Vertika Shukla
D.K. Upreti
Rajesh Bajpai

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Vertika Shukla
Environmental Sciences
Babasaheb Bhimrao
Ambedkar University
Lucknow, UP, India

D.K. Upreti
Lichenology Laboratory
CSIR - National Botanical
Research Institute
Lucknow, UP, India

Rajesh Bajpai
Lichenology Laboratory
CSIR - National Botanical
Research Institute
Lucknow, UP, India

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Preface

Among the different organisms, lichens are considered as one of the best bioindicators of environmental changes either due to natural or man-made disturbances. Lichens show differential sensitivity towards wide range of pollutants. Certain species are inherently more sensitive, while some species show tolerance to high levels of pollutants. These characteristics make certain lichen species suitable for being utilised as an indicator species (based on their sensitivity and tolerance) for various pollutants including metals, metalloids, radionuclides and organic pollutants. Lichens as indicators possess an undeniable appeal for conservationists and land managers as they provide a cost- and time-efficient means to assess the impact of environmental disturbances on an ecosystem.

Information about the sensitivity of lichens towards pollutants and their use in pollution monitoring is available since the sixteenth century; however, more systematic studies utilising lichens in biomonitoring studies were initiated in the 1960s in Europe. Lichen biomonitoring studies were introduced in India in the 1980s, and it was after 1995 that more systematic studies were carried out in different regions of the country. Owing to vast geographical area and rich lichen diversity of the country, few such studies are available in context with India that too scattered in different reports, journals or other published scientific articles. Thus, to popularise the subject in the country, the present attempt has been made.

This book is a valuable reference for both students and researchers interested in environmental monitoring studies involving lichens and from different fields of science including environment, botany and chemistry.

Lucknow, India — Vertika Shukla
Lucknow, India — D.K. Upreti
Lucknow, India — Rajesh Bajpai

About the Book

The book embodies the detailed account about unique symbionts, i.e. *lichens* in ecosystem monitoring. The first chapter deals with the unique characteristic features of lichens which facilitate their survival in extreme climates and make them an ideal organism for ecosystem monitoring. Biosynthesis of secondary metabolites is known to protect lichens against increasing environmental stresses; therefore, the second chapter provides insight into various chromatographic and modern spectroscopic techniques involved in separation and characterisation of lichen substances.

The third chapter elaborates the criteria for selection of biomonitoring species and characters of host plant that influence lichen diversity and detail about different lichen species utilised for biomonitoring.

One can retrieve preliminary information about the air quality based on the lichen community structure and distribution of bioindicator species as lichen communities/indicator species provide valuable information about the natural-/anthropogenic-induced changes in the microclimate and land-use changes due to human activity. Therefore, for identification of species, a key to genera and species provides concise information to identify the lichen species based on their morphological and anatomical characters and chemicals present. Keys provided in Chap. 4 will help the beginners to identify some common lichen species based on the distribution in different climatic zones of India. The section also provides comprehensive information about the bioindicator communities and bioindicator species from India.

Chapter 5 provides the details of factors affecting the ecosystem (natural as well as anthropogenic disturbances), and the role of lichens in ecosystem monitoring in India has been discussed in detail.

Chapter 6 discusses the need and utility of indicator species especially lichen biomonitoring data in sustainable forest management and conservation.

The content about lichens in biomonitoring will be a valuable resource for researchers from different fields and will provide an essential reference for people interested in lichens and its role in ecosystem monitoring. The book will also hopefully popularise lichenological studies in India and will generate more active participation of lichen biomonitoring studies in management and conservation of natural resources in India.

Contents

1 Introduction

Lichens are composite organisms comprised of a fungus and one or more algae living together in symbiotic association in which the algal partner produces essential nutrients for the fungal partner through photosynthesis, while the fungal partner provides mechanical support to the algal partner. Development and establishment of lichen on a substratum is achieved by fruiting bodies (apothecia) produced by the fungal partner, which must germinate and find an algal partner before they can form a new lichen thallus or may produce minute fragments (as finger-like outgrowths, isidia or sugar-like granules, soredia) containing both partners, which can disperse quickly and colonise available habitats.

Being pioneers on rock surface lichens are important component of the ecosystem that establishes life on rock and barren disturbed sites. As lichens colonise rocks, they trap dust, silt and water which leads to biogeophysical and biogeochemical weathering of the rock surface leading to soil formation.

Lichens occur in all available substrata and in all possible climatic conditions, but the lichen diversity of an area of interest or substratum is highly dependent on prevalent microclimatic conditions. Apart from morphology and anatomy of lichens, the high success of lichens in extreme climates has been attributed to the secondary metabolites produced by the fungal partner to protect the algal partner.

This chapter discusses the unique characteristics about lichens which facilitate their survival in extreme climates and makes them an ideal organism for ecosystem monitoring.

1.1 Introduction

The word lichen has a Greek origin, which denotes the superficial growth on the bark of tree, rock as well as soil. Theophrastus, the father of botany, introduced the term 'lichen' and this group of plants to the world. Lichen species collectively called as 'stone flower' in English, 'Patthar ka phool' in Hindi, 'Dagad phool' in Marathi, 'Kalachu' in Karnataka, 'Kalpasi' in Tamil, 'Richamkamari' in Urdu and 'Shilapushpa' in Sanskrit.

Lichen is a stable self-supporting association of a mycobiont (fungus) and a photobiont (alga) in which the mycobiont is the exhabitat (Hawksworth 1988). The plant body of lichen is called 'thallus', and it had been considered a single plant till 1867 when Schwendener (Swiss botanist) demonstrated the lichen thallus to be a composite body made up of fungus and an alga, and he propounded his well-known dual hypothesis for this body. This view was not accepted by the prominent lichenologist of the time, but later the composite nature of lichen thallus was universally accepted, and the two components were considered to be in a symbiotic association. The mycobiont predominates and the gross morphology of lichen thallus is generally determined by mass, nature and modifications of the fungal hyphae. The photobiont (Fig. 1.1), on the other

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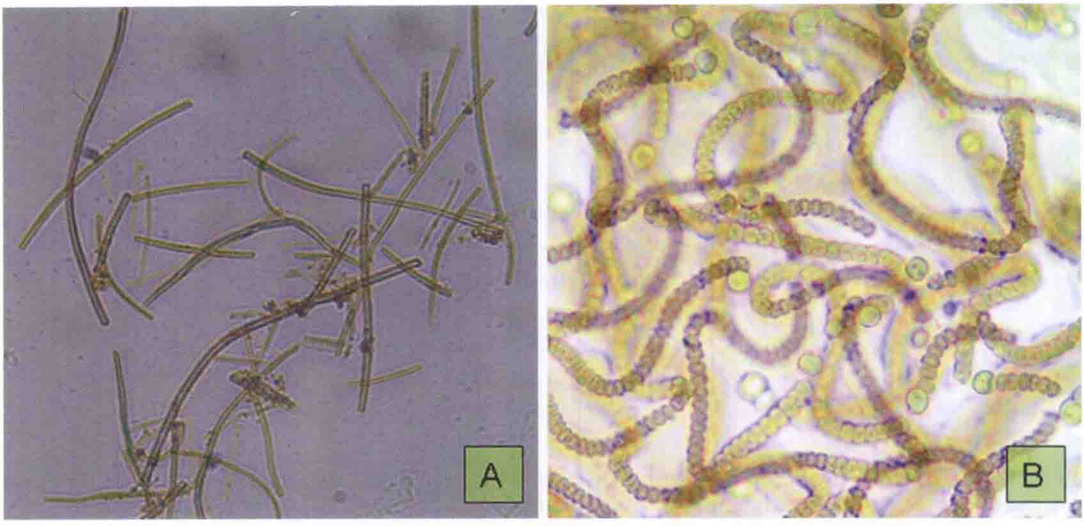

Fig. 1.1 Common photobionts which facilitate lichenisation with compatible fungal partner resulting in formation of lichen thallus. (**a**) *Trentepohlia* and (**b**) *Nostoc*

hand, also plays an important role in the development of the thallus. The resultant thallus is unlike the two symbionts in morphological appearance and physiologically behaving as a single autonomous biological unit (Awasthi 2000). About 85 % of lichens have green algae as symbionts, approximately 10 % have blue-green algae and/or cyanobacteria, and less than 5 % of lichens have both green algae as primary symbionts and blue-green algae as secondary symbionts. The lichen fungus is typically a member of the Ascomycota or rarely Basidiomycota and hence termed as ascolichens and basidiolichens, respectively. The hyphae of mycobiont are septate, branched and thin or thick walled and possess either a single or three septate through which the cytoplasmic contents of the adjoining cells are connected by plasmodesmata; rarely, the septum may be multiperforate (Honegger 2008).

Repeated septation, branching and different degree of compactness, coalescence or conglutination result in the formation of diverse type of tissue. The development of such tissues is also necessary for a durable and proper functioning of the symbiotic relationship in a lichen thallus. It is necessary that the photobiont, which is basically and essentially aquatic in nature, remains protected from desiccation in a lichenised terrestrial condition.

Most of the cyanobacterial photobiont possess a mucilaginous sheath, which protects them from desiccation to some extent, but no such protective sheath is present in the green-algal photobiont, which predominate in lichen taxa. The protection, however, is provided by the mycobiont through the development of specialised hyphal tissues in the form of a cortex over the stratum of the photobiont (Ahmadjian 1993).

Lichens have a poikilohydric nature to survive in various climatic conditions as they have no mechanism to prevent desiccation; they desiccate and remain dormant when their environment dries out but can rehydrate when water becomes available again. Lichens usually absorb water directly through their body surface by aerosol, mist and water vapours; due to this nature, lichens live long in dry areas even on stones and rocks used for construction of monuments and other building artefacts.

The role of alga in lichen partnership is that of producing food for themselves and their partner, the fungus. The fungus (mycobiont) in a lichen partnership cannot live independently. The fungus partner is able to obtain and hold water, which is essential for alga. The mycobiont attached firmly to the algal cell (photobiont) cannot be easily washed away by water or blown by wind. Due to this type of relationship, lichens are eminently successful and enjoy worldwide distribution and occur in every conceivable habitat, growing on a variety of substrata, including most natural substrata as well a host of human-manipulated or manufactured substrata. The common natural substrata on which lichens can colonise and grow successfully include all categories of rock (saxicolous), trees (corticolous), soil (terricolous) wood (lignicolous) and leaves (foliicolous), while manmade substrata include rubber, plastic, glass, stonework, concrete, plaster, ceramic, tiles and brick.

1.2 About Lichens

Lichens are perennial plants with very slow growth rate which is mainly attributed to the growth of the mycobiont. There is no supply of nutrients from the central part to the growing part, and the food produced by the photobiont at the growth site is used by the mycobiont. The pattern of growth in general is centrifugal, apical and marginal. In crustose and foliose lichen radical growth occurs, while in fruticose lichens there is an increase in length. The annual radial increase has been found to be 0.2–1.0 mm in crustose and 1.0–2.5 mm in foliose, while in fruticose lichens 2.0–6.0 mm growth can be seen in a year (Awasthi 2000).

1.2.1 Thallus Morphology and Anatomy

Growth forms (Fig. 1.2) are categorised mainly on the basis of morphology without direct reference to ecological adaptations, yet distribution of growth form primarily reflects competition and adaptation to abiotic environmental conditions, mainly water relations (frequency and intensity of periods of water shortage). Based on the external morphology (growth form), lichen thalli exhibit three major growth forms: crustose, foliose and fruticose. Crustose lichens are tightly attached to the substrate with their lower surface, which cannot be removed without destruction. Water loss is restricted primarily to the upper, exposed surface only. Crustose lichens may be subdivided as leprose, endolithic, endophloeodic, squamulose, peltate, pulvinate, lobate, effigurate and suffruticose crusts. Majority of crustose lichens grows directly on the surface of the substrate and is referred to as episubstratic, while a small minority grows inside the substratum called endosubstratic. The episubstratic thallus consists of a crust-like growth adherent or attached to the substratum throughout its underside by hyphae and cannot be detached without destruction (Büdel and Scheidegger 2008).

The leprose thallus is effuse and consists of a thin layer of uniformly and loosely disposed photobiont cells intermixed with hyphae forming a yellow, greyish-white or reddish powdery mass on the surface of the substratum. In terms of complexity, the powdery crust, as found in lichen genus *Lepraria*, is the simplest and lacks an organised thalline structure. Algal structure is embedded in the loose fungal hyphae, having no distinct fungal or algal layer.

Endolithic (growing inside the rock) and endophloeodic (growing underneath the cuticle of leaves or stems) are more organised as compared to leprose lichens. In most cases, an upper cortex is developed. The upper cortex can consist of densely conglutinated hyphae forming a dense layer named 'lithocortex' as seen in *Verrucaria* species.

In some crustose lichens as in genus *Rhizocarpon*, there is a prothallus which is a photobiont-free, white or dark brown to black zone, visible between the areolate and at the growing margins of the thallus.

A thallus is effigurate when the marginal lobes are prolonged and are radially arranged, as in genus *Caloplaca*, *Dimelaena* and *Acarospora*.

The squamulose thallus is an intermediate form between crustose and foliose forms. It generally has rounded to oblong minute lobules or squamules distinct from each other as they develop individually. The squamules are dorsiventral, attached to the substratum along an edge or by rhizoidal hyphae from the lower surface as in genera *Peltula*, *Psora* and *Toninia*. The flat scaled squamulose thalli, with more or less central attachment area on the lower surface, are called peltate as in *Peltula euploca*. Extremely inflated squamules in the lichen genus *Mobergia* are called bullate, while in some genera coralloid

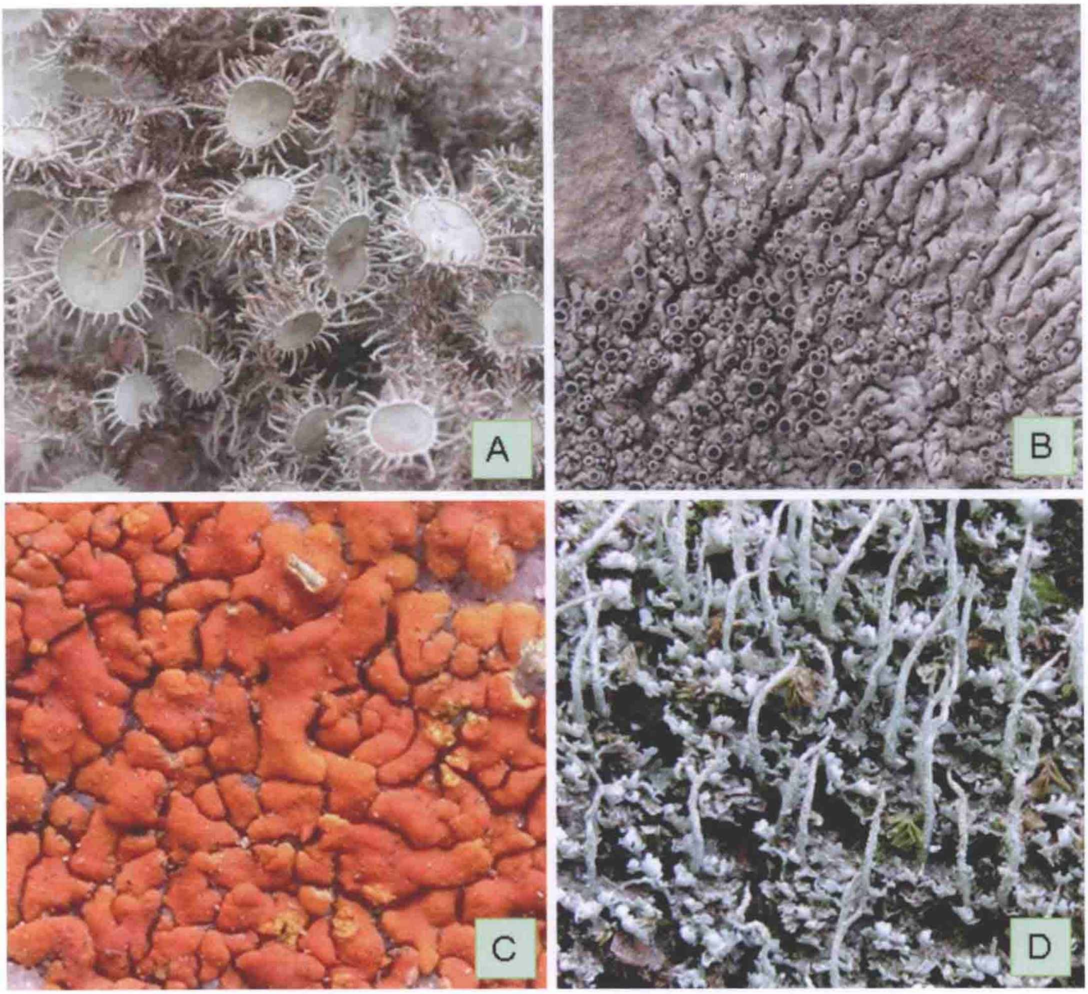

Fig. 1.2 External morphology of the lichen thallus can be categorised into (**a**) fruticose, (**b**) foliose, (**c**) crustose and (**d**) dimorphic growth forms

tufted cushions termed as subfruticose are formed. In some species of *Caloplaca* and *Lecanora*, a thallus becomes radially striated with marginal partially raised lobes termed as lobate thallus.

The foliose or leafy thallus of lichens is typically flattened, dorsiventral, spreading and expanding horizontally outwards and usually attached to the substratum by rhizines arising from the lower surface. Foliose lichens develop a great range of thallus size and diversity.

Lacinate lichens are typical foliose lichens. They are lobate and vary considerably in size, which may be gelatinous–homoiomerous (e.g. *Collema*, *Leptogium*) or heteromerous. The lobes may be radially arranged (*Parmelia*) or overlapping like tiles on a roof (*Peltigera*). Sometimes thallus lobes can become inflated, having a hollow medullary centre (*Menegazzia* species). These foliose lichens are cosmopolitan in distribution.

Umbilicate foliose lichens have circular thalli, consisting either of one single, unbranched lobe or multilobate thalli with limited branching patterns, attached to the substrate by a central umbilicus from lower surface.

An ecologically interesting group of foliose lichens are vagrant lichens such as *Xanthomaculina convolute*, which do not remain adhered to the substratum and have hygroscopic movement.

In dry conditions, the thalli roll up and expose lower cortices. When they take up water, thalli unroll and expose their upper surface to the sunlight. In rolled condition they can be blown with the wind to longer distances.

Fruticose type of lichen is either erect or pendent shrubby growth attached to the substratum at the base by basal disc or holdfast (formed by mycobiont hyphae). Some groups have dorsiventrally arranged thalli (*Sphaerophorus melanocarpus*, *Evernia prunastri*) but majority possess radial symmetric thalli (*Usnea* species and *Ramalina* species).

Genera like *Baeomyces* or *Cladonia* develop a twofold, dimorphic thallus that is differentiated into a fruticose thallus verticalis and a crustose–squamulose to foliose thallus horizontalis.

Another peculiar type of anatomy is that of the thread-like growing genus *Usnea*; *Usnea longissima* is the world's longest lichen, which has a strong central strand of periclinally arranged, conglutinated hyphae that provide mechanical strength along the longitudinal axis.

Highly branched fruticose lichens have a high surface to volume ratio that results in more rapid drying and wetting pattern compared with lichens having lower surface to volume ratio. This phenomenon seems to be the main reason for attributing high sensitivity to this class of lichens towards slight change in the microenvironment. Fruticose growth forms can preferentially occur either in very wet, humid climates and in the dry urban climates its distribution is restricted.

Among the different growth forms of lichens in the evolutionary series, leprose are considered pioneers followed by crustose, placodioid, squamulose and foliose, dimorphic and fruticose being the latest. Leprose, crustose, some placodioid and squamulose lichens are called microlichens as they are smaller in size and mostly require a compound microscope for identification. Foliose, fruticose and dimorphic lichens on the other hand are called macrolichens. Macrolichens have a comparatively larger thallus and a hand lens and stereozoom microscope are sufficient for identification.

1.2.2 Anatomical Organisation of Algal and Hyphal Layer

1.2.2.1 Homoiomerous and Heteromerous (Stratified) Thallus

In homoiomerous thalli mycobiont and photobiont are evenly distributed, while in majority of lichens including many crustose species, internally stratified (heteromerous) thalli are found. The main subdivisions are into upper cortex, photobiont layer, medulla and lower cortex. These layers may include various tissue types, and their terminology follows the general mycological literature. Pseudoparenchymatous and/or prosoplectenchymatous tissue types are present where hyphae are conglutinated to the extent that single hyphae are indistinguishable.

1.2.2.2 Cortex, Epicortex and Epinecral Layer

In most of the lichens, the algal layer is covered by a cortical layer ranging from a few microns to several hundred microns. In many dark lichens, pigmentation (which is due to secondary metabolites' UV protective nature) is confined to fungal cell walls of cortical hyphae (Esslinger 1977; Timdal 1991) or the epinecral layer. In gelatinous lichens the secondary metabolites are primarily confined to the outer wall layers of the mycobiont (Büdel 1990). Pseudoparenchymatous or a prosoplectenchymatous fungal tissue mainly forms the cortex in foliose and fruticose lichens. Usually living or dead photobiont cells are completely excluded from the cortex, but in the so-called phenocortex collapsed photobiont cells are included (e.g. *Lecanora muralis*). In Parmeliaceae some species have a 0.6–1 mm thick epicortex, which is a noncellular layer secreted by the cortical hyphae. This epicortex can have pores, as in *Parmelina*, or have no pores, as in *Cetraria*. In a broad range of foliose to crustose lichens, an epinecral layer of variable thickness is often developed which is composed of dead, collapsed and often gelatinised hyphae and photobiont cells. Thalli often have a whitish, flour-like surface covering, the so-called pruina that consists primarily of superficial deposits, of which calcium oxalate is the most common as in *Dirinaria applanata*. The amount of calcium oxalate is probably dependent on ecological parameters, such as calcium content of the substrate and the aridity of the microhabitat (Syers et al. 1964).

Functions of the upper cortex and/or its pruina include mechanical protection, modification of energy budgets, antiherbivore defence and protection of the photobiont against excessive light (Büdel 1987). Light- and shade-adapted thalli of several species differ considerably in the anatomical organisation of their upper cortical strata (e.g. *Peltigera rufescens*). In a nearby fully sun-exposed habitat, the thickness of the cortex is reduced, but a thick, epinecral layer with numerous air spaces is formed giving the thallus a greyish-white surface due to a high percentage of light reflection (Dietz et al. 2000). This cortical organisation results in decreased transmission of incident light by 40 % in the sun-adapted thallus measured at the upper boundary of the algal layer. Epinecral layers of *Peltula* species are also known to contain airspaces that may also act as CO_2 diffusion paths under supersaturated conditions (Büdel and Lange 1991).

1.2.2.3 Photobiont Layer and Medulla

In most foliose and fruticose thalli, the medullary layer occupies the major part of the internal thalline volume. Usually it consists of long-celled, loosely interwoven hyphae forming a cottony layer with high intercellular spaces. The upper part of the medulla forms the photobiont layer. In many lichens, the hyphae of the photobiont layer are anticlinally arranged and may sometimes form short or globose cells. The hyphal cell walls of the algal and medullary layer are often encrusted with crystalline secondary products which make medullary hyphae hydrophobic (Honegger 1991).

1.2.2.4 Lower Cortex

In some foliose lichens such as *Heterodermia*, the medulla directly forms the outer, lower layer of the thallus. However, typical foliose lichens of the Parmeliaceae and many other groups have a well-developed lower cortex. As is the case with the upper cortex, it is either formed by pseudoparenchymatous or a prosoplectenchymatous tissue. But unlike the upper cortex, the lower cortex is often strongly pigmented. Its ability to absorb water directly is well documented. Only low water conductance has been found thus far. However, it may play a major role in retaining extrathalline, capillary water (Jahns 1984).

1.2.2.5 Attachment Organs and Appendages

In order to provide strong hold of the substratum for lichenisation, lichen develops a variety of attachment organs from the lower cortex and also occasionally from the thallus margin or the upper cortex to establish tight contacts to the substrate.

In foliose lichens attachment is mainly by simple to richly branched rhizines, mostly consisting of strongly conglutinated prosoplectenchymatous hyphae. Umbilicate lichens as well as *Usnea* and similarly structured fruticose lichens are attached to the substrate with a holdfast, from which hyphae may slightly penetrate into the substrate. Deeply penetrating rhizine strands are found in some squamulose, crustose or fruticose lichens growing in rock fissures, over loose sand.

In crustose lichens a prosoplectenchymatous prothallus is often formed around and below the lichenised thallus. It establishes contact with the substrate from where bundles of hyphae penetrate among soil particles. Members of various growth forms produce a loose web of deeply penetrating hyphae, growing outwards from the noncorticate lower surface of the thalli.

Cilia are fibrillar outgrowths from the margins or from the upper surface of the thallus. A velvety tomentum consisting of densely arranged short, hair-like hyphae may be formed on the upper or lower cortex. Tomentose surfaces are mainly reported from broad-lobed genera such as *Pseudocyphellaria*, *Lobaria*, and *Sticta* and few *Peltigera* species.

1.2.2.6 Cyphellae and Pseudocyphellae

Upper or lower cortical layers often bear regularly arranged pores or cracks. Pseudocyphellae, as found on the upper cortex of *Parmelia sulcata* or on the lower side of *Pseudocyphellaria*, are pores through the cortex with loosely packed medullary hyphae occurring to the interior. Cyphellae are bigger and anatomically more complex than pseudocyphellae and are only known from the genus *Sticta*. In the interior portions of the cyphellae, hyphae form conglutinated, globular terminal cells, and this is the main difference from pseudocyphellae.

Pseudocyphellae and young cyphellae are the regions in the cortex having lower gas diffusion resistance. The pseudocyphellae and cyphellae are hydrophobic structures of lichens and may act as pathways for gas diffusion into thalli only when there is drying of the thallus (Lange et al. 1993).

1.2.2.7 Cephalodia (Photosymbiodemes)

Representatives of the foliose Peltigerales with green algae as the primary photobiont, and members of such genera as *Stereocaulon*, *Chaenotheca*, and *Placopsis* usually possess an additional cyanobacterial photobiont. In *Solorina*, the secondary photobiont may be formed as a second photobiont layer underneath the green-algal layer, but usually it is restricted to minute to several millimetres wide cephalodia. Cephalodial morphology is often characteristic on a species level and ranges from internal verrucae to external warty, globose, squamulose or shrubby structures on the upper or lower thallus surfaces. Cephalodial morphology usually differs completely from the green-algal thallus, and this emphasises the potential morphogenetical influence of the photobiont on the growth form of the mycobiont–photobiont association. Because many cyanobacterial photobionts are nitrogen-fixing, these lichens may considerably benefit from cephalodia, especially in extremely oligotrophic habitats.

1.2.2.8 Differentiating Lichens from Other Groups of Plants

Along with lichens, non-lichenised fungi, algae, moss, liverworts (bryophytes) are the plants which grow on rocks, bark and soil and may create confusion for beginners in the field. However, lichens can be easily be differentiated from these group of plants as lichens are never green as algae, liverworts and mosses. Foliose lichens growing in moist places or in wet condition may look greener but have thick, leathery thallus, while in contrast liverworts have non-leathery and slimy thallus. The dimorphic forms of lichens such as *Cladonia* may be confused with the leaf liverworts and mosses in the field. Leafy liverworts and mosses have dense small leaf-like structures throughout the central axis of the plant, while in the case of dimorphic lichens, the squamules of semicircular shape usually present at the base of the central axis or sparse throughout. Dried algal mat on rocks and bark may look like lichens, but it may be checked by spraying some water on these mats as upon hydration algae regain its colour and texture which may be distinguished clearly.

The non-lichenised fungi are the most confusing ones with crustose lichens in the field. Such fungus usually forms patches with loosely woven hyphae, while lichens form smooth, perfect thallus which can be distinguished under the microscope. The fungus are usually whitish in colour and lichens are usually greyish, off-white, but sometimes yellowish, yellowish-green or bright yellow or yellow-orange in colour which is attributed to the presence of lichen substances in the cortex of the thallus as in the case of *Xanthoria parietina* (orange) due to the presence of parietin. The greenish colour of the thallus is mainly due to the presence of algal cells in the thallus. The lichen thallus usually bears cup-shaped structures called apothecia or bulged, globular structures called perithecia. Some crustose lichens belonging to family Graphidaceae bear worm-like structures, lerielle, which are modified apothecia (Fig. 1.3). Asexually reproducing fruiting bodies present on the thallus surface may be finger-like projections called isidia or granular, powder-like structure called soredia (Fig. 1.4). While collecting lichens, it is necessary to look for such structures with the help of the hand lens. When a lichen thallus does not have any such structures, it makes it difficult to differentiate it from fungus.

In any case it is observed that a beginner usually collects fungus and other plants in place of lichens. Usually fungus of various colour (mostly appearing like mushrooms) are confused for lichens and collected by beginners. Such specimens can be identified by taking a thin section of the thallus and studying them under a

Fig. 1.3 Sexually reproducing fruiting bodies, (**a**) apothecia, (**b**) perithecia and (**c**) lerielle, which are exclusively produced by fungal partner

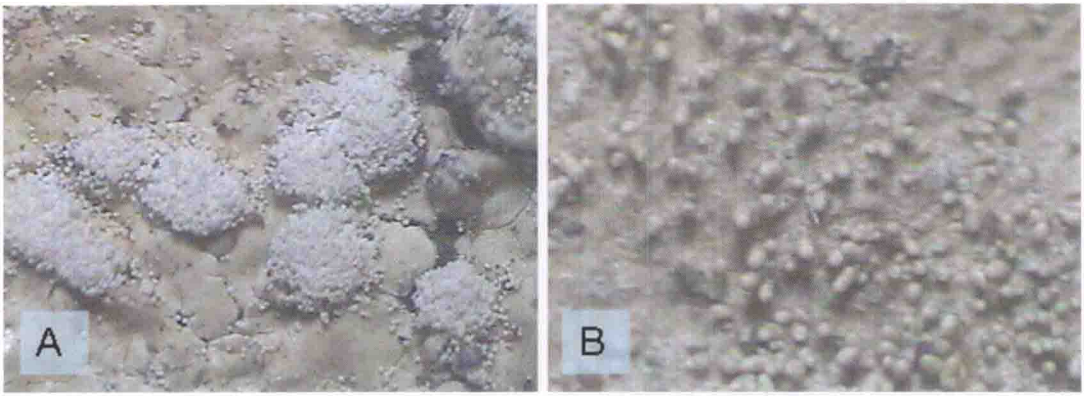

Fig. 1.4 Asexually reproducing bodies. (**a**) Soredia. (**b**) Isidia containing both fungal hyphae and algal cells

microscope. If the section contains both fungal tissue and algal cells, then the specimen is lichen; otherwise, it may be some other plant group. In India basidiolichens (looking like mushrooms) are rare or absent (Nayaka 2011).

1.3 Development and Establishment

Development and establishment of lichen thallus, termed as morphogenesis, involves the process of lichenisation (spore/propagule dispersal), acquisition of compatible partners, competition and growth of lichen thallus resulting in its establishment on the substratum.

Lichen-forming fungi express their symbiotic phenotype (produce thalli with species-specific features) only in association with a compatible photobiont. About 85 % of lichen mycobionts are symbiotic with green algae, about 10 % with cyanobacteria ('blue-green algae') and about 3–4 %, the so-called cephalodiate species, simultaneously with both green algae and cyanobacteria (Tschermak-Woess 1988; Peršoh 2004).

Majority of lichen-forming fungi reproduce sexually and thus have to re-establish the symbiotic state at each reproductive cycle. Compatible photobiont cells are not normally dispersed together with ascospores; exceptions are found in a few species of Verrucariales with hymenial photobionts (e.g. *Endocarpon pusillum*). Many tropical lichen-forming fungi associate with green-algal taxa that are widespread and common in the free-living state (e.g. *Cephaleuros*, *Phycopeltis*, *Trentepohlia*) (Honegger 2008).

1.3.1 Colonisation

The ability of lichens as primary colonisers on barren rock is evident by distribution of *Rhizocarpon geographicum* on rocks and moraines exposed by glacier retreat phenomenon and is used worldwide in lichenometric studies to study paleoclimatic condition. Resistance to drought condition and extreme temperatures and presence of lichen substances enable lichens to colonise on rock surface.

Colonisation on bark surface is governed by water relation, pH, light and nutrient status which determine lichen diversity on the bark surface, while on soil surface colonisation by lichens is limited by their poor competitive abilities compared to the higher plants, and because of their small structures, they are more prone to trampling and trekking activities. Most of the soil-inhabiting lichens fix atmospheric nitrogen like species of *Stereocaulon*, *Peltigera* and *Collema* due to the presence of cyanobacteria *Nostoc*. The ability to accumulate nutrients from rain or runoff (in which nutrients are present in small quantities) enables them to colonise on varied substratum (Brodo 1973).

1.3.2 Growth

Growth rate has a pronounced effect on colonisation and competitive ability of the new thalli resulting in establishment of the thalli. The balance between growth rate and reproductive activity varies with environmental changes (Seaward 1976). Growth varies over the geographical range of a species, and the size ratio of equal-aged thalli of two species may differ in different regions. Rainfall is important for many species as in *Xanthoria elegans* growth rate correlated linearly with the annual rainfall (Beschel 1961).

In species *Parmelia caperata* occurring in colder climate shows frost damage, while alternations in regimes of incident light and humidity are essential for growth of *Parmelia sulcata* and *Hypogymnia physodes*.

Nutrient enrichment also affects growth rate; moderate levels of nutrients are found to favour growth, while excessive levels of nutrients (pollutants) result in slow growth rate depending on the species.

Lichens colonising on non-vertical surfaces of the substratum show good growth rate in comparison to the vertical surfaced substratum, as non-vertical surface retains moisture content for longer periods of time.

Growth rate also depends on the age of the thalli. The life cycle of fruticose lichen *Cladonia* has been divided into three periods: generation, renovation and decline. In generation, phase growth is continuous (5–25 years); in the second podetia decay from below, while growth continues at the tips (80–100 years); and in the final period (20 years) decay predominates. But in the case of crustose lichen especially *Rhizocarpon geographicum*, growth rate is approximately constant with time and this feature is exploited in lichenometric studies. Growth rate affects biomass, i.e. productivity and carbon assimilation potential of the species (Seaward 1976).

1.3.3 Succession

Replacement of one growth form or community structure with another in the course of colonisation and establishment refers to succession. Succession, in general, begins with crustose continuing with foliose and concluding with fruticose. But in the case of epiphytic lichens, foliose lichens may colonise first on tree bases and on twigs (Kalgutkar and Bird 1969).

In successions on soil, colonising species vary; it has been observed that after forest fires *Lecidea* species colonises first; same is the case in the Arctic where *Stereocaulon*, *Cetraria* and *Peltigera* are primary successors. Many successions, especially in mesic or humid environments, do not involve lichens and in xeric environments, mosses compete with lichens by colonising on similar niches. In several studies conducted involving rock substratum like granite, rock ledges and sloping cliffs, mosses are found to be the primary coloniser (Topham 1977).

The prominent role of lichens in succession indicates their contribution to community structure. Lichens increase the intrabiotic fraction of inorganic nutrients, as corticolous species trap nutrients from the phorophytes and from rainwater, while saxicolous species mobilise and extract mineral nutrients from substrates, rainwater and airborne dust.

In the process of succession, lichen diversity increases as do the vascular plants. Species diversity is found to increase in early stages of succession until a closed community is formed (Degelius 1964).