Pharmacognosy Reviews, 2024; 18(36):127-136.
www.phcogrev.com

Review Article

Ecological Facets of Varied Plant Life Forms and their Therapeutic Relevance

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ABSTRACT
Life forms depict the sum of adaptive features attributed to the ecological relationships of species. Adaptation plays a crucial role in the natural selection of an organism and sustains an organism's survival in its habitat. These are evolutionary changes inherited by plants for their survival in nature and to cope with competition and stresses in the environment. Varied plant life forms exist in nature and are classified by Eugen Warming considering their corresponding traits and the associated response to the environment viz. hydrophytes, helophytes, oxylophytes, psychrophytes, halophytes, lithophytes, psammophytes, chersophytes, eremophytes, psilophytes, sclerophyllous, coniferous and mesophytes. These adaptive life forms bring about structural and physiological changes and evolve for the successful survival of organisms in nature. Secondary metabolites, fungal endophytes and phytohormones play a vital role in the adaptation process by providing them a defensive shield against stressors. When explored therapeutically, these adapted plants containing secondary metabolites contributed to preventing and treating a wide array of diseases and disorders and seem promising sources of drug discovery.

Keywords: Adaptation, Life forms, Secondary metabolites, Warming.

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Received: 14-10-2024;
Revised: 17-10-2024;
Accepted: 30-10-2024.

INTRODUCTION

Greek philosopher and polymath, Aristotle (384-322) classified plant life forms considering their habitat and general appearance. Later on, his pupil, Theophrastus (371-287 BC) laid the concept of plant life forms by mentioning the botanical description and uses of several species in his famous writings. Carl Linnaeus (1707-78) strengthened this concept by recognizing algal groups along with vascular life forms and proposed a biological classification system.[1] Although the term 'life form' came into light from the Aristotle period but was originally coined by Eugenius Warming in 1896.[2] Danish botanist Christen Raunkier's established and further strengthened the fundamentals of the applied life form scheme.[3] Plants possess an inherent ability to interact with biotic and abiotic agents and can survive under the extremities of nature.[4] Plant adaptation is an extraordinary characteristic of a plant that facilitates it to survive under peculiar conditions of corresponding habitat.[5] Limiting factors viz. food, competition, temperature, altitude and sunlight have a great impact on the ecological profile of an organism. Around 1895, a Danish botanist Eugenius Warming, studied the importance of these limiting factors on vegetation in ecology and classified plants into various ecological groups on the criteria of water requirements and the nature of substrate on which a particular species flourish.[6] Warming, in his book 'Oecology of Plants- An Introduction to the study of plant communities' mentioned about oecological classification of plants (Table 1, Figure 1) and categorizing plants into several classes from Class 1 (section IV) to Class 13 (section XVI) viz. class 1 (hydrophytes), class 2 (helophytes), class 3 (oxylophytes), class 4 (psychrophytes), class 5 (halophytes), class 6 (lithophytes), class 7 (psammophytes), class 8 (chersophytes), class 9 (eremophytes), class 10 (psilophytes), class 11 (sclerophyllous), class 12 (coniferous), class 13 (mesophytes).[7] Later on, this categorization of plants was modified and refined by various scholars due to advancements in our understating of ecological traits. These life forms undergo structural and physiological changes for their survival. Several morphological traits of these adaptive plants are depicted in Figure 2A.

DOI: 10.5530/phrev.20241976

Hydrophytes

Plants that dwell in water and wet places partially or wholly submerged are known as hydrophytes. Concerning their relationship with air and water, they can be classified into amphibious, floating and submerged types. Several adaptations found in hydrophytes include thin leaves, long slender, flexible stems having lacunae (submerged plants) and waxy cuticles.[6] Examples include *Eichhornia crassipes*,[8] *Ceratophyllum* *demersum*,[9] *Polygonum senegalensis*,[10] *Nymphaea lotus*,[11] *Typha domingensis*.[12]

Helophytes

Generally regarded as Marsh plants, helophytes are among the category of aquatic plants, whose assimilatory organs are submerged in water or soil or at most swim on the surface of water. They have reduced leaf surface, adventitious roots and horizontal rhizomes attributed to their adaptability. Examples are *Typha latifolia, Phragmites australis*.[13]

Oxylophytes

Plant formations on sour/acidic soil are generally termed Oxylophytes. They are acid-loving plants adapted to free humous acidic soil. Well-developed coating of hairs, papillae, wax and thick cuticles are among the most common adaptive features of these plants e.g. *Vaccinium uliginosum*.[7]

Psychrophytes

These plants are adaptable in cold and wet or excessively wet habitats represented by varied life forms viz. shrubs, under shrubs, sub-shrubs and perennial grasses. These plants are usually xeromorphic having stiff leaves with hard epidermis. Examples include *Ranunculus glacialis*,[14] *Saxifraga flagellaris*.[15]

Halophytes

They possess unique adaptive features viz. regulation of osmotic pressure and homeostasis, excretion via salt glands, altered membrane compositions, etc. which help them to tolerate high saline conditions.[16] A few examples of halophytes are *Aerva javanica*, *Kochia scoparia*,[17] *Acacia modesta*,[18] *Rhizophora mucronata*,[19] *Salicornia brachiata*.[20]

Lithophytes

Rock-dwelling plants are often termed 'lithophytes' which generally obtain their nutrition from decomposing plant litter from surroundings, dew, rainwater, etc. They possess haptera by which they attach themselves to rocky surfaces and can also tolerate high calcium levels.[7,21] Some examples of these rock-dwelling species are *Selaginella bryopteris*,[22] *Pteris vittata*,[23] *Dendrobium nobile*.[24]

Psammophytes

These sand dune plants possess reduced leaves and exposed root systems to combat the extremities of gravel and sand.[25] Examples include *Agriophyllum squarrosum*,[26] *Alhagi sparsifolia, Artemisia ordosica*,[27] *Artemisia scoparia*,[25] *Canavalia rosea*,[28] *Digitaria ciliaris*,[29] *Setaria vindis*,[30] *Vitex trifolia*.[31]

Chersophytes

These are the plants that dwell on wasteland and play a crucial role in preventing soil erosion, as well as soil stabilization e.g. *Poa bulbosa*.[7]

Eremophytes

Plants dwell on the desert and steppe remarked as eremophytes. Reduction in leaf size, sunken stomata, strong cuticle and thick-walled epidermis are among a few adaptive features of these plants[7] e.g. *Haloxylon ammodendron, Nitraria sibirica*.[27,32]

Psilophytes

They resemble chlorophyta (filamentous green algae) having true stems, sporangia, slender and branching rhizomes.[33]

Sclerophyllous

Vegetation adapted to long stress periods of heat and dryness encompassing hard leaves and short internodes.[34] Examples include *Eucalyptus camaldulensis*.[35]

Coniferous

Plants having needle-like evergreen leaves, strong cuticularization of the epidermis and cone-bearing seeds are among the most distinguishable adaptive features of coniferous.[36] Some commonly found coniferous plants are *Pinus roxburghii*, *Abies alba*.[37]

Mesophytes

Plants that flourish in moderate or average water requirements/ conditions are termed Mesophytes. The primary distinguishing characteristics of this species are its well-developed roots with root caps, straight and branched branches, thick bark and waxy cuticles.[38] *Solanum lycopersicum*[39] and *Biophytum sensitivum*[40] are a among few examples of mesophytes.

MULTIPLE FACETS OF LIFE FORMS

It has been observed that plants that were present in one life form can thrive in another. The most prominent example in this regard is of orchids, which are found to be inhabited in different life forms viz. terrestrial, lithophytic, epiphytic and saprophytic.[41] This adaptive feature is also observed in Araceae,[42] Lentibulariaceae[43] and Orchidaceae.[44] Danish Botanist, JEB Warming (1841-1924) mentioned the formations on the rocks (lithophytes) in oecological classification Section VIII, Class 6. The term 'lithophyte' was coined by Schimper in around 1898 representing the vegetation found on rocks or stones, whereas the term 'chasmophyte' was used for plants dwelling on crevices in rocks.[45] Lithophytes adapted to rocky substrates and generally obtained their nutrition from the atmosphere.[46] It is quite fascinating that many plants are adapted over time and able to flourish in distinct habitats representing multiplicity in their

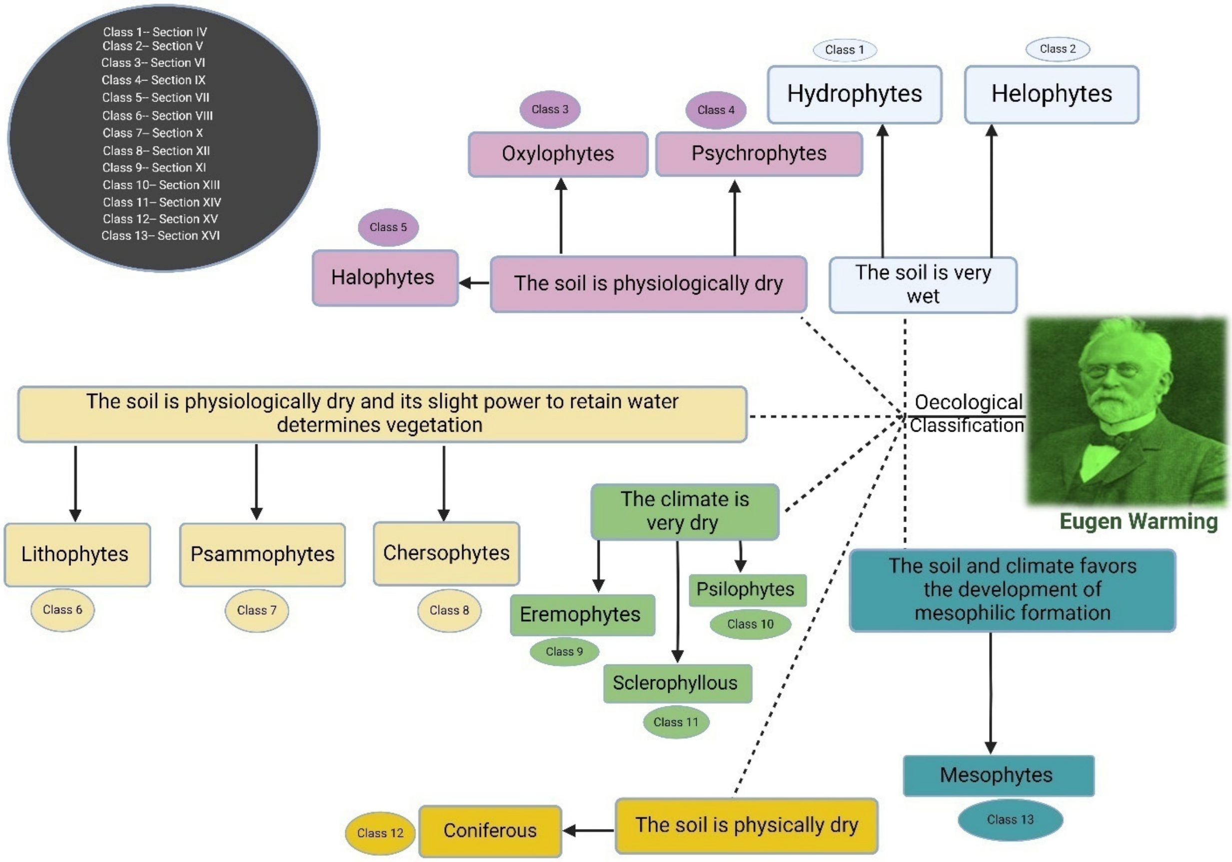

Figure 1: Overview of oecological/ecological classification.

Table 1: Warmings Oecological classification.[7]

Class	Soil condition	Type	Formations on	Section
1	The plant has access to plenty of water and the soil is extremely wet.	Hydrophytes	Water	IV
2		Helophytes	Marsh	V
3	Physiologically dry soil and only partially supplied with water for plant utilization. Therefore, the formations are primarily made up of xerophilous type.	Oxylophytes	Acidic soil	VI
4		Psychrophytes	Cold soil	IX
5		Halophytes	Saline soil	VII
6	Physically dry soil and its low water capacity predict the vegetation; therefore, formations are somewhat xerophilous.	Lithophytes	Rocks	VIII
7		Psammophytes	Sand, gravel	X
8		Chersophytes	Wasteland	XII
9	The climate is very dry and determines the character of the vegetation and also controls soil properties; formations are also xerophilic.	Eremophytes	Desert and steppe	XI
10		Psilophytes	Savannah	XIII
11		Sclerophyllous	Bush, forest	XIV
12	The soil is physically dry.	Coniferous	Forest	XV
13	The soil and climate favors mesophilic formations.	Mesophytes	Forest	XVI

life forms. *Begonia alicida* exists in both terrestrial and lithophytic life forms,[47] *Persicaria capitata* is usually found in terrestrial habitats but is also found to dwell on dry rocks.[48,49] *Peristylus monticola*, an orchid also inhabited terrestrial and lithophytic life forms.[50] *Coelogyne corymbose*, an epiphytic orchid, weeping fern (*Lepisorus krameria*), and *Peperomia macrostachya* exist in both epiphytic and lithophytic life forms.[51-53] *Selliguea griffithiana* and *Ficus tinctoria* exist in terrestrial and epiphytic forms[54,55] whereas *Rhododendron lochiae* exists in three life forms viz. terrestrial, lithophytic and epiphytic[56] as documented in Table 2. Not only plants but several lichens were also found to flourish on rocks/stones as well as exist in epiphytic form. Hammered shield lichen (*Parmelia sulcata)* is frequently inhabited on the oak bark of various trees but is also found in the saxicolous form.[57]

Table 2: Some examples of plants exist in varied life forms.

Species	Life form			
	Terrestrial	Lithophytic	Epiphytic	References
Begonia alicida *Begoniaceae*	+	+	-	[47]
Persicaria capitata *Polygonaceae*	+	+	-	[48,49]
Peristylus monticola *Orchidaceae*	+	+	-	[50]
Coelogyne corymbosa *Orchidaceae*	-	+	+	[51]
Lepisorus krameria *Aspleniaceae*	-	+	+	[52]
Peperomia macrostachya *Piperaceae*	+	+	-	[53]
Selliguea griffithiana *Polypodiaceae*	+	-	+	[54]
Ficus tinctoria *Moraceae*	+	-	+	[55]
Rhododendron lochiae *Ericaceae*	+	+	+	[56]

(+) represent existence in particular life form, (-) means non-existence in respective life form.

CHEMICAL RELEVANCE

PSM (Plant Secondary Metabolites), fungal endophytes and phytohormones are involved in the defense mechanism of plants and can help them withstand the extremities of nature and other stressors which further aids in adaptation[58] as represented in Figure 2B. It has been reported that a higher number of secondary metabolites viz. saponins, carotenoids, flavonoids, anthocyanins, etc. were produced in case plants flourish under alkaline soil conditions.[59] Nitrogenous compounds viz. alkaloids have a prominent role in building plant defense mechanisms against herbivory and pathogens.[60] Volatile organic compounds,[61] flavonoids,[62] anthocyanins,[63] iridoids, tannins and polyphenols have a significant role in plant adaptation.[64]

Fungal endophytes have also been reported to modulate plant growth are involved in adaptations and facilitate evolutionary transitions in plants.[65] Brassinosteroids, a plant steroidal hormone have an important role in plant adaptation in response to abiotic stress[66] along with jasmonic acid which plays a critical role in tissue wounding.[67] Nevertheless, the role of ethylene, abscisic acid and salicylic acid has already been well-established in abiotic stress tolerance.[68]

THERAPEUTIC RELEVANCE

Plants evolved via adaptation and showed a wide array of pharmacological activities due to the presence of secondary metabolites as summarized in Table 3. These secondary metabolites have also been reported to be involved in providing defense to organisms against various types of stressors as well as helping them to adapt to peculiar conditions.[58] Water hyacinth *Eichhornia crassipes* showed antibacterial and antifungal activities when evaluated using several microbial strains.[8] Several extracts of common hornwort (*Ceratophyllum demersum*) exhibited wound-healing properties.[69] In a study involving a hydrophyte, *Polygonum senegalensis* hydroalcoholic extract was found potential inhibitor of α-glucosidase thus proving its curative role in treating diabetes.[70] Hydro-ethanolic extract from white Egyptian lotus (*Nymphaea lotus*) scavenges free radicals in DPPH, lipid peroxidation and reducing power assays.[71] Aerial parts of southern cattail (*Typha domingensis*) encompass complex secondary metabolites that successfully decrease levels of total cholesterol and triglycerides in Wistar rats.[72] Helophytes viz. *Typha latifolia* and *Phragmites australis* showed anti-inflammatory properties.[73,74] Crude extract and polyphenolic fractions of *Vaccinium uliginosum*, an oxylophyte showed antioxidant activity.[75] Psychrophytes *Ranunculus glacialis* and *Saxifraga flagellaris* exhibited hemolytic and anticancer activities respectively.[76,77] Halophytes *Aerva javanica* and *Salicornia brachiata* were reported as promising

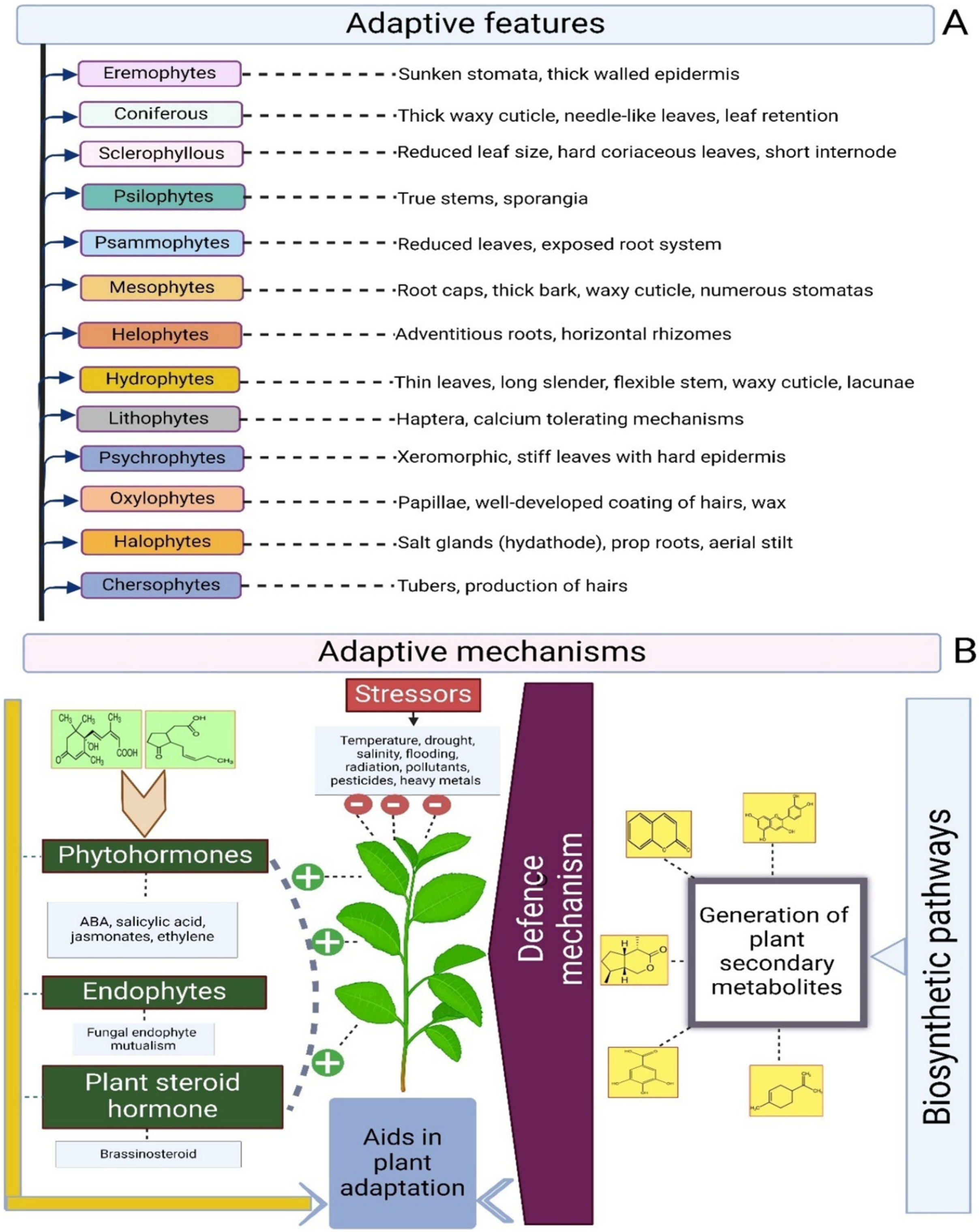

Figure 2: 2A) Adaptive features of plants, 2B) Adaptive mechanisms in plants.

antimicrobial plants.[78,20] Mexican fireweed *Kochia scoparia* showed anticancer activities when evaluated in human breast cancer cells[79] where as halophytes *Acacia modesta* and *Rhizophora mucronata* reported anti-inflammatory and antiviral activities respectively.[80,19] *Selaginella bryopteris*, a lithophytic plant showed its potential to treat stress.[22] Fronds of lithophytic fern *Pteris vittata* showed wound-healing properties,[23] whereas fragrant orchid *Dendrobium nobile* inhibited tumor.[81] Psammophytes (*Agriophyllum squarrosum, Alhagi sparsifolia)* showed hepatoprotective potential.[82,83] *Artemisia ordosica*, *A. scoparia*,

Table 3: Phytopharmacological status of adaptive life forms.

Sl. No..	Plant	Part used	Phytoconstituents	Activity	References
Hydrophytes					
1	*Eichhornia crassipes Pontederiaceae*	Whole plant	Alkaloids, terpenes, phenolics.	Antibacterial, antifungal.	[8]
2	*Ceratophyllum demersum Ceratophyllaceae*	Whole plant	Phenolics	Wound healing.	[69]
3	*Polygonum senegalensis Polygonaceae*	Leaves	Saponins, flavonoids, tannins.	α-glucosidase inhibitory activity.	[70]
4	*Nymphaea lotus Nymphaeaceae*	Leaves	Flavonoid	Antioxidant, anti-inflammatory.	[71]
5	*Typha domingensis Typhaceae*	Aerial parts	Flavonoids, alkaloids, tannins, glycosides, polyphenols, coumarins, terpenes, saponins, proteins, carbohydrates.	Antihyperlipidemic.	[72]
Helophytes					
6	*Typha latifolia Typhaceae*	Fruits	Polysaccharides	Wound healing.	[73]
7	*Phragmites australis Poaceae*	Leaves	Polyphenols	Anti-inflammatory, antiviral.	[74]
Oxylophyte					
8	*Vaccinium uliginosum Ericaceae*	Berries	Organic acids, anthocyanins, vitamins, glycosides.	Antioxidant.	[75]
Psychrophytes					
9	*Ranunculus glacialis Ranunculaceae*	Stem, leaves	Volatile oils, phenolics	Hemolytic activity.	[76]
10	*Saxifraga flagellaris Saxifragaceae*	Whole plant	Polyphenols	Anticancer, antioxidant, phytotoxic.	[77]
Halophytes					
11	*Aerva javanica Amaranthaceae*	Leaves	Alkaloids, cardiac glycosides, steroids, terpenoids, resins.	Antibacterial.	[78]
12	*Salicornia brachiata Chenopodiaceae*	Leaves	Alkaloids, flavonoids, tannins.	Antibacterial.	[20]
13	*Kochia scoparia Chenopodiaceae*	Fruits	Triterpenoid glycosides, saponins.	Anti-cancer.	[79]
14	*Acacia modesta Fabaceae*	Bark	Tannins	Anti-inflammatory, antipyretic, analgesic.	[80]
15	*Rhizophora mucronata Rhizophoraceae*	Bark	Polysaccharides	Anti-viral.	[19]
Lithophytes					
16	*Selaginella bryopteris Selaginaceae*	Whole plant	Hexoses, proteins	Anti-stress, antioxidant.	[22]
17	*Pteris vittata Pteridoideae*	Fronds	Polyphenols	Wound healing.	[23]

Sl. No..	Plant	Part used	Phytoconstituents	Activity	References
18	*Dendrobium nobile* *Orchidaceae*	Entire herb	Alkaloids, bibenzyl, phenylpropanoids, phenanthrene, polysaccharides	Antitumor, anti-inflammatory.	[81]
Psammophytes					
19	*Agriophyllum squarrosum* *Amaranthaceae*	Aerial parts	Oligosaccharides	Hepatoprotective.	[82]
20	*Alhagi sparsifolia* *Fabaceae*	Aerial parts	Flavonoids, alkaloids, polysaccharides, phenolic acids.	Antioxidant, hepatoprotective.	[83]
21	*Artemisia ordosica* *Asteraceae*	Root, stem, leaf	Dicaffeoylquinic acids.	Anti-inflammatory.	[84]
22	*Artemisia scoparia* *Asteraceae*	Aerial parts	Flavonoids,coumarins, chromones, phenolic acid, steroids,volatile oil.	Anti-inflammatory.	[85]
23	*Digitaria ciliaris* *Poaceae*	Flower	Xycaine, hexadecanoic acid, octadecanoic acid, linolenic acid, heptacosane, pentacosane.	Promote skin wound healing.	[86]
24	*Vitex trifolia* *Lamiaceae*	Leaf	Artemetin, casticin, vitexilactone, maslinic acid.	Anti-inflammatory.	[87]
25	*Canavalia rosea* *Fabaceae*	Leaves	Saponins, flavonoids, alkaloids, phlobatannins, cardiac glycosides.	Antimicrobial.	[88]
26	*Setaria vindis* *Poaceae*	Aerial parts	Tricin, p-hydroxycinnamic acid, vitexin 2"-O-glucoside.	Antioxidant.	[89]
Chersophyte					
27	*Poa bulbosa* *Poaceae*	Stem, leaves	Alcohols, amines.	Antibacterial.	[90]
Eremophytes					
28	*Haloxylon ammodendron* *Amaranthaceae*	Leaves	Quercetin, β-sitosterol, daucosterol	Antibacterial, antifungal.	[91]
29	*Nitraria sibirica* *Nitrariaceae*	Leaves	Flavonoids	Antioxidant, anti-proliferative.	[92]
30	*Sophora alopecuroides* *Fabaceae*	Aerial parts, seeds	Alkaloids, steroids, flavonoids, polysaccharides	Anticancer, antiviral, anti-inflammatory.	[93]
Sclerophyllous					
31	*Eucalyptus camaldulensis* *Myrtaceae*	Leaves	Phenolics	Antimicrobial.	[94]
Coniferous					
32	*Pinus roxburghii* *Pinaceae*	Stem bark	Monoterpenes	Analgesic and anti-inflammatory.	[95]
33	*Abies alba* *Pinaceae*	Seed, cone	Essential oils	Antimicrobial, antiradical.	[96]
Mesophytes					

Sl. No..	Plant	Part used	Phytoconstituents	Activity	References
34	*Biophytum sensitivum* *Oxalidaceae*	Whole plant	Carbohydrates, proteins amino acids, flavonoids, saponins, tannins	Anti-urolithiasis.	[97]
35	*Solanum lycopersicum* *Solanaceae*	Fruit	β-carotene, vitamins, phenolics, carotenoids, glycoalkaloids	Anti-oxidant, anti-cancer.	[98]

Digitaria ciliaris, Vitex trifolia showed anti-inflammatory activities in various pharmacological models.[84-87] *Canavalia rosea* and *Setaria vindis* possess antimicrobial and antioxidant properties.[88,89] Silver nanoparticles synthesized from bulbous bluegrass (*Poa bulbosa*), a chersophyte showed antimicrobial potential.[90] Organic extracts from several eremophytes viz. *Haloxylon ammodendron, Nitraria sibirica, Sophora alopecuroides* showed potent antimicrobial, antioxidant and anti-cancer activities respectively.[91-93] Ethyl acetate extract from leaves of *Eucalyptus camaldulensis*, commonly known as river red gum showed antimicrobial and inhibitory action in schistosomiasis.[94] Coniferous (*Pinus roxburghii, Abies alba*) and mesophytic plants (*Biophytum sensitivum, Solanum lycopersicum*) have already shown their well-established therapeutic potential when evaluated in different experimental models.[95-98]

CONCLUSION

Adaptation seems to be an immensely invaluable gift that nature gave to organisms and proved necessary to bring evolutionary changes in them. The emergence of adaptive characteristics in an organism helped them to remain in harmony with the environment and for their optimum survival. Plant communities can adjust their life forms considering ecological factors and survive under the extremities of nature by undergoing modifications at structural and physiological levels. Several species also existed in distinct life forms by acquiring adaptive features in the evolutionary process and ultimately marked their importance from an ecological point of view viz. lithophytes and epiphytic. Secondary metabolites viz. polyphenols, flavonoids, iridoids and terpenoids emerged as protective agents in building the defense system of plants. Fungal endophytes and several phytohormones are also involved in the adaptation process and help adaptive life forms to withstand biotic and abiotic stresses. Adaptive life forms also encompassing a plethora of complex constituents emerged as a potential agent in the treatment of several diseases when tested experimentally using different pharmacological models. In this review, an attempt has been made to highlight multiple facets of the adaptive life form of plants and the role of agents involved in the process of adaptation.

ACKNOWLEDGEMENT

The authors are extremely grateful to Lovely Professional University, Punjab, for hosting the International Conference on Recent Advances in Health Sciences (ICRAHS) and allowing a scientific research platform for consideration of this research. The authors also thank Dr. Vinay Thakur, Principal, Govt. Pharmacy College Rakkar; Dr. Vivek Sharma, Professor, Govt. College of Pharmacy Rohru; and CT University, Ludhiana, Punjab, for their ongoing encouragement and support.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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Cite this article: Arya V, Gill AK, Jamwal A. Ecological Facets of Varied Plant Life Forms and their Therapeutic Relevance. Pharmacog Rev. 2024;18(36):127-36.