigations have demonstrated that allantoin extracted from *D. batatas* led to a significant reduction in body weight, modifications in biochemical parameters of plasma, and the prevention of damage to the liver, pancreas, and skeletal muscle in diabetic mice.

Other biomolecules

Many other bioactive compounds reported from yam species possess tannins, phytates and oxalates (Polycarp *et al.,* 2012; Wanasundera and Ravindran, 1994; Otegbayo *et al.,* 2018). These substances are termed "antinutritional compounds" due to the adverse effects linked to their ingestion. Tannins are recognized for their bitter flavor and their capacity to attach to and cause the precipitation of various organic substances, such as alkaloids, amino acids, and proteins. This action reduces both digestibility and palatability (Chen *et al.,* 2018). The structures of biomolecules are given in Fig. 3.

Antimicrobial Activities

Antibacterial and antifungal activities of Dioscorea species

Different antibacterial and antifungal activities of *Dioscorea* species are given below:

Dioscorea alata L.

Plants contain many natural products that can serve as antimicrobials (Ernst, 2005; Pandey *et al.,* 2024). Silver nanoparticles of *D. alata* tuber extracts were prepared by infusing $AgNO_3$ and *D. alata* extract. Their antibacterial potential was tested against two G (+) and G (-) bacterial strains. TEM analysis revealed 10-20 nm silver nanoparticles with polycrystalline nature. The inhibitory activity of both *D. alata* tuber extract and AgNPs was tested at a dose of 100µl. The antibacterial activity of AgNPs was reported to be more significant with prominent zone of inhibition (ZOI) values against both the bacterial strains than that of tuber extract which inhibited the growth of only G (+) bacterium with less significant ZOI value in reference to the standard. The ZOI values obtained for photosynthesized AgNPs were comparable to that of the reference drug kanamycin. The nanoparticles showed dose-dependent antibacterial potential toward tested pathogenic bacterial strains (Pugazhendhi *et al.,* 2016). The antibacterial efficacy of *D. alata* bulbs was evaluated in methanolic crude extract against 6 G (+) and 6 G (-) bacterial strains. All the clinical strains demonstrated inhibitory actions, while *Staphylococcus epidermidis* showed no response. Out of these 11 bacterial pathogens, *Shigella dysenteriae* showed the highest inhibition value (Anisuzzman *et al.*, 2016).

The phytochemical investigation indicated the presence of multiple bioactive compounds viz., glycosides, tannins, terpenoids and saponins in *D. alata* tubers, leaves, stem and bulbils. The antimicrobial potential of tubers of *D. alata* was examined against 2 G (+) (*Streptococcus mutans* and *Streptococcus pyogenes*) and 3 G (-) (*Sheigella flexneri, Vibrio cholerae* and *Salmonella typhimurium*) bacterial forms in 4 different fractions (aqueous, acetone, methanol and n-hexane). The inhibitory actions were evaluated using the agar cup plate method and found to be dose-dependent. The hexane fraction at 0.25 mg/mL concentration showed activity against *S. pyogenes* and *S. mutans.* At this concentration, all other fractions were not effective. *S. pyogenes* and *S. mutans* were repressed in the acetone and methanol fractions at 0.50 mg/mL concentration. However, at a high dose 1-mg/mL, *S. pyogenes* was inhibited by acetone, methanol and aqueous extracts with the highest inhibition occurring in an aqueous solvent. Similarly, *S. typhimurium* was inhibited by all 4 fractions with ZOI values ≥ 1cm while *V. cholerae, S. mutans, S. flexneri* have less ZOI than *S. pyogenes* and *S. typhimurium* at similar concentrations (Kumar *et al.,* 2017a).

Dioscorea bulbifera L.

Extracts of bulbils of *D. bulbifera* were assessed for their antimicrobial potential against some microbial strains using petroleum ether, chloroform, and distilled water as solvent. Out of these, petroleum ether and chloroform extracts represented potent activity against *Aspergillus fumigatus,* and *Rhizopus nigricans*. Petroleum ether and distilled water extracts showed good activity against *Klebsiella pneumonie* whereas the chloroform extract represented weak potential against *Staphylococcus aureus* (Seetharam *et al.,* 2003). Six diterpenoid compounds were segregated from bulbils of *D. bulbifera* in a methanolic extract as well and their fractions and antimicrobial activity were tested against microbial and multidrug-resistant (MDR) microbial strains. The methanol extract and its ethyl acetate fraction showed positive results against all the tested strains, however, there was no microbial inhibition in n-butanol fraction. The maximum inhibitory actions were revealed in compound 3, while compounds 1 and 6 exhibit feeble minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC) values. The significant MIC value showed in compound 3 against *Escherichia coli* AG100A, *Mycobacterium tuberculosis* strains ATCC 27294 and MTCS2 and *M. smegmatis* ATCC 700084. Out of these isolated compounds, compound-2, 3, 4 and 5 showed broad spectrum inhibitory activities with the lowest MIC and MBC values (Kuete *et al.,* 2012). Similarly, the antibacterial efficacy of *D. bulbifera* tubers, peels and bulbils was evaluated in aqueous and ethanolic solvents against five G (+) and five G (-) bacterial strains. The ethanolic fraction from peels was more potent in bacterial inhibition than tuber and bulbil extracts. At higher dose (1000 µg/mL) the ZOI value was more than 14 mm for most of the microorganisms except *Serratia liquefaciens*. Aqueous extract from the tuber has some prominent inhibition activity against *Proteus vulgaris* (16 mm) and *Pseudomonas aeruginosa* (17 mm) at the same concentration. Peel ethanolic extracts showed effectiveness against five isolates viz., *E. coli, K. pneumoniae, S. liquefaciens, Bacillus cereus* and *Citrobacter freundii* with MIC value 125 µg/mL. The antibacterial property was in coherence with phytochemical studies. The peel has more secondary metabolites than bulbils and whole tuber with saponin 32.28 mg/g, tannin 4.79 mg/g, phlobatannin 1.87 mg/g, flavonoid 9.17 mg/g, terpenoid 8.48 mg/g, and cardiac glycosides 15.90 mg/g (Adeosun *et al.,* 2016). The antibacterial activity of *D. bulbifera* was evaluated against 5 bacterial strains. Out of these 4 strains showed moderate inhibitory profile while 1 strain was neutral against all the 3 solvents. The crude ethanolic extract demonstrated maximum ZOI against *Bacillus pumalis, E. coli, Pseudomonas aeruginosa,* and *Staphylococcus aureus* (Win, 2020).

Dioscorea pentaphylla L.

Tubers of *D. pentaphylla* have several biomolecules and after their analysis, it confirms the presence of diosgenin, which has a vast diversity of pharmacological activities viz. antibacterial, antifungal, anti-inflammatory, etc. The methanolic extract was prepared and further fractionated into three fractions water, methanol and acetone. Out of these, the methanolic fraction showed potent antibacterial efficacy. Antibacterial activity was tested against 3 (G -) *Vibrio cholerae, Salmonella typhi* and *Shigella flexneri* and 2 (G +) *Staphylococcus mutans* and *S. pyogenes* bacterial strains in methanolic fraction. The inhibitory actions were evaluated by using broth dilution assay, disc diffusion technique and agar well diffusion assay.

Both the (G +) bacterial strains *S. mutans* and *S. pyogenes* were significantly inhibited which was comparable to antibiotics Kanamycin and Penicillin as standard (Kumar *et al.,* 2017b). Mondal *et al.,* (2018) examined the antimicrobial activity of leaves extract of *D. pentaphylla* using ethyl acetate and methanol as solvents. The antimicrobial efficacy was tested by disc diffusion technique on the 4 G (+) and 4 G (-) bacterial strains. For this experiment, 400µg/disc concentration was utilized and amoxicillin and blank discs were used as positive and negative controls, respectively. The antibacterial activity in ethyl acetate fraction was found to be in the range between 4.51 ± 0.34 to 13.73 ± 1.74 mm while it was reported to be in a range between 7.17 ± 0.32 to 20.85 ± 0.19 mm for methanolic solvent. The ethyl acetate extract has maximum antibacterial efficacy against *E. coli* while the highest potency was showed in methanolic extract against *B. megaterium.*

Dioscorea hispida Dennst

The antimicrobial activity of *D. hispida* tubers was tested in the solvents viz., methanol, ethanol, aqueous and carbon tetrachloride against 5 G (+), 8 G (–) bacterial and 3 fungal strains. Among all these clinical strains, the G (-) bacterial pathogens were prominently inhibited in comparison to G (+) and fungal strains. The highest ZOI showed in the dichloromethane soluble fraction against *P. aeruginosa* (Miah *et al.,* 2018). Suryowati *et al.,* 2020 evaluated the antimicrobial efficacy of *D. hispida* tubers against G (+) and G (-) bacteria *S. aureus* and *E. coli* respectively by employing the agar disc diffusion method with chloramphenicol as a positive control. They evaluated the presence of heptanes-1-methyl, n-hexadecanoic acid, azabicyclo-hexaoxaacyclooctadecane, conjugated linoic acid and hydroxymethylfurfural as potent sources of pharmacological activity.

Dioscorea wallichii Hook.f.

The antibacterial activity was investigated from *D. wallichii* leaves in different solvents. The methanolic fraction was found to be more effective against *S. aureus* while *E. coli* was prominently inhibited by methanolic and acetone fractions as demonstrated in ZOI values. The result showed that the antimicrobial activity was due to the presence of secondary metabolites as found in phytochemical analysis of leaf extracts (Irulandi *et al.,* 2016).

Dioscorea pyrifolia Kunth

The antibacterial efficacy of tuber extracts of *D. pyrifolia* was tested against two bacterial strains *E. coli* and *S. aureus* using hexane, methanol and ethyl acetate as solvent by cell damage assay. The prominent antibacterial activity was reported in ethyl acetate extract against *E. coli* and in methanol extract towards *S. aureus* with maximum ZOI values. Similarly, the ethyl acetate extract exhibited significant MIC and MBC values towards both the tested bacterial strains. The antibiotic drug chloramphenicol which was used as positive control for this study exhibited significant ZOI values which were comparable to values of ethyl acetate tuber extracts. After SEM analysis, it was clarified that the morphology of the cell changed due to the leakage of K^+ and Ca^{2+} from the cell. The method of cell damage could be confirmed by SEM analysis, UV-spectrophotometry and atomic absorption spectrophotometry (Mierza *et al.,* 2019).

Dioscorea oppositifolia L. *and Dioscorea hamiltoni* Hook.f.

Paul *et al.,* (2020) worked on sex-specific variations, and phytochemical and antimicrobial activity of *Dioscorea* by agar well diffusion method with streptomycin as positive control. The female tubers were more efficient in comparison to the male tuberous plant. The male and female tubers of *D. oppositifolia* most prominently inhibited *K. pneumonia* while the highest bacterial inhibition value for *D. hamiltoni* was reported against *Streptococcus pneumonie.*

Dioscorea opposita Thunb.

Wang *et al.,* (2020) worked on self-decomposed films consisting of mucilage of *D. opposita*, carboxymethyl cellulose (CMC), glycerol and AgNPs. The biodegradable films were identified by FTIR spectroscopy. The films exhibited antimicrobial potential towards *E. coli* and *S. aureus*. They were analyzed for toxicological activities and identified no toxicological responses. The film with AgNPs (from F2-F5) represented a higher inhibition rate (100%) and no microbial colonies were developed.

Dioscorea deltoidea Wall. Ex Griseb.

D. deltoidea tubers have a huge reservoir of pharmacological properties. They showed potent antibacterial efficacy against 10 G (+) and G (-) bacterial strains by using ethanol as a solvent. The crude extracts showed higher inhibitory actions than the standard (erythromycin) at the dose of 50 mg/mL. The antifungal potential of *D. deltoidea* tubers was evaluated against 3 fungal strains in aqueous and ethanolic extract. Both the extracts represented significant inhibitory potential which was comparable to the standard (ketoconazole). All these three clinical strains exhibited the same susceptibility at the same dose i.e. 50 mg/mL (Chandra *et al.,* 2013).

Dioscorea batatas Decne

Silver nanoparticles were synthesized from the rhizome extract of *D. batatas* and tested for their antifungal activity against two fungal strains, two gram-positive and one gram-negative bacterial strain. The inhibitory actions were examined against both the fungal strains viz., *C. albicans and S. cerevisiae* at the dose of 50 µg/mL. The significant antifungal potential was reported in both the fungal strains (Nagajyothi and Lee, 2011).

Dioscorea dumetorum (Kunth) Pax *and Dioscorea hirtiflora* Benth

The phytochemical screening revealed a number of biomolecules in the 80% methanolic fraction of *D. dumetorum* and *D. hirtiflora* tubers. In this, phenolic contents of the crude extract have significant antimicrobial potential against 5 bacterial and 2 fungal strains. The feeble inhibitory actions were shown in *D. dumetorum* while *D. hirtiflora* demonstrated a significant ZOI value. The methanolic fraction exhibited maximum inhibitory potential against *Bacillus subtilis* with the highest ZOI value (Sonibare and Abegunde, 2012).

Dioscorea nipponica Makino

Cho *et al.,* (2013) examined the antimicrobial activity of the bark of *D. nipponica* roots against 4- fungal pathogens. They also extracted a type of steroidal saponin dioscin which was able to damage the fungal membranes. The sample extracted

Table 3: Antimicrobial activities of *Dioscorea* species

S. No.	*Name of the Plant species*	*Plant Parts*	*Solvent/ extract used*	*Method*	*Most sensitive strain*	**In-vitro *effects***			*References*
						MIC	*MBC*	*ZOI*	
1	Dioscorea deltoidea	Tubers	Ethanol Aqueous	Disc diffusion method	*S. aureus* *P. aeruginosa* *E. coli* *C. albicans* *A. parasiticus*	- -	- -	19 ± 1 mm 17 ± 1 mm 15 ± 1 mm 9 ± 1 mm 9 ± 1 mm	Chandra *et al.,* 2013
2	*D. alata*	Tubers	AgNPs	Agar well diffusion method	*E. coli* *S. auricularis*	-	-	1.8 cm 1.7 cm	Pugazhendhi *et al.,* 2016
3	D. alata	Tubers	Aqueous	Agar cup method	*S. pyogenes*	-	-	1.30 cm	Kumar *et al.,* 2017a
4	*D. bulbifera*	Tubers Bulbils Peels	Ethanol Ethanol Ethanol	-	*E. coli* *K. pneumonia* *P. aeruginosa* *Serratia liquefaciens* *B. cereus* *K. pneumonia* *K. pneumonia*	- 500 µg/mL - 500 µg/mL 500 µg/mL - -	1000 µg/ mL 1000 µg/ mL 1000 µg/ mL - - - -	In mm 17.66 ± 0.57 22.00 ± 0.00 21.66 ± 0.57	Adeosun *et al.,* 2016
5	*Dioscorea* sps. *(elephant yam)*	Tubers	NiNPs	Disc diffusion assay	*S. aureus* *E. coli* *B. cereus* *K. pneumonia*	- - - -	- - - -	14 mm 13 mm 10 mm 09mm	Helen and Rani, 2015
6	*D. villosa*	Tubers	Ethanol	Disc diffusion method	*S. aureus* *E. coli* *K. pneumonia* *P. aeruginosa* *B. subtilis*	2 mg/mL 4 mg/mL 8 mg/mL 4 mg/mL 4 mg/mL	4 mg/mL 2 mg/mL 8 mg/mL 8 mg/mL 4 mg/mL	18 mm 20 mm 12 mm 14 mm 15 mm	Roy *et al.,* 2011
7	D. bulbifera	Tubers	Aqueous Ethanol Methanol n-hexane chloroform	Agar well diffusion assay	*K. pneumonia* *E. coli* *Acenatobacter* *C. albicans*	- - - - - -	- - - - - -	17 ± 0.15 mm 13 ± 0.11 mm 11 ± 0.12 mm 10.8 ± 0.11 mm	Dahiya, 2017

8	*D. pyrifolia*	Tubers	Ethyl acetate Methanol Hexane	Agar well plate diffusion technique	*E. coli* *S. aureus*	12.5 mg/mL 50 mg/mL	25 mg/mL 75 mg/mL	18.55 ± 0.12 mm 14.11 ± 0.21 mm	Mierza *et al.*, 2019
9	D. bulbifera	Tubers	Ethanol Acetone Water	Agar well diffusion method	*S. aureus* *P. aeruginosa* *B. pumalis* *E. coli* *C. albicans* *B. subtilis*	- - - - - -	- - - - - -	11 mm 11 mm 11 mm 11 mm 11 mm -	Win, 2020
10	*D. cayenensis*	Rhizome	50%Methanol Fractions n-Butanol Dichloromethane Hexane	Broth dilution test	*C. tropicalis* *C. albicans* *C. glabrata*	25 µg/mL 12.5 µg/mL 12.5 µg/mL	- - -	- - -	Sautour *et al.*, 2004
11	D. pentaphylla	Tuber	Methanol Water Acetone	Disc diffusion assay Agar well diffusion method Broth dilution assay	*S. pyogenes* *S. mutans*	- -	- -	25.00 ± 1.00 mm 19.00 ± 0.76 mm	Kumar *et al.*, 2017b
12	*D. alata*	Bulb	Methanol	Disc diffusion method	*Shigella dysenteriae*	-	-	17.16 ± 0.00 mm	Anisuzzman *et al.*, 2016
13	D. esculenta	Tuber	Ethanol	Well diffusion method	*E. coli* *P. aeruginosa* *S. aureus*	-	-	25 mm at 50 µg concentration	Begum and Anbazhakan, 2013
14	*D. hispida Dennst.*	Whole plant	Methanol Petroleum ether Carbon tetra-chloride Dichloromethane aqueous	Disk diffusion method	 *P. aeruginosa*	-	-	 16.50 ± 0.58	Miah *et al.*, 2018

15	D. nipponica	Root bark	Methanol		*C. albicans* *C. parapsilosis* *T. beigelii* *M. furfur*	22.5 ± 9.2 11.3 ± 4.6 11.3 ± 4.6 22.5 ± 9.2	-	-	Cho *et al.,* 2013
16	*D. pubera M/F*	Tuber	Methanol	Agar well diffusion method	*K. plisneumonia* *S. pneumonia* *E. coli* *S. dysenteriae* *C. albicans* *C. tropica*	-	-	9.43 ± 0.51/20.56 ± 0.40 11.76 ± 0.68/11.76 ± 0.68 10.53 ± 0.50/9.8 ± 0.2 10.86 ± 0.23/8.60 ± 0.52 8.56 ± 0.40/10.80 ± 0.20 6.83 ± 0..20/8.93 ± 0.20	Paul *et al.,* 2020
17	D. wallichii Hook. f.	Leaf	Methanol Acetone Ethyl acetate	Agar well diffusion method	*S. aureus* *E. coli*	-	-	18 mm 17.67 mm	Irulandi *et al.,* 2016
18	*D. bulbifera*	Bulbils	Petroleum ether Chloroform Ethanol Distilled water	Agar well diffusion method	*A. fumigates* *R. nigricans*	-	-	16.5 mm 20.5 mm	Seetharam *et al.,* 2003
19	D. pentaphylla	Leaf	Methanol Ethyl acetate	Disc diffusion technique	*B. megaterium*	-	-	20.85 ± 0.19	Mondal *et al.,* 2018
20	*D. bulbifera*	Bulbils	DBB2	MABA	*E. coli AG100A*	8.00 µg/mL	32.00 µg/mL	-	Kuete *et al.,* 2012
21	*D. pentaphylla*	-	Ethanol Petroleum ether Chloroform	agar radial well diffusion method	*S. aureus* *P. aeruginosa* *K. pneumonia* *C. albicans* *Trichophyton rubrum* *Microsporumadouini* *M.gypseum* *T. tonsurans*	- - - - - - - - - -	- - - - - - - - - -	20.63 ± 0.09 20.50 ± 0.28 19.26 ± 0.14 18.13 ± 0.09 14.37 ± 0.19 14.42 ± 0.09 20.37 ± 0.09 16.23 ± 0.15	G. Prakash and B. B. Hosetti, (2010)

in methanol and its 3 fractions (water, chloroform and ethyl acetate) were prepared. The highest MIC was observed against *Candida albicans* and *Malassezia furfur*.

Dioscorea cayenensis Lam.

The antifungal potential of 3 compounds viz. compound-1(unidentified), compound-2 (dioscin) and compound-3 (diosgenin) isolated from aqueous methanolic extract of rhizomes of *D. cayenensis* was evaluated. The activity was tested against 3 fungal strains *Candida tropicalis, C. albicans* and *C. glabrata* by evaluating the MIC values using the broth dilution test method. The most significant antifungal efficacy was reported for dioscin against tested strains of yeast while compounds 1 and 3 were found to be less effective. The antifungal potential of dioscin was noted to be more significant than the standard drug α-hederin (MIC: 25-50 µg/mL) which was used as a positive control in this study (Sautour *et al.,* 2004).

Antimicrobial activities and activities against MDR microbes

Shriram *et al.,* (2008) examined the antimicrobial activity against MDR bacterial strains from the aqueous methanolic extract of *D. bulbifera* tubers. They identified the specific compound 8-epidiosbulbin E acetate (EEA) as a bioactive component that acted upon the R-plasmid strains of bacterial forms. The vancomycin-resistant and MDR bacterial strains were counteracted by the EEA and disintegrated their plasmids.

Dahiya, 2017 determined the antibacterial potential of tubers of *D. bulbifera* in different solvents and it was found that the aqueous fraction exhibited significant activity. He evaluated inhibitory action against 10 MDR bacterial strains and prominent activity was shown against *K. pneumoniae* in water as a solvent.

Antiviral activity

Diosgenin, a plant-derived sapogenin used as a dietary supplement, inhibits hepatitis C virus (HCV) replication with an EC_{50} of 3.8 µM, showing no cellular toxicity. It also reduces viral RNA, viral proteins, and phosphorylation of STAT3. When combined with interferon-R, it exhibits an additive anti-HCV effect (Wang *et al.,* 2011). Recent studies revealed diosgenin and yamogenin, key compounds in *Dioscorea*, exhibited *in-vitro* antiviral activity against hepatitis B and vesicular stomatitis viruses, with varying effectiveness during different infection stages (Liu *et al.,* 2013). *D. bulbifera* contains lectins, with one particular mannose-binding lectin displaying robust anti-reverse transcriptase (RT) activity. Notably, a novel lectin was isolated as a prominent RT inhibitor (IC_{50} at 0.93 µM). Another trypsin-stable lectin from *D. bulbifera* demonstrated RT inhibition with an IC_{50} at 73 µM. These findings underscore the enormous potential of *D. bulbifera* as a prominent source of nutraceutical compounds with significant anti-RT properties (Sharma *et al.,* 2017; Chaniad *et al.,* 2016; Li *et al.,* 2008; Wong and Ng, 2003). The quest for HIV-1 integrase inhibitors (IN) sourced from plant origins has resulted in the identification of compounds derived from *D. bulbifera* bulbils. The chloroform fractions of bulbils possessed clerodane diterpenoids, flavonoids and sterol glucoside. Among these compounds, quercetin exhibited the most potent anti-HIV-1 IN activity with IC_{50} at 16.28 µM (Chaniad *et al.,* 2016).

Antileishmanial activity

A study presents the first-ever synthesis of spherical nanoparticles with a core of gold (Au) and a silver (Ag) shell using a novel biological method called DBTE. This innovative approach utilizes the medicinal plant *D. bulbifera*. The resulting nanoparticles demonstrated remarkable biofilm inhibition towards both G (-) bacteria, especially *Acinetobacter baumannii,* and G (+) bacteria like *S. aureus*. The observed mechanism for this inhibitory activity involves severe cell damage leading to cell wall disintegration and the release of cellular materials. Furthermore, these nanoparticles showed significant effectiveness in combating *Leishmania donovani,* indicating their potential as powerful antibiofilm and antileishmanial agents (Ghosh *et al.,* 2015b). The antimicrobial studies are given in Table 3.

Conclusion and Future Perspectives

Dioscorea species are generally regarded as a source of carbohydrates and energy having antimicrobial, antioxidant, hypocholesterolemic, immune-modulatory and hypoglycemic potential. Many species of this genus are used as nutraceuticals and as therapeutics in chronic conditions. These nutraceuticals are also a source of potent antimicrobials. Also, *Dioscorea* genus fulfills the nutritional demand and confers food security as an alternative feed source in many countries. Future work is needed to unearth the biologically active constituents for the genesis of new drug formulations and drug discovery to cure different maladies especially caused by microorganisms.

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Conflict of Interest

There is no conflict of interest.

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