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Review on Fern: A Fascinating Foliage

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Ferns are the fascinating non-flowering vascular plants found mostly in humid areas as ornamental plants. These are grown all over the word mainly in tropical rain forest areas, which can be easily propagated by spores or vegetatively by rhizomes or bulblets. Because of its varied morphology in frond structures, used as a filler material in decorations, bouquets, flower arrangements and as groundcover, pot plant in landscaping. This review aims to provide a comprehensive and nuanced portrayal of ferns, emphasizing their intricate morphology, phylogenetic classification, reproduction and importance in food industry, medicinal benefits industrial utility and ecological importance.

Keywords: Fern; frond; medicinal; morphology; ornamental spores.

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1. INTRODUCTION

Ferns are most primitive group of vascular plants appeared on earth around 360 million years ago in the middle Devonian period with approximately 12,000 living species. 'Pteridophyte' is derived from two Greek words *i.e.* "pteron" - feather and "phyta"- plant means the plants which bears feather like fronds are called pteridophytes [1].

Belongs to:

Kingdom : Plantae
Clade : Tracheophyta
Division : Pteridophyta
Class : Filicopsida or Polypodiopsida

These are non-flowering and spore-bearing plants classified under 'Cryptogams'. The word "cryptogamae", Greek words "kryptos" and "gamia" means "hidden reproduction." They can be perennial, annual, terrestrials, aquatics or epiphytes [2]. "Ferns are considered as National emblem of New Zealand and feather on its passport and in the design of its National airline, Air New Zealand and its rugby team" [3].

Fern diversity: World flora consists of 13,600 species and 400 genera of ferns, out of which India contributes about 10.76% globally [4]. India is one among 10 mega diversity centres because of its conducive atmosphere suitable for fern growth [5].

Pteridophytic diversity in India: "Ferns are majorly distributed in Central India, Western India, Eastern India and Southern India and in Andaman and Nicobar Islands. The country is home to a wide range of habitats, from tropical rainforests to alpine meadows, providing favourable conditions for pteridophytes to thrive" [6].

Distribution and Habitat: "Ferns are widespread in their distribution with the greatest richness of population in the tropics, and least in arctic areas. The greatest diversity occurs in tropical rainforests. The pteridophytes are grown in different habitats like moist or dry rocks and boulders, on tree trunks, as hydrophytes in lakes, ponds, etc., on forest floors and edges, along perennial streams and deep ravines, grasslands, tea and coffee estates", *etc* [8].

- **Tropical Rainforests:** Ferns are abundant in tropical rainforests, where they thrive in the warm and humid conditions. These forests provide a diverse range of habitats, including the forest floor, understory and tree trunks, where ferns can grow in the shaded and moist environments [9].
- **Temperate Forests:** Ferns are also found in temperate forests, where they are often seen growing on the forest floor, rock crevices, or on decaying logs. They are well-adapted to the cooler temperatures and moderate moisture levels of these regions [7].
- **Wetlands and Swamps:** Many fern species are adapted to wetland habitats, including marshes, swamps, and along riverbanks [10]. They can tolerate saturated soil conditions and often form dense stands in these areas.
- **Coastal Environments:** Ferns are frequently found in coastal habitats such as sand dunes, mangrove forests, and salt marshes [11]. These environments possess challenges such as salt spray, shifting sands, and tidal fluctuations, but certain fern species have adaptations that allow them to thrive in these conditions.
- **Alpine and Subalpine Zones:** Some ferns have adapted to high-altitude habitats, including alpine meadows, subalpine forests, and rocky slopes [12]. These ferns are adapted to withstand colder temperatures, strong winds, and shorter growing seasons.
- **Epiphytic Habitats:** Many ferns are epiphytes, meaning they grow on the surfaces of other plants, such as tree trunks or branches. Epiphytic ferns can be found in a variety of ecosystems, including tropical rainforests, cloud forests, and even temperate forests [13].
- **Crevice and Rock Habitats:** Certain fern species have adaptations to grow on rock crevices, cliffs, or walls. They are able to take root in small soil pockets or attach themselves to rocky surfaces [14].

Terrestrial Pteridophytes: Stem shows erect or creeping growth habit and the leaves held more or less upright, either vertical or spreading nature. Erect stems are generally unbranched with rosette leaves and woody or arborescent. Creeping rhizomes have spaced fronds and stem is branched or unbranched type [15].

Aquatic Pteridophytes [15]: Some of the ferns or truly aquatic or subaquatic (Rheophytic), possessing compact or creeping stems which float freely on the surface of water, or completely submerged and rooted in bottom of sediment (Isoetes).

Table 1. Pteridophytic diversity in India

Location	Species	Genera	Family
Central India	1135	204	64
Western India	321	101	49
Eastern India	810	179	60
Southern India	336	117	53
Andaman and Nicobar Islands	125	60	34

Table 2. Pteridophytic diversity in Karnataka [7]

District	Number of species	Author
Uttar Kannada	90	Blatter and Almeida (1992)
Hassan	10	Holttum *et al*. (1958)
Chikkamagalur	12	Yoganarasimhan *et al*. (1981)
Chamarajanagar	25	Kammathy *et al*. (1967)
Mysore	70	Razi and Rao (1971)

Epiphytic Pteridophytes: The stems are attached to trunks or branches of trees, having compact growth habit where fronds are pendulous, erect or arching type that helps to climb the trees. Sub-epiphytes are grown on decaying detritus matter, also occur on mossy ground and mossy rocks [16].

Molecular phylogenetic: Generally, ferns are classified under the division Pteridophyta, which includes several different groups or subdivisions based on their characteristics and evolutionary relationships. The two main divisions of ferns are as follows [16].

- **Polypodiophyta (Leptosporangiate ferns):** This division contains the majority of fern species and is referred as "true ferns" [17]. The key characteristic of polypodiophytes is the presence of leptosporangia, which are small, typically one-celled sporangia that produce spores [18]. This division includes range of ferns from small delicate species to large tree ferns.
- **Psilotophyta (Whisk ferns):** The whisk ferns are a small group of primitive fern-like plants that are considered to be living fossils. They have very simple structures and lack true roots and leaves [19]. Instead, they have small, scale-like appendages called enations. Whisk ferns reproduce through spores and their spores are borne in sporangia at the tips of branched structures [20]. These are considered to be the earliest vascular plants.

Table 3. Pteridophyte habitats are presented below [6]

Habitat	Examples
Terrestrial ferns	*Dryopteris, Cyclosorus, Adiantum*, *Striatus* , *Pteris and Alsophila*
Aquatic ferns	*Azolla*, *Marsilea* and *Salvinia*
Epiphytic ferns	*Polypodium, Drynaria, Lepisorus* and *Platycerium*
Lithophytes (growing on rocks)	*Notholaena*, *Argyrochosma, Cheilathes*, *Adiantum, and Asplenium*

The first higher-level pteridophyte [21] classification (Fig. 1) and considered the ferns as monilophytes, as follows (Karnataka biodiversity board, 2018):

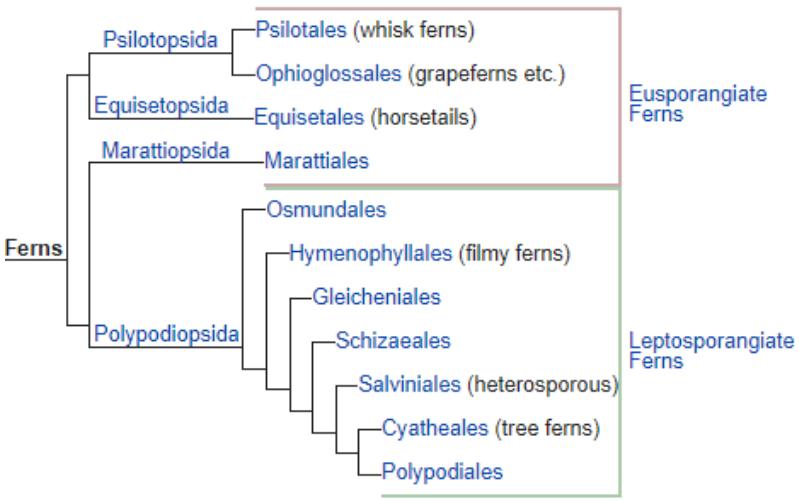

Fig. 1. Molecular phylogeny

Class Psilotopsida

Order – Psilotales (Whisk ferns)

- **Family – Psilotaceae – "**Plants lacking true roots, rhizomatous and perennial ferns, stems are dichotomously branched, leaves are simple lacking vascular enations, look like miniature leaves. Includes 2 genera (*Psilotum*, *Tmesipteris*) (Fig. 2) with 12 species found mainly in tropical and warm temperate regions" [22].

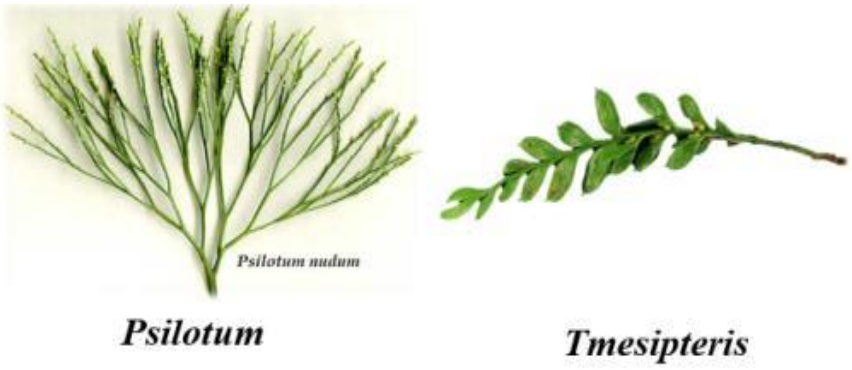

Fig. 2. Genera of Psilotaceae family showing morphology of leaves

Order – Ophioglossales (grape ferns)

- **Family-**Ophioglossaceae (Adder's tongue, Grape ferns, Moonworts) **– "**Plants usually with fleshy stems and roots; leaves are simple to compound type divided into sterile and fertile segments (eusporangia), consists of 4 or more genera (*Botrychium*, *Helminthostachys*, *Ophioglossum*, and *Mankyua*) (Fig. 3) with 80 species" [23].

Fig. 3. Fern genera of Ophioglossacea family showing morphology of plant

Class Equisetopsida

Order – Equisetales (Horsetails)

- **Family -** Equisetaceae - Stems with whorled branches, longitudinally ridged, hollow aerial shoots, leaves are whorled and non-photosynthetic in nature, reduced to a ring of small scale like structures, includes 1 modern genus (*Equisetum*) (Fig. 4) with 15 species [24].

Equisetum

Fig. 4. Fern genera of Equisetaceae family showing morphology of plant

Class Marattiopsida

Order – Marattiales (Giant ferns)

- **Family -** Marattiaceae – "These are terrestrial ferns, leaves are generally large and pinnately divided, pulvinate (enlarged or swollen at attachment point of leaflets) in living genera, 6 modern genera (*Angiopteris*, *Christensenia*, *Danaea*, *Eupodium*, *Marattia*, and *Ptisana*) (Fig. 5) with about 150 species are widely distributed in tropical regions" [25].

Angiopteris *Christensenia* *Danaea*

Fig. 5. Fern genera of Marattiaceae family showing morphology of leaves

Class Polypodiopsida

This class fern species are leptosporangiate ferns.
Order – Osmundales

- **Family -** Osmundaceae (Royal ferns) - Plants often found in wetlands; rhizomes are often stout, usually erect stems or ascending, occasionally trunk like, possess dimorphic leaves with sori and indusial are absent; 6 genera (*Claytosmunda*, *Leptopteris*, *Osmunda*, *Osmundopteris*, *Plenasium*, and *Todea*) (Fig. 6) and 20 modern species are present in this family [26].

Claytosmunda *Leptopteris* *Osmunda*

Fig. 6. Fern genera of Osmundaceae family showing morphology of leaves

Order – Hymenophyllales (Filmy ferns)

- **Family - Hymenophyllaceae -** Mostly these are rainforest epiphytes; mostly tiny ferns ferns (Fig. 7) with blades, slender with creeping growth habit lacking stomata [27] spores are globose, 9 genera with 600 species found in tropical regions around the world, a few species extending into temperate areas.

Fig. 7. Fern genera of Hymenophyllaceae family showing morphology of leaves

Order – Gleicheniales

- **Family - Gleicheniaceae** (Forking ferns) **–** Grown in soil or on rocks; rhizomes having creeping habit; leaves (Fig. 8) mostly sprawling over other vegetation, falsely dichotomous, due to presence of resting bud it is placed in gleicheniaceae, protostelic (its stele lacking pith and leaf gaps); *Gleichenia, Dicranopteris*, and 4 other genera with about 125 species, distributed in the tropics.

Fig. 8. Fern genera of Gleicheniaceae family showing morphology of leaves

- **Family - Dipteridaceae** (Umbrella ferns) **-** Rhizomes having creeping habit, leaf blades (Fig. 9) usually palmately divided into 2 or more lobes, sori arranged in linear series on either side of midrib, possess 2 genera, *Dipteris*, with about 11 species distributed mostly in the Paleotropics and *Cheiropleuria*, with 1 species (*Cheiropleuria bicuspis*) in the Paleotropics.

Fig. 9. Fern genera of Dipteridaceae family showing morphology of leaf blades

- **Family - Matoniaceae -** Leaves either fanlike (Fig. 10), with lobed narrow segments, or climbing habit with long midribs; sporangia are with oblique annuli, the simple sori covered by a thick umbrella-shaped indusium like structure; has 2 genera (*Matonia* and *Phanerosorus*) with 4 species, distributed in the Paleotropics.

Fig. 10. Fern genera of Matoniaceae family showing morphology of leaves

Order – Schizaeales

- **Family - Schizaeaceae -** Leaves more or less grasslike (Fig. 11), with a long petiole and a linear or fan-shaped blade; veins possess dichotomously branching habit, sporangia are often pyriform or flask shaped and are trilete; 2 genera (*Schizaea* and *Actinostachys*) with 30 species are mostly found in tropical regions.

Fig. 11. Fern genera of Schizaeaceae family showing morphology of leaves

- **Family – Lygodiaceae -** Rhizomes having creeping habit (Fig. 12), leaves are indeterminate in growth, climbing and often twining nature bearing pseudodichotomous pinnae, 1 genus (*Lygodium*) with about 25 species are mostly distributed in the tropics.

Fig. 12. Fern genera of Lygodiaceae family showing plant habit

- **Family – Anemiaceae -** Rhizomes are creeping to erect, hairy; stems are usually four angled, leaves are simple and oppositely arranged (Fig. 13) with the basal pair (or, rarely, more) of

primary divisions are modified, mostly lacking laminar tissue, and densely covered with sporangia; 1 genus (*Anemia*) with about 100 species, mostly in the Neotropics.

Fig. 13. Fern genera of Anemiaceae family showing leaf morphology

Order – Salviniales (Heterosporous)

- **Family - Salviniaceae** (floating ferns) **– "**Salvias are aquatic ferns relatively short, mostly dichotomously branched (Fig. 14), sometimes lacking roots; they possess two different spores (micro and mega spores) develop into different gametophytes, consists of 2 genera (Azollaceae and Salviniaceae), *Azolla* (about 6 species) and *Salvinia* (about 10 species), distributed mostly in the tropics" [28].

Fig. 14. Fern genera of Salviniaceae family showing leaf morphology

- **Family - Marsileaceae** (Clover ferns) **-** Plants are heterosporous; rhizomes are long-creeping, slender, glabrous or hairy; 3 genera with 60 species of aquatic plants rooted in the substrate (Fig. 15) - *Marsilea* (Waterclover), *Pilularia* (Pillwort), and *Regnellidium*

Fig. 15. Fern genera of Marsileaceae family showing plant growth habit

Order - Cyatheales (Tree ferns)

- **Family - Cyatheaceae** (Scaly tree ferns) – These are arborescent, stems (Fig. 16) are erect and mostly trunk like (to 25 metres) or less commonly creeping or sprawling to short-ascending, leaves are mostly large (up to 5 metres) but in few species only 10–40 cm (about 4–16 inches), more than 600 modern species are widely distributed in tropical regions.

Fig. 16. Fern genera of Cyatheaceae family showing plant growth habit

- **Family – Thyrsopteridaceae -** Stems erect and trunklike (Fig. 17) or sprawling, hairy and with a mantle of roots, often producing slender runners; leaves are large (up to 3.5 metres) 3 to 5 times pinnately compound, 1 genus (*Thyrsopteris*) with a single species (*T. elegans*), endemic to the Juan Fernández Islands.

Fig. 17. Fern genera of Thyrsopteridaceae family showing plant growth habit

- **Family - Loxsomataceae -** Long-creeping rhizomes bearing hairs; leaves (Fig. 18) are medium-sized to large (0.5–5 metres long), includes 2 genera, *Loxsoma*, with 1 species (*L. cunninghamii*) in Northern New Zealand, and *Loxsomopsis*, with 1 species (*L. pearcei*) from Costa Rica to Bolivia.

Fig. 18. Fern genera of Loxsomataceae family showing leaf morphology

- **Family – Culcitaceae –** These are large plants that can reach upto 2mts in height, fronds of 2mtr long (Fig. 19), includes 1 genus (*Culcita*) with 2 or more species that are widely distributed, mostly in tropical regions.

Fig. 19. Fern genera of Culcitaceae family showing leaf morphology

- **Family - Plagiogyriaceae -** The leaves are pinnately (Fig. 20) compound and tip of leaves (young leaves) is covered with mucilage; the fertile fronds contracted and bearing dense sporangia on the under surface of leaf [29], 1 genus (*Plagiogyria*) with about 15 species, distributed in tropical regions.

Fig. 20. Fern genera of Plagiogyriaceae family showing leaf morphology

- **Family – Cibotiaceae -** Rhizomes has creeping to erect habit and often trunk like grow up to 6 metres with soft yellow hairs toward the tip; leaves are large [up to 4 metres], 1 genus (*Cibotium*) with about 11 species, distributed in tropical regions (Fig. 21).

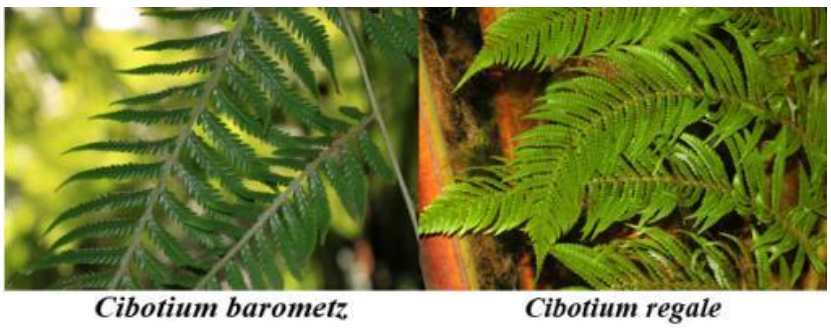

Fig. 21. Fern genera of Cibotiaceae family

- **Family - Dicksoniaceae** (Hairy tree ferns) **-** Stems are mostly erect and woody trunklike (up to 10 metres), leaves are rough textured mostly large with tripinnate nature (up to 3.5 metres), includes 3 genera (Fig. 22) (*Calochlaena*, *Dicksonia*, and *Lophosoria*) with 30 modern species, widely distributed in tropical region.

Fig. 22. Fern genera of Dicksoniaceae family

- **Family - Metaxyaceae -** Rhizomes has dense roots not forming a mantle; leaves are 1–2 metres (3.3–6.6 feet) long, 1 genus and 2 species (*Metaxya rostrata* and *M. lanosa*) (Fig. 23), are found at low elevations in the Neotropics, particularly in the Amazonian region.

Fig. 23. Fern genera of Metaxyaceae family

Order – Polypodiales (Fig. 24) **[30]**

- **Family - Davalliaceae** rabbit's-foot fern - Plants are epiphytic or sometimes grow on rocks; rhizomes are long-creeping habit, fronds are tripinnatified and spores are monolete (more or less bean-shaped); 1 genus (*Davallia*) with 40 species distributed in tropical and warm temperate regions.
- **Family - Dryopteridaceae –** Epiphytic in nature; rhizomes are short- to long-creeping or ascending to erect, scaly texture; spores are monolete (more or less bean-shaped); 45 genera with about 1,700 species, is the largest genera, *Dryopteris* (log fern, about 250 species), *Polystichum* (shield fern, about 250 species), and *Elaphoglossum* (tongue fern, 600–700 species), distributed nearly worldwide.
- **Family - Lomariopsidaceae –** Grown in soil, on rocks, or climbing (hemiepiphytic); rhizomes short- to long-creeping habit; spores are monolete (more or less bean-shaped); 4 genera (*Cyclopeltis*, *Dracoglossum*, *Dryopolystichum*, and *Lomariopsis*) with about 70 species were widely distributed in tropical regions.
- **Family - Nephrolepidaceae -** Plants widely distributed in tropical regions and sometimes cultivated as ornamental sword ferns; 1 genus (*Nephrolepis*) with about 30 species; formerly placed in Lomariopsidaceae.

Fig. 24. Fern genera of Polypodiales

Morphology of ferns: "The ferns are extremely diverse in habitat, form and reproductive methods, they range from minute filmy plants only 1–1.2 cm (0.39–0.47 inch) tall to huge tree ferns 10 to 25 metres (30 to 80 feet) in height" (Borthakur *et al*., 2001). "Some are twining and vine like, others float on the surface of ponds. Fern consists of large, highly dissected and shiny green feathery leaves. The plant body is differentiated into roots, stem and leaves (Fig. 25). The roots and stem are underground and only the leaves are aerial" [31].

Rhizomes - A rhizome is an underground stem that acts as the link between the roots, which draw moisture, and nutrients from the soil.

Root: Underground aerial division because they contain feathery leaves.

Crozier: Is an unfurled frond having circinate vernation called as fiddlehead or crozier.

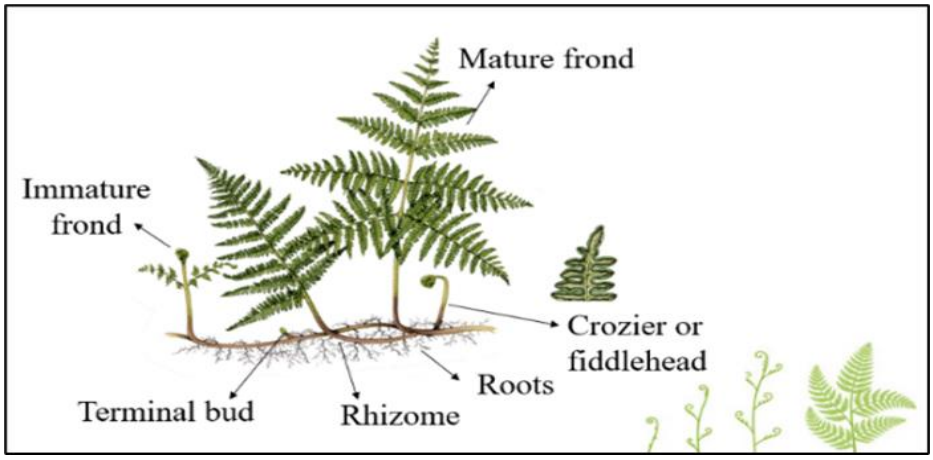

Fig. 25. Morphology of fern

Frond/leaf – "The green, photosynthetic part of the plant is technically a megaphyll and in ferns, it is often referred as frond. Leaves are divided into trophophyll and Sporophyll based on production of spores" [16]. Trophophyll, a vegetative leaf which doesn't produce spores, instead only prpduce sugars by photosynthesis. Sporophyll is a fertile leaf which produces fertile spores born in sporangia that clustered to form sori.

Parts of Frond (Fig. 26)**:**

- **Frond:** An entire leaf of fern is called a frond
- **Leaf blade:** Whole frond other than stipe
- **Stipe:** The portion of the rachis without pinnae is referred to as the stipe (petiole)
- **Rachis:** Main axis of leaf which is subdivided into further branches

- **Pinna:** Primary leaflet of frond, 25-45^0 proximal pinna
- **Pinnule:** Secondary leaflet of frond
- **Coasta:** Main axis of secondary pinna

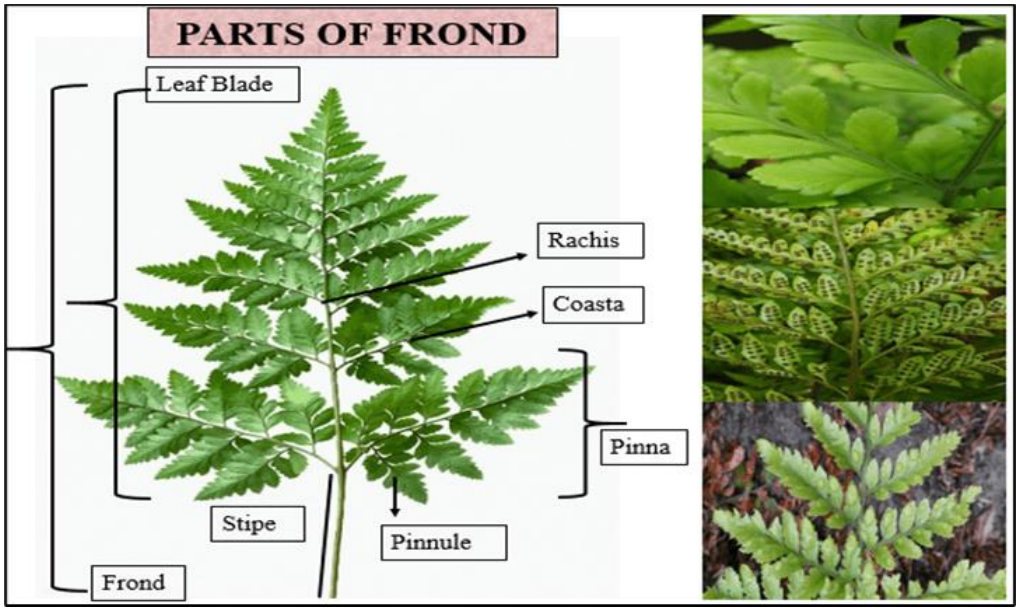

Fig. 26. Parts of frond

- **Blade** - Located above the stipe, the blade is made of the supporting stalk called the **rachis** and the "leafy" structures called a **pinna**.
- The midrib of pinna is termed a **costa** and the midrib of pinnule is called as **costule.**
- Under side of leaf black numerous tiny dot like structures called as **spores.** Leaves are oval shape with serrated margins. The spores are haploid; that is, they have one set of chromosomes. They are produced in specialized organs-the spore cases, or sporangia.
- **Coverings** - The frond possess hair like structures which helps in identify a species of ferns. Most fern stems also are covered with a protective indument, consisting of hairs, known as **trichomes,** or scales; these are so distinctive that they are valuable in identification.

Leaf Divisions

“Depending on the species, fern leaves display a wide array of divisions. Various degrees of leaf divisions (Fig. 27) are shown in series of frond” [3].

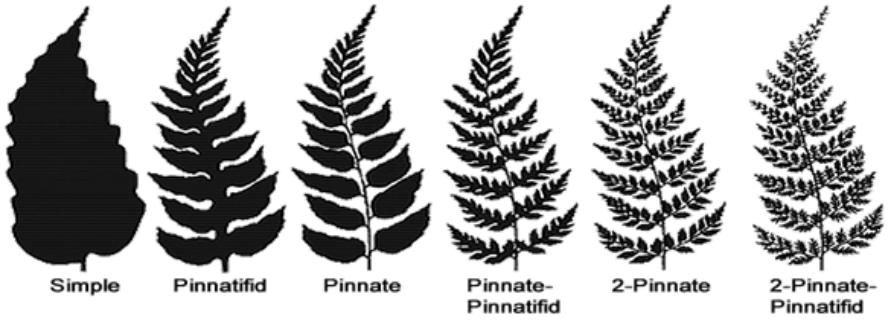

Fig. 27. Degrees of leaf divisions in fern frond

- **Simple:** Some fern species have undivided fronds, meaning they are not divided into distinct leaflets. These fronds are usually lanceolate or ovate in shape (Fig. 28a) and have a

continuous, undivided surface Heart's tongue fern (*Asplenium scolopendrium* var. *americanum*).

- **Pinnatifid:** The frond is divided into segments divided from each other almost to the rachis. Pinnate fronds are divided into leaflets or pinnae (Fig. 28a) along a central axis called the rachis. The leaflets are arranged in a feather-like pattern on both sides of the rachis. The leaflets can be evenly spaced or alternate in size along the rachis. Ex: Sensitive fern (*Onoclea sensibilis*), Licorice fern (*Polypodium glycyrrhiza*).
- **Pinnate:** The frond is divided into segments completely separated (Fig. 28a) from each other. Maidenhair spleenwort (*Asplenium trichomanes*)

Fig. 28a. Morphology of leaf divisions in different ferns

- **Pinnate-pinnatified –** *Rumohra adiantiformis* (Fig. 28b)
- **Bipinnate:** fronds are further divided, with each primary leaflet (pinna) being divided into smaller leaflets called pinnules (Fig. 28b). This creates a double feather-like arrangement. Bipinnate fronds have a more intricate appearance compared to pinnate fronds. Beech fern (*Phegopteris connectilis*)
- **Bipinnate pinnatifid** - Some fern species have fronds that are divided into multiple levels of leaflets (Fig. 28b). The primary pinnae are divided into secondary leaflets called pinnules, and these pinnules are further divided into tertiary leaflets. This creates a highly dissected and intricate frond structure. Northern wood fern (*Dryopteris expansa*).

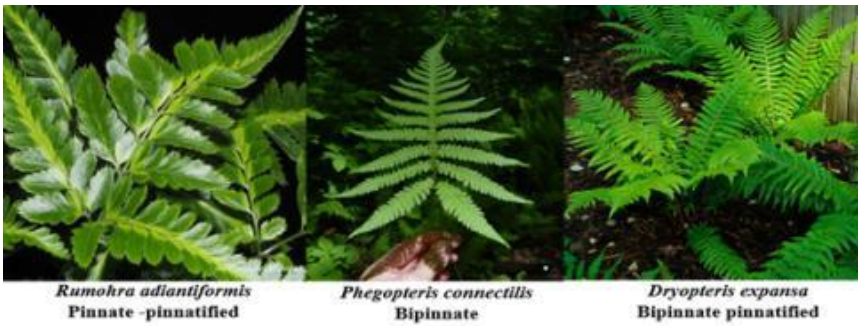

Fig. 28b. Morphology of leaf divisions in different ferns

Chromosome numbers and polyploidy: "The chromosomes of ferns tend to have high base or *x*, numbers ranging from approximately 20 to 70, with the majority between 25 and 45. The familiar genus *Osmunda*, for example, has *x* = 22, *Pteris* (29), *Asplenium* (36), *Dryopteris* (41), *Botrychium* (45), and *Pteridium* (52), *Ophioglossum reticulatum* has 1,440 chromosomes, the highest number of any organism known to science" [32]. "Among **homosporous** ferns, exceptions to the rule of high chromosome numbers are rare; in one species of filmy fern (*Hymenophyllum peltatum*), *x* = 11, the lowest number reported. Among **heterosporous** ferns, low base numbers" (*Marsilea*, *x* = 10, 13, or 19; *Salvinia*, *x* = 9; *Azolla*, *x* = 22) [29].

Propagation: Propagation can be achieved through several methods, including spore propagation, division of rhizomes, and tissue culture. Here are the main techniques for propagating ferns.

Sexually by spores - ex: *Asplenium scolopendrium, Rumohra*

Sporangiia: "The reproductive structure of ferns. These are small sacks or capsules containing the spores by which ferns reproduce (Fig. 29). Ferns display a wide diversity of spore types in terms of shape, wall structure, and sexuality, and these types prove to have great value in determining taxonomic relationships. Sori can vary considerably in shape, arrangement, location and coverings depending on the kind of fern. These differences can be useful for identifying ferns" [33].

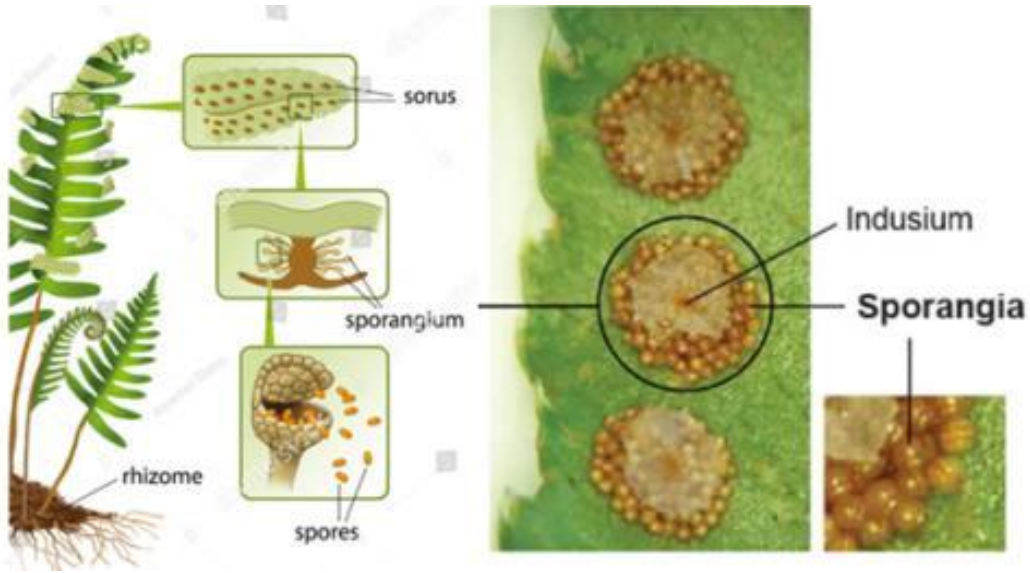

Fig. 29. Production of spores from sporangia

- **Shape: "**The basic spore shape among ferns is **tetrahedral;** the proximal face (the one facing inward during the tetrad, or four-cell, stage following reduction division, or meiosis). The tetrahedral structure is commonly obscured in so-called globose spores, the walls of which are thin and soft. The wall is composed of exospore (outer spore layer) only, there being no additional jacket, or perispore. Most bilateral spores in ferns are bean-shaped and jacketed by a perisporial layer, a distinctive covering of the outer wall" [15].
- **Size:** Most ferns are homosporous, each plant having spores of one shape and size, usually 30 to 50 micrometres in length or diameter, although some reach more than 100 micrometres. A few fern families, however, have **dimorphic spores,** small ones (microspores) and large ones (megaspores). The microspores produce sperm in antheridia, and the megaspores produce eggs in archegonia.
- **Wall:** Spore walls may be thick or thin. Thick-walled spores are capable of surviving for number of years, in some cases up to several decades. Young sori are commonly covered by flaps of protective tissue called **indusial** (singular indusium), [21].

The following are some of the most common of sori are (Fig. 30);

- **Sori without indusia:** The sori of polypody ferns do not have indusia.
- **Sori with umbrella-shaped indusia:** The indusium is round, shaped like a tiny umbrella and attached to the leaf from the middle. Individual sporangia are easily visible around the edge of each sorus.
- **Sori with hood-like indusia:** The indusium is attached at the lower edge and partially under the sorus. The hoodlike indusia of fragile fern are easy to see early in the season.

- **Sori with kidney-shaped indusial:** Northern wood-ferns have kidney-shaped indusia that are attached to the bottom of the frond by a narrow band of tissue.
- **Linear sori with linear indusia:** The tiny fronds of maidenhair spleenwort ferns bear few linear sori on their undersides. *Asplenium trichomanes* ssp. *densum*.
- **Sori with false indusia:** False indusia are not formed of specialized tissue (as are true indusia), but are leaf tissue rolled or folded over the sori. They can be marginal, along the side of the pinna, or at the tip of the pinna as in the maidenhair ferns.

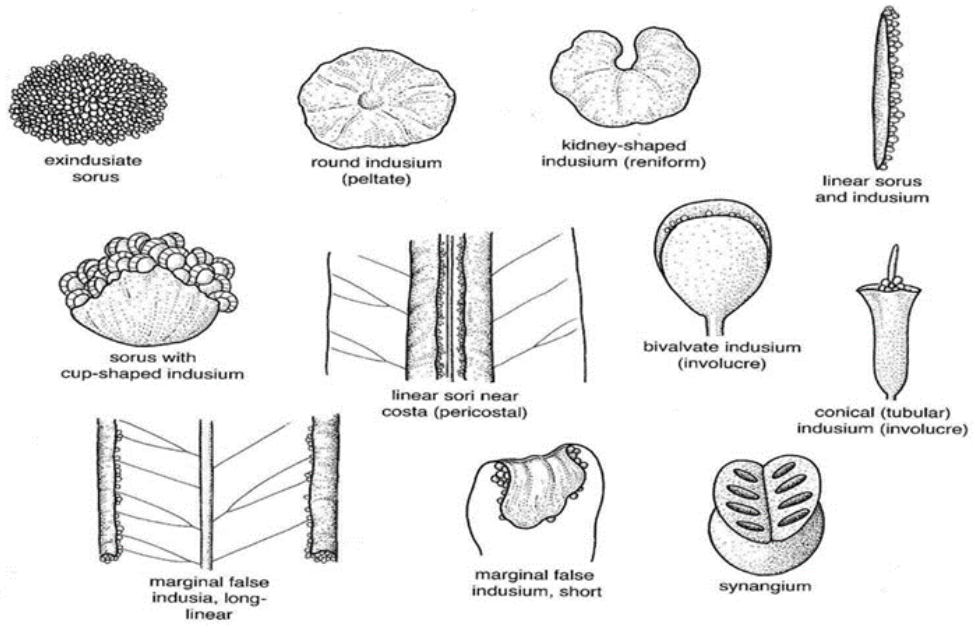

Fig. 30. Different shapes of indusium with sori present on ferns

The life cycle of a typical fern (Fig. 31) proceeds as follows [33];

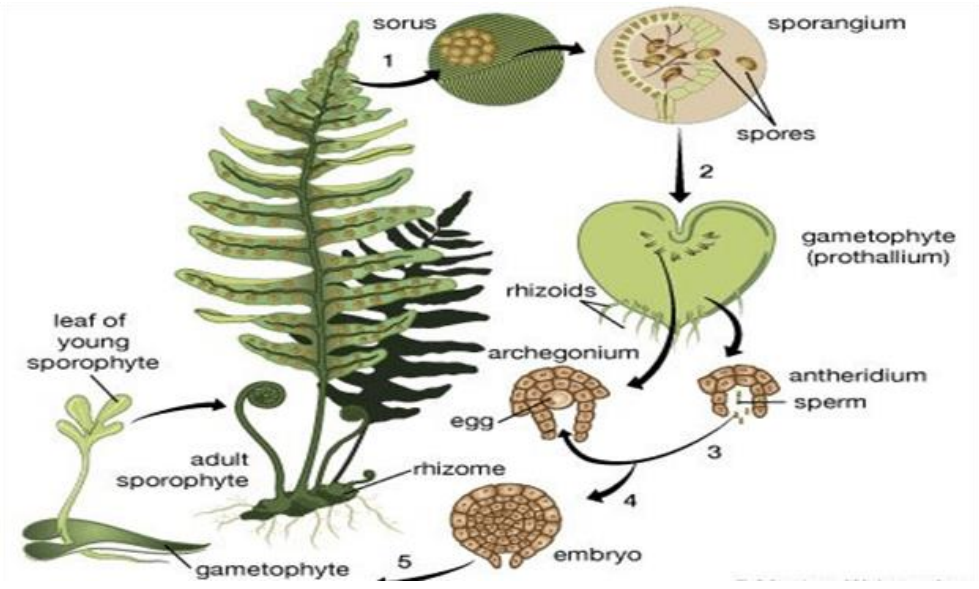

Fig. 31. Life cycle of fern reproduction sexually from spore to new plant

"The fern life cycle requires two generations of plants to complete itself. This is called **alternation of generations**. One generation is **diploid**, meaning it carries two identical sets of chromosomes in each cell or the full genetic complement (like a human cell). The leafy fern with spores is part of the diploid generation, called the **sporophyte"** [34]**.** In a haploid plant, each cell contains one set of chromosomes or half the genetic complement (like a human sperm or egg cell). This version of the plant looks like a little heart-shaped plantlet. It is called the **prothallus** or **gametophyte**. The process of fertilization is accomplished by sperm and eggs produced upon the same or more commonly different gametophytes, and both the fertilized egg (zygote) and the resultant embryo are held within the tissues of the prothallium until the embryo grows out as an independent plant. The average size of the gametophyte at the time of fertilization is approximately 2 to 8 mm (0.08 to 0.32 inch) long and up to 8 mm wide.

The **prothallia** are tiny—usually less than 8 mm (0.3 inch) long—and kidney-shaped in the majority of species. **Prothallus:** A green, photosynthetic structure that is one cell thick, usually heart- or kidney-shaped, 3-10 mm long and 2-8 mm broad. The thallus produces gametes by means of:

- **Antheridia:** Small spherical structures that produce flagellate sperm.
- **Archegonia:** A flask-shaped structure that produces a single egg at the bottom, reached by the sperm by swimming down the neck.

The diploid sporophyte has 2*n* paired chromosomes, where *n* varies from species to species. The haploid gametophyte has *n* unpaired chromosomes, i.e. half the number of the sporophyte.

1. The diploid sporophyte produces haploid spores by **meiosis**
2. Each spore grows into a photosynthetic prothallus (gametophyte) *via* **mitosis**. Because mitosis maintains the number of chromosomes, each cell in the prothallus is haploid. This plantlet is much smaller than sporophyte fern.
3. Each prothallus produces gamete *via* mitosis. Prothallus produces both sperm and eggs on the same plantlet. While the sporophyte consisted of fronds and rhizomes, the gametophyte has leaflets and **rhizoids**. Within the gametophyte, sperm is produced within a structure called an **antheridium**. The egg is produced within a similar structure called an **archegonium**.
4. When water is present, sperm use their flagella to swim to an egg and fertilize it.
5. The fertilized egg remains attached to the prothallus. The egg is a diploid zygote formed by the combination of DNA from the egg and sperm. The zygote grows *via* mitosis into the diploid sporophyte, completing the life cycle.

Spore propagation (Fig. 32)**:**

- Spores are fine dust like particles similar to pollen on underside of fronds. March to July is best month for spore propagation
- When small capsules turn brown cut the frond and wrap it with smooth paper, after 2 days unwrap and collect the spores
- Media: spores are sown same as seeds in compost. Leaf mould: peat: coarse sand: loam provide better drainage and sterile media for fern growth
- Cover the pot with lid or plastic bag to prevent contamination and to create humidity. It is essential to keep compost moist and in a shady location. Within 1yr seedlings are ready for planting.

Asexually:

- **Rhizome cuttings/Clippings** - Underground stems called rhizomes, which can be divided to create new plants. This method is suitable for ferns with clumping or spreading growth habits. To propagate ferns by rhizome division, carefully separate a portion of the rhizome, ensuring that each division has enough healthy roots and fronds attached. Transplant the divided sections into suitable growing conditions, providing adequate moisture and shade until they establish themselves. ex: Rabbit foot fern
- **Stolons /runners** - ex: Boston ferns
- **By division** – ex: *Bird's nest fern*
- **Fernlets /bulblets** – Bulblets are small vegetative buds that grow on the fronds of several fern species. When the bulblet is pressed to the ground or falls off the fern, it may take root and grow into a mature fern. Examples: Anderson's holly fern of the Northwest coast. ex: *Asplenium bulbiferum*

Fig. 32. Propagation of fern from spores

Economic importance

1. **Food source -** Unfurled croizer of ostrich fern, *Rumohra* fern used as a salad in U.S

- Some ferns are used for food, including the fiddleheads of *Pteridium aquilinum* (Bracken), *Matteuccia struthiopteris* (Ostrich fern), and *Osmundastrum cinnamomeum* (cinnamon fern) [22]. *Diplazium esculentum* is also used in the tropics (for example in *budu pakis*, a traditional dish of Brunei) as food [22].
- The spores are rich in lipids, protein and calories
- The sprouts of *Lophosoria quadripinnata* called as perritos in South of Chile as a salad vegetable [16].
- Fern tubers were used by the Guanches to make gofio in the Canary Islands. Licorice fern rhizomes were chewed by the natives of the Pacific Northwest for their flavour [33].

2. **Cultural significance [35]**

- The silver fern used as a trademark on dairy products as early as 1885
- Logo for rail operator KiwiRail, Railcar and on National air-line in New Zealand
- New Zealand people use tattoo mark, as a statement of being from New Zealand [36].
- Logo of former New Zealand Progressive party

3. **Ornamental –** Due to their attractive triangular feather like evergreen leaves used as foliage. Eg: *Adiantum*, Boston fern, Leatherleaf fern used in terrariums, flower decorations, bouquet preparations, in hanging baskets, hedge, edges also in window boxes and table decorations, as potted plant: *Dryopteris, Adiantum, Nephrolepis etc* [37].

- **Pteridomania -** Pteridomania is a term for the Victorian era craze of collecting fern and used in decorative art including pottery, glass, metals, textiles, wood, printed paper, and sculpture "appearing on everything from christening presents to gravestones and memorials" [38].
- *Microsorum pteropus* (Java fern), popular as fresh water aquarium fern [34].

4. **Medicinal –** Used in allopathy, homeopathy, Ayurveda because of bioactive compounds like alkaloids, phenolics and flavonoids present in ferns [39]. Extracts or preparations from certain ferns have been used to treat ailments such as wounds, skin conditions, respiratory disorders, and digestive issues [33].

- *Polystichum* – Leaves and rhizome for scorpion bite treatment, spores for leprosy and skin diseases [40].
- Clumbmoss- Treatment of epilepsy [41].

- *Adiantum capillus-veneris* and *Marsilea minuta* L. are used as Ayurvedic medicine mentioned in Charaka Samhita [42].
- *Dryopteris cristata,* roots are effective in expelling intestinal parasites from mammals [39].
- The decoction of fronds of *Actiniopteris radiata* is used against excessive bleeding in ladies during mensuration or abortion [43].
- *Selaginella bryopteris* popularly known as Sanjiwani is widely used as tonic in India [44].
- *Notholaena standleyi,* tea from fronds to promote fertility in women and Notholaenic acid, isolated from this has anti-HIV-1 activity activity [34].
- *Phlebodim aureum* extracts are effective immunomodulators, neuroprotective agents, antipsoriatics and also protect skin from UV damage [45].
- *Dryopteris filix-mas* root used as anthelmintic to expel tapeworms [39].
- Rhizome of *Polystichum squamosum* known as 'Nirviri' in India, used against scorpion bite and insect bites [6].
- *Pteridium aquailinum* or *Pteridium esculentum* contain carcinogenic compounds like ptaquiloside, where fiddle heads are used as cooked vegetable and milk contaminated with ptaquiloside compound as a treatment for stomach cancer/human gastric cancer in Japan [46].

5. **Air purifiers –**Ferns widely used in interioscaping because of their ability to maintainance aesthetically pleasing appearance. They have the ability to absorb major toxins like benzene, formaldehyde and tricholoroethylene. Ex. *Rumohra adiantiformis* [11].

6. **Industrial –** *Gleichini hirta, Dicranopteris linearis a*- soap manufacturing*,*

- *Pteridium* leaves green dye extraction, spores in preparation of lubricants [36].
- Polypodium are known for their property of sweetness. A variety of *Polypodium vulgare* L. was used to flavour tobacco for its liquorice taste and it contains small amounts of ostadin, a steroid saponin 3000 times as sweet as sucrose and species were used in Ireland to treat coughs, colds and asthma [47].
- Lycopodium powder has also been used as a lubricating dust on latex gloves
- Tree ferns *Cyathea mendullaris*, used as rough building material in tropical areas [48].
- *Cyathea incana* is used in production of Brazilian soft drinks Mineirinho and Mate [16].
- The roots of *Osmunda* fern used in production of fibre, that can be used as a substrate for orchid cultivation and other epiphytic plants [49].

7. **Forensic investigation** – Spores of fern and club moss, Ceratopteris richardii, a model plant for teaching and research, often called as C-fern [50].

8. **Insecticide –** Filicin compound present in *Dryopteris* helps in prevention of embryonic development of pest and insects ex: *Spodoptera litura* [51].

- The gene that express the protein Tma12 in an edible fern, *Tectaria macrodonta*, has been transferred to cotton plants, which became resistant to whitefly infestations.
- Protein extract from *Asplenium platyneuron*, deter insect predation in soyabean [47].

9. **Agricultural** – Azolla (*Anabaena azollae*) as green manure/biological fertilizer for nitrogen fixation which having symbiotic association with blue green algae in rice field [52].

- Feed to cow increases milk production
- The stems of some tree ferns are used extensively as a substrate for the cultivation of epiphytes

10. **Phyto-remidiation –** As bioremediation of waste water Eg: *Azolla* – heavy metals, *Pteris vittata*- Arseni 2.3% [53].

11. **Ecotourism and Recreational Activities:** Fern-rich habitats, such as fern forests and botanical gardens, attract ecotourists and nature enthusiasts. People visit these areas to appreciate the beauty of ferns, learn about their ecology, and engage in recreational activities like hiking, birdwatching, and photography.

- *Matteuccia* species used as food by lepidopteran larvae

12. **Ecological importance:** Contribute to soil conservation, nitrogen fixation contributing to soil fertility, prevent erosion, and provide habitats for various small organisms [54-57].

2. CONCLUSION

Pteridophytes are majorly concentrated in forest areas, as they love humid areas and shady locations. Now a days among the cut foliage ferns are contributing about 9.1% in total cut foliage sales because of its triangular symmetry of leaves found much utility in flower arrangements, vase and stage decorations as a filler material either of its own or along with flowers because of their aesthetic look, delightful herbage and cheap in cost. These are highly demanded not only for ornamental purpose but also as food, industrial usage, medicines, in agriculture utility etc. Due to deforestation and industrialization, the forest areas are depleting and many native species have been getting extinct, hence there is need to conserve the fern species *in-situ* or *ex-situ* by cultivating in botanical gardens to maintain the ecological balance.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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