REVIEW OF LITERATURE

Herbivore dung is a partially digested, highly complex, organic matter. It is composed of the remains of ingested vegetation in the form of waste products, along with microbial population residing in the herbivore rumen. The dung contains nitrogen which is as high as 4%, a three to four-fold increase over the ingested material (Bell, 1983). The fungi which germinate, grow and sporulate on dung are termed 'coprophilous' (Ingold, 1953, 1971). On dung, especially after voided off, the nitrogenous compounds influence the growth and fruiting of coprophilous fungi (Bell, 1983). Herbivore dung generally has a higher pH, usually above 6.5. This has some selective effect on the fungi appearing on dung. The coprophilous fungi possess a wide variety of characteristics that assist their survival and reproduction on nutrient rich dung substrate. Although fungi are reported from all types of dung, herbivore dung is considered as rich repository of coprophilous mycota (Webster, 1983). In the decomposition of carnivore and omnivorous dung, bacteria play an important role (Bell, 1983).

Coprophilous Fungi

Dung inhabiting fungi are diverse. Members of all classes of the Kingdom Fungi, from Zygomycota, Ascomycota (and their anamorphs) to Basidiomycota, appear on herbivore dung (Richardson, 2001; Wicklow, 1981; Furuya and Udagawa, 1972; Valdoserra and Guarro, 1992). Coprophilous fungi play an important role in the decomposition and mineralization of herbivore dung (Angel and Wicklow, 1975). Besides, the dung provides a nutritional base for coprophilous and mycophagous arthropods (Malan and Gandini, 1966). Fungi also influence the microbial
composition and activity in the rumen and affect the digestive efficiencies of herbivores (Brewer and Taylor, 1969; Brewer et al., 1972).

First reference of a coprophilous fungus is known, in the form of record of a *Pilobolus* on horse dung in 'Historia Plantarum', by Johannes Bannister from Virginia in 1688. The same fungus was later referred and figured maas 'Fungus virginianus' on horse dung from London (Petiver, 1696). The formal name, 'Pilobolus crystallinus', was provided to the fungus much later (Tode, 1784). Thus, the knowledge on fungal association with dung was known to the botanists since the 17th century.

Systematic work on coprophilous fungi however began only towards the end of the 19th century. Several well known mycologists of the latter half of 19th and early 20th century took interest in this group of fungi. These included Zopf (1874, 1880, 1881) and in Germany; Crouan and Crouan (1857, 1858, 1867), Bainier (1882, 1909), Van Tieghem, 1875, 1876; Van Tieghem and Le Monnnier, 1873) in France; Saccardo (1877a,b; 1874-1880) and Cesati and De Notaris (1863) in Italy; Chalckowsky (1892) and Schroeter (1888, 1894) in Poland; Oudemans (1882) in Holland; Hansen (1876) in Denmark; Sterbäck (1889) in Sweden; Coemans (1861-1862), Marchal (1884a, b, c, 1885, 1889, 1891, 1894, 1895), Bommer and Rousseau (1884, 1886, 1887, 1890) and Monton (1886) in Belgium; Heimerl (1889) and Zukal (1886a, b, 1887, 1889, 1890) in Austria, Karsten (1870, 1885) in Finland; Woronin (1870) in Russia; Cooke (1864); Phillips and Plowright (1874, 1874, 1881, 1885), Massee and Salmon (1901, 1902) in England; Speggazini (1871, 1921) in South America; Griffiths (1901) and Griffiths and Seaver (1910) in North America.

The work of these pioneers, and those followed them subsequently, have enriched our knowledge not only on the types of fungi that occur on herbivore dung but also on the
physiology, spore discharge, germination and dissemination, ecology and cytology of these fungi.

**Life cycle of coprophilous fungi**

The germination, growth, and sporulation of a coprophilous fungus follow a definite cycle on freshly deposited dung after the fungal spore adhered on the herbage are apparently engulfed by the herbivore. The spore while moving, along with herbage, in the gut of the animal is treated by the acidic digestive juices present within. This mechanical and chemical digestion process benefited the germination of spores to many folds (Bell, 1983; Furuya, 1990; Larsen, 1971).

While grazing, herbivore animals ingest a variety of fungal spores, along with feed, which include both coprophilous and non-coprophilous. The slightly high temperature and a cocktail of gastric juices present in the gut of the animals evidently destroy most of non-coprophilous species, whereas the coprophilous fungi are protected due to certain adaptive features. Once the dung is voided off, viable fungal spores germinate, grow, fruit and discharge their spores onto surrounding herbage where by good fortune they are eaten by herbivores and thus the cycle continues. Schematic presentation of the cycle is given in Fig. 2.1 (Bell, 1983).

**Adaptations of coprophilous fungi**

**Phototropism and violent spore-discharge:** Although taxonomically quite unrelated, the coprophilous fungi in general show a number of adaptations to their habitat. Phototropism is the most common phenomenon demonstrated by the spore-bearing structures (Ingold, 1953). In most coprophilous fungi, the spore-producing structures such as the sporangiospore in Zygomycetes, conidiophores of hyphomycetes, asci and basidia in higher fungi, all get phototropically oriented towards source of light and
Fig. 2.1 Life Cycle of Coprophilous Fungi

Fig. 2.2 Adaptations acquired by fungi for coprophilous habitat

Violent spore discharge: Adhesive projectiles: Mucilaginous spores:

Resistance to digestive enzymes and acids while in animal gut:
eject the spores to relatively long distances (Ingold, 1971). This is often supplemented by a mechanism of violent spore discharge, so as to get the spores dispersed towards the light, away from their staling substratum and onto the surrounding herbage (Richardson, 2008). The phenomenon of violent spore discharge is best demonstrated in *Pilobolus* (Webster, 1970). During spore dispersal, the mature sporangium is thrown more than 2m by dehiscence of mucilage found at the junction of columella with sporangium, by rupture of the subsporangial vesicle (Webster, 1983; Dix and Webster, 1995). The spore projectile often consists of many spores, sometimes the entire contents of asci or sporangia. The larger the projectile is the less limiting to dispersal. The projectile is often mucilaginous so that once impacted on an aerial substrate such as leaf blade or branches, the spore adheres there rather than falling to the soil. The spore walls are often pigmented and the protoplasm gets protected from excessive exposure to sunlight (Ingold, 1971). The spores are ingested with the herbage and survive passage through the alimentary canal of the animal. Majority of coprophilous fungi, but not all, require such treatment before they germinate (Webster, 1983). These are intricate ecological adaptations acquired by the dung inhabiting fungi, with which, the fungal spore is not only thrown high in air so as to enable the latter to fall on vegetation but also, in the next feeding of herbivores, the dispersed spores along with forage get into the stomach of animals (Dix and Webster, 1995).

Other than violent discharge, there are additional modes of spore dispersal which takes place by rain splash, insects, arthropods and even mammals. Amongst these, insects (Stevenson and Dindal, 1987) and mites (Malloch and Blackwell, 1992) play important role in the dispersal of fungal spores. Possession of modified appendages, in some cleistothecial ascomycetes, enables the attachment of fruiting
bodies to the fur of mammals, especially carnivorous mammals, and thereby dispersal of fungi to distant locations (Wicklow, 1981).

**Adhesive projectiles:** Coprophilous fungi have been well studied with respect to appendaged spores (Ingold, 1971; Jones, 1994, 1995; Lundqvist, 1972). Usually, ascospores are armoured with gelatinous appendages or sheaths, as extension of their spores. These projectiles enable attachment of spores to the herbage without being washed off by wind or water and losing viability and hence, the probability of being consumed by the grazing animals is large (Richardson, 2008; Dix and Webster, 1995). The elaboration or fragmentation of cell wall leads to the formation of primary appendages, whereas secondary appendages are formed by exudation through one or more pores in the spore wall (Read and Beckett, 1996). In *Zygopleurage zygospora*, each ascospore consists of two pigmented cells, linked by a hyaline intercalary cell and this can be seen within the ascus (Bell, 1983).

**Pigmentation in spore-wall:** It was an observation that the spore wall or exospores are often pigmented and provide protection against UV exposure while on discharge (Richardson, 2008; Krug et al., 2004).

**Mucilaginous spores:** Most of coprophilous ascomycetes have ascospores with brief or elaborate mucilaginous appendages which aid effective attachment of the spores to the substrata (Bell, 1983; 2005; Lorenzo and Havrylenko, 2001). The gelatinous ascospores of coprophilous fungi, as in species of *Sordaria* and *Podospora*, favour adherence of the propagules to adjacent vegetation. These, when consumed by herbivores along with the vegetation, the normal coprophilous fungal cycle gets continued (Caretta, 1998). In *Saccobolus citrinus*, the ascospores stick together to produce a contiguous projectile which enable the spore column to get fired to some
distance from the ascoma (Brummelen, 1967; Ingold, 1971). The gelatinous ascospore sheath swells in water, increasing in diameter and effecting greater adhesion to the surface (Jones, 2006). Spores of coprophilous fungi, as in Graphium sp. and Mucor hiemalis, are mucilaginous and these stick upon the vegetation for long periods without being washed off or losing viability even when the mucilage gets dried. These spores are apparently dispersed by arthropods or mites which are specialized inhabitants on dung (Kendrick, 1992).

Resistance to digestive enzymes and acids while in animal gut: Passage of spores through the gut of an animal is very often necessary to facilitate germination of spores of coprophilous fungi (Richardson, 2008). The passage through the animal gut leads to stimulation to germinate, leading to the vegetative stage followed by sporulation. Spores are triggered to germinate following exposure to the chemical and physical environment of the animal gut (Kuthubutheen and Webster, 1986). The fungi which have survived digestion and appear on dung have been termed ‘true coprophilous’ (Larsen, 1971).

The vegetation generally possesses certain amount of other fungal spores from the vicinity, which in turn is taken up by the grazing herbivores along with the spores of coprophilous fungi. However, the harsh conditions in the alimentary canal, to which these spores are subjected, provide no prospect of survival for fungi other than coprophilous (Richardson, 2008). These adaptations are diagrammatically represented in Fig. 2.2.

Significance of growth factors for coprophilous fungi: The species of Pilobolus require a growth factor, coprogen, present in the herbivore dung for growth and fruiting. The coprogen, an organo-iron compound, a precursor of protoporphyrinogen,
is apparently produced by various fungi and bacteria, in dung (Webster, 1983; Dix and Webster, 1995). Besides, fatty acids are present in herbivore dung and Pilobolus makes better growth on these as carbon source rather than it does on simple pentoses and hexoses.

Ecological succession

Among the ecological concepts, succession is well studied (Richardson, 2001). Although the fungal succession has been studied on many substrates (Dix and Webster, 1995), little is known about the mechanism which drives this phenomenon. The difference between succession in herbivore dung and other substrate such as plant litter is that decomposition of plant remains, viz. deciduous tree leaves, pine needles and dry grasses lack the initial Phycomycete phase. The low content of easily available sugar and nitrogen in plant litter led to the absence of mucoraceous members (Fryar, 2002).

Ecological succession is also the cause of sequential change in community composition (Morin, 1999). Various mechanisms such as facilitation, tolerance and inhibition drive the compositional change (Connell and Slatyer, 1977). Studies of fungal succession carried out on various substrates show certain uniformity in occurrence of fungi with time, i.e. early, intermediate or late colonisers. The time taken for fungal succession varied with each study and the examined substratum (Eaton and Iones, 1971a; Sivichai et al., 2000; Tsui et al., 2000). The appearance of fungi on the substrate has been characterised as common, infrequent and rare, depending on the percentage frequency of occurrence (Jones, 1963; 1999; Cai et al., 2002; Kane et al., 2002; Sivichai et al., 2000). Amongst all factors, succession of
fungi is more affected by temperature, light, and humidity (Wicklow, 1992; Kuthubutheen and Webster, 1986; Wicklow and Moore, 1974; Morinaga et al., 1980).

**Fungal succession**

Fungal succession is defined as the “sequential occupation of the same site by thalli (usually mycelia) of different fungi or of different associations of fungi” (Rayner and Todd, 1979). The fungal replacement is caused by communities of mycelia, both in space and time (Frankland, 1998). Fungal succession occurs at two levels: micro- and macro- (Suzuki, 2002). The association of different kinds of fungi with a plant community leads to the formation of macro-scale. Whereas, the fungal succession associated with plant succession at the patch level is micro-scale (Swift, 1982; Suzuki, 2002). Since the fungal growth is entirely dependent on plants’ substrata, the succession of fungi is related to plant succession at different levels (Prentice, 1992). Theoretically, the saprobic fungal numbers reach zero value, once the substrate is exhausted. However, this value is hardly attained during fungal succession (Frankland, 1992). The pattern of succession is schematically presented with Fig. 2.3.

**Fungal succession on herbivore dung**

Freshly voided herbivore dung, on incubation in a damp chamber, showcases a host of fruiting fungi in succession, with the Phycomycete sporangiophores such as those of species of *Mucor*, *Pilaria* and *Pilobolus* dominating the first phase. This is followed by apothecial Ascomycetes including genera such as *Ascobolus*, *Coprobia* and *Rhparobius*, after 6-7 days. By 9-10 days the perithecial asscomycetes, viz., *Sordaria*, *Podospora* and *Chaetomium*, appear. These persist for up to 3-4 weeks and
Fig. 2.3 Spectrum of fungi appearing in succession on incubated herbivore dung

<table>
<thead>
<tr>
<th>Zygomycetes</th>
<th>1-4 DAYS</th>
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<tbody>
<tr>
<td>Ascomycetes</td>
<td>4-8 DAYS</td>
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<tr>
<td>Hyphomycetes</td>
<td>8-12 DAYS</td>
</tr>
<tr>
<td>Basidiomycetes</td>
<td>8-12 DAYS</td>
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finally leading to the appearance of basidiocarps of *Coprinus, Stropharia* and *Panaeolus* (Webster, 1983).

The exact succession pattern, timing and species list varies with the dung. The nutrient utility in dung is often considered as the reason for fungal succession (Webster, 1971). The sugars, starches and proteins are chiefly utilized by the mucorales, also known as sugar fungi. Ascomycetes lead the consumption of the cellulose and the basidiomycetes exhaust both cellulose and lignin present in the substrate (Webster, 1983). The observation of succession sequence is based on the appearance of reproductive structures, (sporangiophores, ascocarps or basidiocarps), while the mycelial development sequence may not be the same. It is demonstrated that in the absence of any pre-treatment leads to the failure of a few coprophilous fungi to germinate, even on fresh dung. Whereas, when the spores are treated with pancreatin for 5 h at 37°C, led to their successful germination within 6 h (Dix and Webster, 1995). Apart from this, succession is also explained based on the minimum time required to produce the fungal fruiting structures, when grown on sterile dung or standard culture medium. For example, *Mucor hiemalis* takes 2-3 days, *Sordaria fimicola* 9-10 days and *Coprinus heptemerus* 7-13 days in culture (Webster, 1970). Thus, the minimum time for fruiting provides an explanation for the succession. From an ecological stand-point, succession is influenced by competition (Krug et al., 2004). Basidiomycetes are not necessarily the last group of fungi appearing in the successional sequence. Certain ascomycete genera, notably *Coprots*, *Podospora* and certain Gymnoascaceae develop theirs fruit-bodies after 35-50 days of incubation or plating (Bell, 1983).
Competition among fungi in herbivore dung

Being a nutrient rich substrate, competition amongst the resident micro-organisms exists in the dung. Apparently this has little effect on the actual time of appearance of fruit bodies (Webster, 1970). The duration of fungal fruiting on dung varies based on the various on-going activities in the substrate, viz., competition for nutrients, antibiotics production or antagonism among the existing micro-flora (Bell, 1983). The non-fungal competitors such as, arthropods and worms also influence the growth and survival of certain fungi. The diversity of mycobiota is influenced by the fragmentation of dung caused by these organisms. Certain arthropods and fly-larvae act as predators on certain fungi (Helsel and Wicklow, 1979). These activities encourage the growth of rarer fungal species, by reducing fungal competitors (Wicklow, 1981).

Factors influencing succession

Antagonism: Certain fungi are antagonistic in nature and suppress the fruiting of other fungi and this phenomenon is widespread among coprophilous fungi (Harper and Webster, 1964) Coprophilous basidiomycete such as *Coprinus* spp. are antagonistic to species of *Pilaria* and *Ascobolus* (Ikediugwu and Webster, 1970a, b). The phenomenon of antagonism is observed only after the hyphal interference. The hyphae of *Coprinus* when come in contact with cells of *Ascobolus*, it leads to cell vacuation, damage to permeability and loss of turgor. This might be the reason for dominance of Basidiomycetes, especially *Coprinus*, at the later stage of succession. Certain fungi such as *Chaetomium* sp., *Coniochaeta* sp. are equipped with perithecial hairs which perform as defence mechanisms (Wicklow, 1981).
Synergistic effects: Synergistic interactions lead to better fruiting in *Ascobolus furfuraceus*, in the presence of bacteria. Similarly, the release of ammonia by *Mucor plumbeus* gives an opportunity for *Pilobolus kleinii* to fruit better. It is thought that combination and interaction of all these factors determine the succession (Dix and Webster, 1995).

Dependency on the surroundings: To certain extent, the mycobiota appears to be specialized on particular kinds of dung. Some fungi appear on dung of certain animals. It was observed that *Perichaena corticalis* var. *liceoides* prefers the dung from domestic animals, whereas *Stemonitis fusca* prefers those from forest animals (Eliasson and Lundquist, 1979). The food preferences and habits and the type of digestive system of the different herbivorous animals, *viz.* *Connochaetes taurinus* (Blue wildebeest), *Equus burchelli* (Burchell’s zebra), *Loxodonta africana* (African elephant) and *Giraffa camelopardalis* (Giraffe), had an effect on the coprophilous fungal species composition and diversity (Ebersohn and Eicker, 1991).

Optimal conditions for growth of coprophilous fungi: The pre-requisite for coprophilous fungi to grow is a narrow range of conditions. Diverse groups of fungi are recovered when the dung was subjected to various temporal conditions. Differences in humidity, temperature, decomposition stage and the pH of the substratum mattered. Majority of the coprophilous fungi find a pH of 7 optimal for growth (Krug et al., 2004). Some fungal taxa are ephemeral and observed only on fresh dung (Krug, 2004).
Effect of seasonal variation on the diversity of coprophilous fungi:

Composition of mycobiota is influenced by the environmental factors to which the dung is subjected. Under cold conditions, certain species of *Thelebolus* and *Preussia* are dominant on leporid dung, whereas during the warmer summer months, the above fungi are replaced by other dominant species such as *Sporormia* (Wicklow and Moore, 1974).

Species-substrate relationship

According to a study carried out in Egypt by Abdel-Azeem (2005), species richness varied tremendously from one type of dung to another. While diverse fungal species were observed on the donkey dung, the lowest value was seen on goat dung. A restricted occurrence of certain species was observed on certain types of dung, e.g. *Thielavia* appeared only on camel dung. Certain species such as *Chaetomium globosum*, *Podospora appendiculata* and *Saccobolus glaber* were present on all types of dung. In some studies, definite species-substrate relationship has been observed (Parker, 1979; Angel and Wicklow, 1975). The physical and chemical properties of the dung differed from animal to animal and consequently the colonization of fungi (Lundqvist, 1972; Richardson, 2001). Some coprophilous fungi have wide ecological adaptations and low preferences of particular herbivore dung (Richardson, 1972; Wicklow, 1975; Tisdall and Oades, 1982; Caretta et al., 1994). The fungi such as *Pilobolus crystallinus*, *Mucor* sp., *Kernia nitida*, *Mycoarachis inversa*, *Preussia isomera*, *Tripterospora erostrata*, *Arnium* sp., *Chaetomium cuniculorum*, *C. pulchellum*, *C. subspirale*, *Coniochaeta discospora*, *C. scatigena*, *Delitschia marchalii*, *D. patagonica*, *D. winteri*, *Hypocopra merdaria*, *Phomatospora hyalina*, *Podosordaria* sp., *P. anserina*, *P. decipiens*, *P. hyalopilosa*, *P. pectinata*, *P.
tetraspora, P. vesticola, Sordaria fimicola, S. macrospora, Sporormia fimaria, Sporormiella affinis, S. australis, S. cymatomaera, S. intermedia, S. lageniformis, S. longisporopsis, S. mimima, Trichodelitschia bispora, Zygopleurage zygospora, Ascobolus immerses, Coprotus disculus, C. glaucellus, C. sexdecimsporus, C. winteri, Iodophanus carneas, Lasiobolus ciliatus, Saccobolus globuliferellus, S. truncatus, Coprinus stercorarius, Psilocybe coprophia and Sclerodermataceae (sterile) were widely distributed on different kinds of herbivore faeces (Ahmed and Cain, 1972; Brummelen, 1967; Cain, 1934, 1956;).

Comparative study: Ruminant vs non-ruminant dung

In a comparative study carried out on occurrence of fungi in the faeces of larger herbivore ruminants (antelopes, buffalo, zebu) and non-ruminants (hippopotamus, zebra) in Kenya, found 15 of 17 fungal species on prong-horn and cattle faeces. Richardson (2006) attributed this higher number of species of fungi in herbivore animals for their ruminant nature of feeding habits.

Diversity and taxonomic studies

Most of hitherto works carried on coprophilous fungi were from Europe, North America and southern South America (Richardson, 2001; 2006; Eliason and Lundqvist, 1979). Recent studies were from Central and East Africa; Japan and some parts of Asia, New Zealand, and Venezuela (Krug et al., 2004). Majority of the coprophilous fungi are cosmopolitan in distribution. Certain fungi however are restricted to specific areas (Richardson, 2001). In most instances, however, estimates of frequency and species richness are correlated with collecting intensity, geographic origin, and the expertise and interest of the mycologists. Therefore, hitherto
statements on distribution of coprophilous fungi may not be absolutely correct (Krug et al., 2004).

Analysis of species richness was possible to some extend in localities such as caves occupied by porcupines and certain wood rats in North America and by hyrax in Africa, wherein the dung was deposited in layers or pushed to the entrance of the cave for several generations. Although many fungi were isolated by moist chamber incubation method (Amann et al., 1995), complete estimation of mycobiota was possible only by usage of PCR-RFLP (polymerase chain reaction–restriction-fragment-length polymorphism) using the ITS region of ribosomal DNA. The application of molecular techniques significantly increased the knowledge on fungal diversity (Viaud et al., 2000).

A number of studies have been carried out around the world, aiming at estimation of coprophilous fungal diversity. Cain (1934) recorded 112 taxa of coprophilous Sphaeriales from Ontario, Canada. From Central African Republic, 91 taxa were recovered (Khan and Krug, 1989). From 50 dung samples, 153 taxa were recovered from the zone 0-30° north and south of the equator. This figure substantially dropped, beyond 40° north or south. In contrast to this, 66 taxa of pyrenomycetes were recorded from New Zealand which supported latitudinal gradient (Bell, 1983).

Studies on coprophilous fungi were carried out in southern California and parts of Arizona and Mexico (Mueller et al., 2004). A five year study in Pakistan resulted in the compilation of 78 species belonging to 26 genera of fungi (Mirza et al., 1979). In Switzerland, 20 species belonging to 10 genera were encountered (Lendner, 1908). A number of studies have been carried out on zygomycetes fungi (Benjamin, 1958, 1959, 1960, 1961, 1962, 1963, 1965, 1966, 1979; Benjamin and Mehrotra,
1963; Benny, 1982; Humber, 1989;). Benjamin (1979) classified the Zygomycetes which was later emended by Humber (1989) and Cavalier-Smith (1998).

Attempt was made to isolate Myxomycetes from cattle dung samples. From 25 dung samples, 80 species belonging to 23 genera of Myxomycetes were recorded (Kowalski, 1969 a,b; Eliasson and Lundquist, 1979). Few of the coprophilous myxomycetes were recorded from Taiwan (Chung and Liu, 1996). Published records of Myxomycetes from dung of carnivorous and omnivorous vertebrates are however rare (Krug et al, 2004).

Abdel-Azeem (2005) examined dung samples of various animals, collected from different locations and incubated in moist chambers, for several weeks. From 3 types of dung, he reported 54 taxa of fungi, of which 26 were true ascosporic. Among these, 46 species were reported from donkey dung, followed by camel (37 spp.) and goat dung (32 spp.) In an earlier study, 12 ascosporic taxa were reported and these included both apothecial and perithecial (Bagy et al., 1986).

In a study carried out on coprophilous fungal communities on wild rabbit dung in Chile, during cold and warm seasons, in all 60 species belonging to 44 genera were isolated (Piontelli et al., 2006). These included Zygomycota (11.6%), Ascomycota (50%), associated mitosporic genera (36.8%) and Basidiomycota (1.6%). Several other workers have recovered a number of rare and new species from Chile (Lazo, 1979; Udagawa, 1980; Piontelli et al., 1981, 1997; Valdoserra and Guarro, 1988; 1994).

In Kenya, studies on coprophilous fungi were done on dung samples of antelope, buffalo, zebra and hippopotamus. A total of 143 fungi belonging to 40 genera and 59 species were isolated. These belonged to Ascomycetes (39%), Deuteromycetes (50.8%), Zygomycetes (8.5%) and Basidiomycete (1.7%). The
common species recovered were *Ascobolus immersus*, *Coprotus niveus*, *Iodophanus carneus*, *Lasiobolus lasioboloides*, *Podospora anserina*, *P. australis* and *Sporormiella minima*, whereas, *Kernia nitida*, *Saccobolus versicolor* and *Sordaria fimicola* were infrequent but interesting ascomycetes. *Sporormiella*, *Podospora*, *Iodophanus*, *Ascobolus* spp. were the most common ascomycetes. The highest number of different species was found in waterbuck faeces (17) followed by reedbuck (16), steenbok (15), impala and bushbuck (14), hippopotamus and zebu (131). On bushbuck, eland, buffalo, steenbok, zebra and dik-dik faeces collected in Savanna, the number of fungal species tended to be fewer (Caretta et al., 1998).

Many novel coprophilous species have been discovered. These included a new ascomycetous genus, *Pseudascozonus*, related to *Ascozonus* and *Thelebolus* of Pezizales (Brummelen, 1985). A novel pleoanamorphic coprophilous hyphomycete named *Basifimbria spinosa* characterized by sympodial conidiophores producing two intergrading types of successive blastoconidia, was described (Buffin and Hennebert, 1985).

Jeamjitt (2006) studied coprophilous hyphomycetes from Thailand. Dung samples of deer, barking deer, eld’s deer, elephant, guar, rabbit, camel, goat, horse, buffalo, cow, mouse and toad were examined. The study resulted with recovery of 406 isolates of fungi. *Nodulisporium gregarium*, *Oidiodendron griseum* and *Pithomyces karoo* were recorded for the first time from Thailand. Two strains of *Mucor* sp. were recovered from canine dung Western Cape, South Africa (Jacobs and Botha, 2008). A new hetetothallic species of *Sordaria*, *S. sclerogenia*, was recovered, from Ceylon (Fields and Grear, 1966). The genus *Kernia*, with *K. nitida* and *K. pachypleura*, has been reported for the first time from Taiwan (Chang and Wang, 2008).
The genus *Podospora* was studied by several workers (Niessl, 1883; Winter, 1885; Cain, 1962; Cailleux, 1969; Garcia-Zorro, 1977; Lundqvist, 1972; Mouchacca, 1986; Mirza and Cain, 1969; Udagawa and Ueda, 1985; Krug and Khan, 1989). A species of *Mortierella, M. hypsicladia*, was isolated from bat dung (Degawa and Gams, 2004). On rhinoceros dung, Ávila et al. (2009) described *Coprotiella venezuelensis* from Venezuela. In a study carried out during the summer months in Orkney and Shetland, 64 species of coprophilous fungi were recorded wherein *Ascobolus brantophilus* was recorded for the first time from UK (Richardson, 2006). A novel species of the genus *Podosordaria, P. leporine*, a xylariaceous ascomycete, was identified from Thailand (Bangyeekhun, 2008). Richardson (1998, 2004) described 27 and 57 species of coprophilous fungi respectively from Scotland and southern Morocco. On the basis of studies carried out in Zulia, Venezuela, a novel species of *Mycotypha, M. indica*, was isolated from turkey dung (Ávila et al., 2007).

A number of coprophilous species of *Chaetomium* was recorded from countries such as Holland and South America, Chile, Germany, Buenos Ayres, North Carolina and New England which included *C. subspirale, C. quadrangulatum, C. convolutum, C. spinosum, C. ampullare* and *C. aureu*, respectively (Cooke, 1969; 1970). *Chaetomium deceptivum, Lasiobolidium orbiculoides* and *Thielavia cephalothecoides* were described and discussed from dung of wood-rat, mouse and deer, respectively (Malloch and Benny, 1973). *Pleuroascus nicholsonii* was reported from wood-rat dung from England (Massee and Salmon, 1901). *Podospora appendiculata* and *P fimiseda* were recorded from New Zealand (Bell and Mahoney, 1997). Novel species of the genus *Ascodesmis obristi* was described and illustrated from Coyote dung collected in Alberta (Currah, 1986). *Corynascella arabica* was isolated and described as a new species from donkey dung from Iraq (Guarrol, 1997).
*Hapsidomyces venezuelensis*, a new genus and species of the Pezizaceae with ornamented ascospores was isolated from Burro dung (Krug and Jeng, 1984). *Periamphisora* was included as a new genus of the Sordariaceae (Krug, 1989). Based on studies done with the aid of light and scanning electron microscopy on ascospores with unusual side view, *Gelasinospora hippopotama* was described as a novel species (Krug et al., 1994). A total of 25 species of coprophilous fungi, mostly of *Arnium* and *Podospora*, were recorded for the first time from Argentina (Lorenzo and Havrylenko, 2001). Lundqvist (1999) described *Podospora austrohemisphaerica* on dung of domesticated herbivores from England.

Meyer and Meyer (1949) described coprophilous ascomycetes from Panama which included species belonging to the genera *Ascodesmis, Ascophanus, Bombardia, Chaetomium, Delitschia, Saccobolus, Sordaria*, and *Sporormia*. Spooner and Butterfill (1999) reported 31 species of ascomycetes belonging to Pezizales from Azores. *Leptokalpion*, a new genus with *L. albicans* as type species, was reported from Thailand (Brummelen, 1977). A new genus *Semidelitschia*, belonging to Sporormiaceae, was described from Canada by Cain and Allen (1969).

**Studies on coprophilous fungi in India**

Earliest work on coprophilous fungi in India was done by Manju (1933) on dung of six herbivores, viz. rabbit, sambar, horse, goat, buffalo and sheep, collected from various zoological gardens. This study resulted with isolation of 29 species belonging to 21 genera of mucorales, ascomycetes, basidiomycetes and hyphomycetes. Ginai (1936) contributed to the study of coprophilous fungi by isolating 48 species belonging to 27 genera (9 species in 3 genera of mucorales; 18 species in 12 genera of ascomycetes, 12 species in 3 genera of basidiomycetes and 9 species in 9 genera of
hyphomycetes) on the dung of cow, nilgai, camel, zebra, donkey and buffalo. Until 1957, only two species of *Coemansia, C. erecta* (Rugmini, 1956) and *C. reversa* (Agnihothrudu, 1957), were reported from India. *Coemansia ceylonensis* was later added to the list of Indian fungi (Prasad, 1965).

Detailed study on the taxonomy and ecology of coprophilous fungi in India was first done in Rajasthan in North India by Lodha (1964). He studied 67 dung samples, belonging to 17 different animals, both carnivorous and herbivorous. He used various isolation methods, viz. moist chamber incubation, serial dilution, particle-plating technique and Warcup’s plating technique and recovered 160 species, belonging to 73 genera which included Mucorales 20 spp. in 10 genera; Hypocreales in 1 sp. in 1 genus; Sphaerales 49 spp. in 9 genera; Pezizales 21 spp. in 5 genera; Hyphomycetes 51 species in 38 genera. Of these, 7 genera and 32 species were new to India. Two new species of *Chaetomium, C. globisporum* Lodha and *C. rajasthanese* Lodha, were described from steamed rat dung and tiger excreta, respectively from Rajasthan (Lodha, 1964).

A few species of *Piptocephalis*, isolated from dung have been described from India. *Piptocephalis debaryana* was isolated from wild rat dung from Allahabad (Mehrotra, 1960). *P. indica* was recovered from rabbit dung collected from Lucknow zoo (Mehrotra and Baijal, 1963). A novel species of *Piptocephalis, P. brijmohanii*, was described from dung of Malayan squirrel, collected from Lucknow zoo (Mukerji, 1968). Several thermophilic fungi were isolated from dung of herbivores, compost and sewage manure. These included *Chaetomium thermophile, Humicola inslens, H. lanuginosa, H. Stellata, Malbranchea pulchella* and *Talaromyces thermophilus* (Maheshwari, 1968). A study carried out on various dung samples in and around Darjeeling district of Eastern Himalaya, lead to the discovery of six discomycetes
belonging to the genera *Cheilymenia, Ascophanus, Ascobolus* and *Thecotheus* (Kar and Pal, 1968). Kar and Pal (1970) described an operculate discomycete, *Iodophanus verrucosporus*, on cow dung from Hooghly, West Bengal. Mukerji (1970) carried out a taxonomic study of fungi in Delhi and isolated three coprophilous ascomycetes, viz. *Preussia isomera, Gelasinospora tetraspora* and *Podospora absimilis*. *Chaetomium warcupii* was reported as yet another novel coprophilous fungus from India (Saxena and Mukerji, 1972). Saxena and Mukerji (1973) described 4 new coprophilous hyphomycetes. *Sympodina coprophila* and *Adhogamina ruchira* were described on goat dung from Jaipur and pony dung from Rishikesh, respectively.

*Bahupaathra samala* and *Angulimaya sundara* were described from cow dung gathered from Dehradun (Subramanian and Lodha, 1964). *Beejasamuha samala* was isolated from goat and rabbit dung from Maduravoyal near Madras in Tamil Nadu (Subramanian and Chandrashekara, 1977). *Bahukalasa samala* was isolated from Hippotragus dung from Bannerughatta, Karnataka and *Candelabrella elegans* was isolated from cow dung collected from Madras, Tamil Nadu (Subramanian and Chandrashekara, 1978). *Chromocera marathwadi*, was isolated from unidentified herbivore dung in Maharashtra (Tilak, 1978). *Coniochaetidium coprophilum* was isolated from dung from Gwalior in Madhya Pradesh (Pathak and Agarwal, 1977). *Coprobia elaphorum*, and *C. flavus* were isolated from Chandanwari, Pahalgam, Jammu and Kashmir and Bisaran, Rajasthan, respectively (Thind and Kaushal, 1978). Another species of *C. striata*, was recovered from cow dung, Darjeeling, W.B. (Waraitch, 1977). *Coprotus argenteus*, was isolated from cow dung in coniferous forest, Narkanda, Mahusu, H.P. (Waraitch, 1977).

*Dispira cornuata* was isolated from mouse dung, Gorakhpur, U.P. (Misra and Gupta, 1978). *D. implicata* was isolated from dung of rodents and excreta of bird. *D.*
simplex was isolated from mouse dung, in Gorakhpur, U.P. (Misra and Gupta, 1978). *Faurelina indica* was another species of coprophilous fungus isolated from cow and goat dung, Nainital, U.P. (Von Arx, 1978). *Iodophanus carneus* and *I. kimboroughii* were isolated from the buffalo and goat dung respectively, from Dalhousie, H.P. (Thind and Kaushal, 1978). *Leucosphaeria indica* was isolated from Nilgai dung gathered from Delhi zoo in New Delhi (Von Arx, 1978). *Mycoarachis inversa*, was reported for the first time from Jaipur, Rajasthan, from buffalo dung (Sharma, 1977). *Paneolus indicus*, was isolated from cow dung from Kottayam, Kerala. *Pilaria anomala* was isolated from cat, cow and peacock dung from Allahabad, U.P. During the same study, several species of the genus *Pilobolus*, viz. *P. crystallinus*, *P. heterosporus*, *P. kleinii*, *P. longipes*, *P. nanus*, *P. roridus*, *P. sphaerosporus* and *P. umbonatus* were identified on dungs of cow, peacock, horse, donkey, goat and horse (Nand and Mehrotra, 1979). *P. ramosus*, was isolated from the dung of buffalo, Kolhapur, Maharashtra (Patil, 1978). *Pleurage glabra*, was isolated from cow dung from Darjeeling, W.B. (Kar and Maity, 1978). On rabbit dung collected from Lalbagh garden, Bangalore, *Sutravarana samala* was isolated by Subramanian and Chandrashekara (1977). *Thecotheus holmskjodii*, was isolated from cow dung, Jandhari Ghat, Dalhousie, H.P. by Waraitch (1977). *Tieghemiomyces parasiticus* was isolated from mouse dung in wheat field in Nagara village, Gorakhpur, U.P. (Misra and Gupta, 1978). Of the four species of genus *Lachnella* discovered, *L. albidofusca* and *L. fraxcinicola* were coprophilous (Bilgrami et al., 1979). *Achaetomium theilavioides* was isolated from Nilgai dung, collected from Delhi Zoo, New Delhi (Von Arx, 1978). *Ascobolus scatigenus* was isolated from dung heap in Mangiter, Sikkim (Waraitch, K.S., 1980) and on cow dung in Kerala (Leelavathy, 1981). *Cheilymenia aurantiaco-rubra* and *C. tandonii* were recovered from the heap of dung.
from Sarangpur, Chandigarh and on cow dung from Narkanda, H.P., respectively (Thind and Kausal, 1980). *C. coprinaria* was isolated from cow dung from Darjeeling, W.B. (Waraitch, 1980). Ghadge and Patil (1988) described several species of *Ascobolus*, viz. *A. behnitziensis*, *A. crenulatus*, *A. foliicola*, *A. geophilus*, *A. hawaiiensis* and *A. sacchariferus* from dung of various herbivores. Species and varieties of coprophilous genus *Saccobolus* viz., *S. diffusus*, *S. humidicola*, *S. versicolor* var. *kasauliensis* and *S. verrucisporus* var. *longisporus* were described as new to science by Kaushal and Virdi (1986).

Manimohan (2007) described nineteen species of fungi belonging to 12 genera of 5 agaric families, from elephant dung in Kerala. These included *Agrocybe guruvayoorensis*, *Bolbitius coprophilus*, *Conocybe brunneoaurantiaca*, *C. pseudopubescens*, *C. volvata*, *Copelandia cyanescens*, *Entoloma anamikum*, *Macrocya gigantea*, cf. *Panaelina rhombisperma*, *Panaelus antillarum*, *P. rickenii*, *Pholiotina indica*, *Psilocybe coprophila*, *Ps. pegleriana*, *Ps. subaeruginascens*, *Ps. subcubensis*, *Stropharia bicolor*, *S. rugosoannulata*, and *Volvariella volvacea*. Of these, *Agrocybe guruvayoorensis*, *Conocybe volvata*, *Conocybe pseudopubescens*, *Pholiotina indica* and *Stropharia bicolor* are known to be encountered only on elephant dung. *Panaelina rhombisperma* was isolated from elephant dung in Wayanad district of Kerala (Noordeloos, 2007). During a study carried out in Satara, Maharashtra, 65 species of fungi were isolated from dung samples. (Thoke and Kore, 2010).

**Activities of coprophilous fungi**

A good proportion of coprophilous fungi so far studied yielded a diverse array of novel and moderately potent antifungal compounds (Ridderbusch, 2004). Few of the
coprophilous taxa produce important chemical compounds that may inhibit competing and invading organisms or stimulate fungal growth (Harper and Webster, 1964).

**Antifungal agents**

Wicklow (1988) reviewed the role of such compounds in deterring predation. Coprophilous fungi, especially those slow-growing taxa developing in middle or late succession, offer a rich source of antifungal natural products (Gloer 1995; 1996; 1997). Many of these compounds possess novel ring systems, e.g., preussomerin A from *Preussia isomera* (Weber et al., 1990), a relatively rare occurrence in natural products chemistry (Gloer, 1995). Coprophilous fungi are thought of a good source of unknown compounds with diverse biogenetic origins and promising biological activity (Gloer, 1997). Chemical investigation of coprophilous fungus, *Apiospora montagnei*, led to the discovery of a novel antifungal metabolite called apiosporamide (Alfatafta and Gloer, 1994).

**Polyphosphate**

Inorganic polyphosphate (poly P) is a linear polymer of phosphoanhydride linked phosphate residues. Polyphosphates occur in all organelles of all organisms, including the fungal cell walls. Different species of Zygomycetes, mostly isolated from herbivore dung, possess polyphosphate molecules of different chain lengths. Depending on the cell growth phase cellular location, structure and distribution of polyphosphate differs. Polyphosphates with low molecular weights exist in free form or are bound to cytoplasmic compounds such as the ribonucleic acids. Extractions in high salt buffer reveal that larger polyphosphates were observed in Mucorales, when compared with other fungi. Presence of poly P in the cell walls of fungi was
investigated using techniques of poly P binding proteins. (PBPs) (Werner et al., 2007).

Rhizoferrin

Rhizoferrin is a novel polycarboxylate or complexone-type siderophore. This compound was originally isolated from *Rhizopus microsporus*, a coprophilous fungus. Rhizoferrin is known to be present in all Zygomycetes. Using high performance liquid chromatography (HPLC) rhizoferrin could be detected in various families of Zygomycetes. For instance, rhizoferrin has been detected in *Rhizopus microsporus* var. *rhizopodiformis*, *Mucor mucedo* and *Phycomyces nitens* (Mucoraceae), *Chaetostylum fresenii* and *Cokeromyces recurvatus* (Thamniidaceae), *Cunninghamella elegans* and *Mycotypha africana* (Choanephoraceae) and *Mortierella vinacea* (Mortierellaceae) and *Basidiobolus microsporus* (Entomophthorales).

Polyunsaturated fatty acid (PUFA)

As part of health knowledge, it is well known that the bad fats include saturated and trans fats, while the good fats include omega-3 (x-3) and omega-6 (x-6) fatty acids. The latter group of fatty acid includes arachidonic acid (ARA), a-linolenic acid (GLA) and linoleic acid (LA) which are essential fatty acids (EFAs) (Dyal and Narine, 2004). An increased intake of omega-3 fatty acids is generally recommended for a healthy life (Bajpai, 1992). Studies project that consumption of food products enriched with fish oil offers potential health benefits, especially protection against cardiovascular diseases (CVD), cancer and improvement of brain development and function (Dyal and Narine, 2004;). The group of fungi gaining maximum attention for the production of EFA is Zygomycetes, especially those belonging to the Class
Mucorales. Among the mucoraceous fungi Mortierella spp. have gained a notable attraction due to their high content of lipids (Dyal and Narine, 2004).

**Arachidonic acid (ARA)**

A fungus containing more than 25% of its biomass in the form of lipids is known as oleaginous (Murphy, 1991). Arachidonic acid, 20:4(n-6), is one of the important PUFAs which helps development of brain in the infants and hence considered as an important constituent of the infant food (Wynn and Ratledge, 2000). ARA also acts as a precursor of prostaglandins, thromboxane, prostacyclin, and leukotrienes, and plays an important role in various physiological actions including uterine muscle contraction, relaxation, vasodilatation, and antihypertensive action in humans (Wynn and Ratledge, 2000). Of all the ARA producing fungi, 94% belonged to the genus Mortierella, the rest of the isolates belonged to Mucor. All the Mortierella isolates produce ARA (Higashiyama et al., 2002). Mortierella alpina is one of the major sources of arachidonic acid hence called as oil producing microorganism (Murphy, 1991). *M. alpina*, can accumulate up to 40% (w/w) lipid, of which up to 40% is arachidonic acid, when cultivated in submerged culture in a fermentor with glucose as a carbon source (Wynn and Ratledge, 2000). Mortierella sp. has a high potential to produce lipids, with a significant portion of EFAs. Due to this, Mortierella sp. has attracted notable attention.

**Eicosapentaenoic acid (EPA)**

Experiments with Mortierella elongata suggested that a maximum yield of EPA is obtained when linseed oil (2%) and yeast extract (0.5%) were used in the basal medium. Maximum EPA content as a percentage of lipids (15.12%) was observed when the latter medium was supplemented with 0.25% urea (Bajpai et al., 1992).
**γ-linolenic acid (GLA)**

γ-linolenic acid stands out tall among the fatty acids because of its numerous functions, including structural component of cellular membrane, formation of prostaglandin E1, control of the permeability of skin and possibly other membranes, and regulation of metabolism and cholesterol (Tauk-Tornisielo et al., 2007). As a precursor of prostaglandin, this acid is used in geriatrics treatment of premenstrual syndrome, prevention of osteoporosis, reduction of inflammatory processes and reduction of blood pressure. The subgenus *Micromucor* produces C-18 fatty acid γ-linolenic acid. Of the 28 Mucorales screened, *Mucor mucedo* and *Cunninghamamella echinulata* were said to be the best yielders of γ-linolenic acid (Shinmen et al., 1989). With use of a basal growth medium consisting 5% dextrose and 1% yeast extract along with Mn$^{2+}$, the production of GLA increased significantly by *Mortierella ramanniana* var. *ramanniana* (Tauk-Tornisielo et al., 2007).

**Food industry**

Fungi are involved in the production of a wide range of blue-veined and white mould cheese and a number of fermented Asian food products including tempeh (Hudson, 1971). Amylase produced by *Rhizopus foetidus* are used to convert starchy substrates to sugars prior to alcoholic fermentation, chocolate production, syrups from cocoa and inverase (Hudson, 1971; Pointing and Hyde, 2001). Extraction of chitosan from *Absidia glauca* var. *paradoxa* was done using 2% Acetic acid and the product is used as fining agents for apple juice (Runsgardthong et al., 2006). The chitosan obtained from fungus turned out to be much effective in reducing the turbidity and gave lighter juices than the sample treated with shrimp chitosan (Runsgardthong et al,
2006). *Rhizopus aarhizus* enriches the protein content, when inoculated in soaked barley. The derived product is used as feed of pigs (Jacela et al., 2010).

Chitosan is a natural polymer derived from chitin. It is a polysaccharide formed primarily by repeated units of β (1-4) 2-amino-2-deoxy-D-glucose or D-glucosamine (Yadav and Bhise, 2004). Chitosan is the deacetylated product formed by the treatment of chitin with concentrated (50%) caustic alkali. Traditionally, chitosan is obtained by chemical conversion of chitin, which is a constituent of the exoskeleton of annelids, coelenterates, crustacean, insects and molluscs (Chatterjee et al., 2005; Rungsardthong et al., 2006; Stamford et al., 2007). The unique properties of biodegradability, biocompatibility, bioactivity, selective permeability, polieletrolic action, chelation, ion exchange properties, antitumor and antimicrobial activity made chitosan very demanding in the fields of agriculture, medicine, biotechnology and pharmaceutical industries (Amorim et al., 2001; Stamford et al., 2007). Among coprophiilous fungi, *Mucor rouxii, Cunninghamellla echinulata* and *C. elegans* are said to be the best strains producing chitosan at commercial scale (Amorim et al., 2001; Franco et al., 2004).

**Ethanol**

When screened, 9 members of the Zygomycetes were found to produce ethanol along with the capacity of fermenting pentoses. These included *Mucor corticolous, M. hiemalis, M. indicus, Rhizopus oryzae, Rhizomucor pusillus* and *R. miehe*. On fermentation, all the strains produced glycerol as by-product, while species of *Rhizopus* and *Rhizomucor* produced lactic acid in significant amount (Millati et al., 2004).
Bioremediation

Chitin and chitosan extracted from *Cunninghamella elegans* were subjected to biosorption in the aqueous solution for the metals, viz. copper (Cu), lead (Pb) and iron (Fe), using polysaccharide solutions (1% w/v). Chitosan and chitin showed high affinity for Cu and Fe adsorption (Franco et al., 2004). *Rhizopus arrhizus* helps in the removal of the Plutonium (Pu), Americium (Am) and Cerium (Ce) from nuclear fuel reprocessing plants (Pointing and Hyde, 2001).

β-Carotene

Although animals incorporate carotenoids, only plants, bacteria and algae can synthesize carotenoids. The carotenes produced by *Phycomyces blakesleeanus* and *Blakeslea trispora* are used as provitamins, pigments and antioxidants in the food and feed, pharmaceutical and cosmetics industries. Due to accumulation of β-Carotene in the mycelia and sporangia, the fungi attain yellow colour. Stimulation for accumulation of the pigment is mediated by the production of trisporic acid from the opposite mating strain (Mehta and Cerda'-Olmedo, 2001). It was reported that mutations in the genes lead to an increase in the β-carotene contents and other carotenes such as lycopene (Mehta and Cerda'-Olmedo, 2001; Kuzina and Cerda'-Olmedo, 2006). It has been studied that the biosynthesis of β-carotene is stimulated by H$_2$O$_2$. With the increase in the content of β-carotene, a decline in the superoxide dismutase and catalase activity was noticed. In *Blakeslea trispora*, β-carotene acts as a major antioxidant during inactivation of enzymes that detoxify reactive oxygen species (Gessler et al., 2002).
Organic acids

The members of Zygomycota have high ability of producing lactic acid. A significant commercial source of lactic acid is a bioprocess employing Rhizopus oryzae and Rhizomucor sp. Along with lactic acid these fungi produced significant amount of fumaric acid, L-malic acid. Species of Rhizopus and Actinomucor have resulted in the yield of 63-69% of lactic acid from a chemically defined medium containing 15% glucose. The production of lactic acid, along with ethanol, leads to the acidification of the environment and thereby discourages the competitors (Magnuson and Lasure, 2004). Lactic acid has found its non-food application as ethyl lactate (biodegradable solvent) along with the primary uses as preservative, flavor enhancer and acidulant in the food industry (Magnuson and Lasure, 2004).

Enzymes

The enzymes are essential proteins which mediate the metabolic processes of all living organisms. They also accomplish degradation of all organic matter on the face of this earth. Enzymes also cause perishable food, fruit and vegetable spoilage. Zygomycetous fungi generally degrade the easily available sugars such as glucose (Dix and Webster, 1995). Representatives of the genus Mucor, viz. M. genevensis, M. circinelloides f. griseo-cyanus and M. circinelloides f. janssenii show high lipase activity, whereas considerable less activity was observed in M. circinelloides f. lusitanicus (Alves et al., 2002). Although, Mucor isolates showed high lipase activity, the enzymatic activity does not establish standards for separation of the taxa at specific level since it varied in different isolates belonging to the same taxon. Protease activity of commercial value is exhibited by Mucor hiemalis, M. racemosus, M. bacilliformis and M. miehei. M. miehei has been studied most extensively for the
production of the lipase (Alves et al., 2002). *Rhizopus* along with *Aspergillus*, *Fusarium*, *Penicillium*, was reported to be a good producer of pectinase. The mycelial extracts of *Rhizopus nigricans* is used to purify the enzyme chitin-deacetylase (Jeraj et al., 2006). Species of *Chaetomium* commonly occur on dung. Species of *Chaetomium* are known to produce copious amount of cellulase (Ames, 1963).

**Secondary metabolites**

Secondary metabolites are not important for the basic metabolic growth of an organism but do possess basic survival functions in nature. They possess complex chemical structures. Secondary metabolites such as mycotoxins, antibiotics, pigments and pheromones are not produced by all organisms, but may be elaborated by some of the species of a genus (Demain, 1986). Decipinin A, with antifungal and antibacterial activity, has been isolated from liquid cultures of the coprophilous fungus, *Podospora decipiens*. Besides, two new compounds, tetracyclic sesquiterpenes lactones, decipienolides A and B, obtained from this isolate had showed antibacterial activity (Che, 2002). Australifungin, a novel inhibitor of Sphinganine N-Acyltransferase was discovered from *Sporormiella australis*. Another antifungal and antibacterial metabolite, Arugosin F, was isolated from the coprophilous fungus, *Ascodesmis sphaerospora* (Hein, 1998). A novel metabolite with strong antimicrobial activity and weaker cytotoxic and phytotoxic activity was isolated from a xylariaceous coprophilous fungus, *Podosordaria tulasnei* (Ridderbusch, 2004). Studies on *Cercosphora sordarioides*, a coprophilous isolate, has led to the isolation of arthrinone, a known fungal metabolite, along with three new related compounds 1-dehydroxyarthrinone, 3a,9a-deoxy-3a-hydroxy-1-dehydroxyarthrinone and cerdarin. Two of the compounds showed strong anti-*Candida* activity (Whyte, 1997).