Review of Literature
The phenology of flowering and fruiting of tropical plants is known to be controlled by a number of environmental factors such as temperature, light, rainfall, relative humidity etc. Comprehensive studies by many authors on reproductive phenology of plants in relation to environment revealed climate functions as the triggering and synchronising master control factor of phenological cycles in tropical rain forests (Frankie et al., 1974; Opler et al., 1976; Newstrom et al., 1994). Fruiting phenology appears to be correlated with seed dispersal mechanisms and phenology of tropical forest trees exhibit some adaptive significance due to seed dispersal when soil moisture conditions are favourable for seedling establishment (van Schaik et al., 1993).

Borchert (1983) opined that in many tree species the switching from vegetative to floral phase requires a signal in which drought or shortage of soil moisture is involved. According to the author, in contrast to habitats subjected to a regular cycle of dry and wet seasons, the synchronisation of phenological events may not be expected, in a perhumid habitat like

Comprehensive Study on the Phenology, Morphology and Seed Germination
evergreen forests, which lack xeric periods, because high degree of species diversity exists in that particular habitat.

Phenological characteristics of 453 individuals representing 39 tree species investigated in two dry forests of Bolivia revealed that flowering and fruiting were bimodal, with a major peak occurring at the end of the dry season (August - October) and a minor peak during January in the rainy season (Justiniano and Fredericksen, 2000). Fruiting at the end of the dry season might have evolved to reduce seedling mortality by dispersing seeds when soil moisture conditions are favourable for seed germination and rapid seedling growth. It has been observed that sub-canopy species are less seasonal in their fruiting and flowering, perhaps because of reduced variability in solar radiation, soil moisture, and relative humidity in the forest under-story (Justiniano and Fredericksen, 2000).

Parallel to the phenological recordings, meteorological parameters also are to be monitored in detail since these factors are closely related to flowering and fruiting of plants. Various hypotheses have been put forth addressing individual elements of the climate as a proximate factor that trigger seasonality in the equatorial tropics (Caldwell, 1968). According to Caldwell \textit{et al.} (1998), rainfall is an indicator of clouds, which appears to play a role in meteorological cues. Similarly factors like, shortage of assimilates during rainy season (Wright \textit{et al}., 1999), prolonged drought and solar
radiation (Numata et al., 2003) and solar irradiance peak (Hamann, 2004) are also known to induce and control flowering and fruiting. Phenological aspects such as the periodicity of flowering and fruiting have been addressed in respect of rhythmic cycles and influence of climatic conditions (Mikich and Silva, 2001).

A comparative study on the phenology of Atlantic rain forest trees by Morellato et al. (2000) revealed that flowering pattern did not differ significantly among trees of four forest sites analyzed, suggesting the occurrence of a general flowering pattern. Fruiting phenologies were seasonal in all the four forests and hence it seems that climatic factors did not limit the fruit production. Those authors concluded that seasonal variation in day length has got influence on ever-wet forest tree phenology.

An analysis of the proximate control of the flowering in tropical deciduous forest species indicated that the timing of vegetative phenology strongly determined the flowering periods and thus flowering depended indirectly on environmental periodicity (Rivera et al., 2002).

Bendix et al. (2006) related the flowering and fruiting activity of 12 tree species in an evergreen tropical rain forest in South Ecuador over a period of 3-4 years, with the meteorological parameters of the area. Those authors observed two groups of trees – one of which flowered during the less humid months (September to October) and the other group started flowering during...
rainy season (April to July) and suggested that rainfall and minimum temperature appear to be the only parameters with a periodicity free of long term variations and the phenological events of most of the plant species show a similar periodicity.

Singh and Kushwaha (2006) analyzed the diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India and suggested that in these forests, common tree species show wide range of leafless periods due to different timings of leaf fall within the annual cycle and in tropical deciduous forest trees flowering periodicity has evolved as an adaptation to the annual leafless duration. According to those authors the wide diversity of seasonal flowering and fruiting with linkages to leaf-flush time and leafless period reflect the fact that variable reproductive and survival strategies are involved in tree species under a monsoonal bioclimate. Those authors further suggested that flowering periodicity has evolved as an adaptation to an annual leafless period and the time required for the fruit to develop. The direct relationship between leafless period (inverse of growing period) and time lag between onset of vegetative and reproductive phases reflect the partitioning of resource use for supporting these phases. Predominance of summer flowering coupled with summer leaf flushing seems to be a unique adaptation in trees to survive under a strongly seasonal tropical climate (Singh and Kushwaha, 2006).
Seed dispersal, germination and dormancy are critical events regulating the spatial and temporal distribution of plants. Dispersal and dormancy traits are considered as adaptive mechanisms and the significance of this behaviour is related to restrict germination during most favourable season of the year (Garwood, 1982). According to this author, maturation, dispersal and germination of tree seeds in the seasonally dry tropical forest ecosystem are synchronized to seasons.

Whitmore (1983) and Garwood (1989) opined that many fast growing shade-intolerant tropical pioneer species produce small, dry and orthodox seeds which may remain viable for several years in the soil, beneath the forest canopy. Those authors further suggested that many slow growing, shade tolerant, primary forest species have relatively large, moist, recalcitrant seeds that never become components of the persistent soil seed bank, but germinate in the moist shaded under-story of the forest. According to Garwood (1983) in the seasonal tropical forests, seeds of many species dispersed in the late rainy season are dormant through the reminder of the rainy season as well as the following dry season and germinate in the next rainy season.

A study undertaken by Murali (1997) on the patterns of seed size, germination and seed viability of 99 tree species in the Western Ghats of Karnataka revealed that there is a strong link between flowering time, fruiting time, seed viability and time of germination. Seed size is influenced by
Review of Literature

dispersal pattern, habit and habitat of the plant species, which depend on the seasonal variations of moisture availability. According to Murali (1997), the species, which flower during the rainy season, have lighter seeds and seeds produced during drier months and in larger quantity are either wind dispersed or explosive dispersed and meant for the lower survival probabilities. They are with longer viability and may show dormancy. Species, which flower during the dry season, produce heavier seeds whereas species, which fruits during the rainy season, have heavier, moist seeds with shorter viability. These larger seeds take more time for germination, and are with shorter maturity and are animal dispersed during wet period.

Seed size is known to control germination pattern and vigour potential. Dharmalingam and Basu (1989) studied the influence of achene size on germination and vigour potential in sunflower seeds and found that 100-achene weight, seed weight and pericarp weight showed a linear association with achene size. Even though the germination potential of achenes did not differ considerably, the field emergence was significantly more in the case of large and medium size achenes than the smaller ones. Seed vigour evaluations confirmed the superiority of the large and medium size achenes over the small and ungraded ones.

Based on a comparative study of tropical seeds which included under three ecologically well defined groups, Garwood and Lighton (1990) stated
that tropical forest species differ in seed moisture content and seed mass and these seeds experience different environmental moisture regimes after dispersal. Plant species differ greatly in seed and seedling traits and these traits are often associated with regeneration in particular habitats (Kitajima and Fenner, 2000)

Earlier studies in tropical forest communities have shown the existence of significant associations of seed mass with cotyledon functions (Garwood, 1996; Kitajima, 1996a; b; Ibarra – Manriquez et al., 2001). According to Garwood (1996), Leishman et al. (2000) and Westoby et al. (2002) seed size and seedlings are associated in such a way that size of the large seed-reserve supports seedling survival in shaded habitat. Zanne et al. (2005) opined that storage cotyledons are less strongly associated with forest than with gap habitats suggesting alternate methods for provision of energy than storage cotyledons for survival in shade. According to Moles et al. (2004), large seeds are most strongly associated with tall trees in closed canopy forest where light availability is low.

Idu and Omonhinmin (2001) described the seed morphology of 136 species of 68 genera of Asteraceae and systematic keys based on seed morphology for the identification of genera have been provided. The orientation, colour, thickness and measurements, which make up the morphometrics differ considerably from taxa to taxa. The differences in the

Comprehensive Study on the Phenology, Morphology and Seed Germination
shape and size of seeds apparently varied considerably between and within different taxa.

An elaborated study on the evolutionary and ecological correlations of early seedling morphology of tree species revealed that seed size and cotyledon morphology are the key juvenile traits that have evolved in response to changes in plant species and habitat strategies (Zanne et al., 2005). According to those authors species with large seeds, big seedlings, thick storage cotyledons, slow germination, large adult stature and dispersal by large animals are associated with forest and gap habitats while species with small seeds, seedlings with thin photosynthetic cotyledons, fast germination, small adult stature and dispersal by small animals are associated with open habitats.

Investigations on the changes in seed dormancy and germination of 23 common species (annual and perennial grasses, legumes and other dicotyledons) from herbaceous communities in northern Australia during storage of 8 months revealed that initial levels of seed dormancy get changed widely during storage and rates of changes in dormancy and response to the different storage conditions showed that species with several types of dormancy characteristics are able to co-exist (McIvor and Howden, 2000). According to those authors, generally, dormancy declined with time in such a way that the rate of greatest decline occurred in the seed exposed on the soil.
Review of Literature

surface and least for those stored in the laboratory. There was an approximately linear increase in germination rate over time for all storage treatments and germination rate of seeds stored on the soil surface, was increased more rapidly than those of seeds stored in laboratory and oven. Those authors suggested that almost all species germinated faster after exposure on the soil surface than after storage for the same time in the laboratory.

Liu et al. (2005) studied the storage behaviour of dormancy and various methods for breaking the dormancy of *Garcinia cowa* seeds in connection with ecological function and germplasm conservation and opined that thick seed coat of *G. cowa* seeds act as a mechanical barrier to both water permeability and radicle protrusion. The failure of germination would be attributed mainly to dormancy and no water-soluble inhibitors exist in the seeds. The most effective method of breaking seed dormancy reported was the total removal of seed coat.

On the basis of seed morphology and germination behaviour, a category, known as recalcitrant seeds are characterized by larger size, high moisture content and short life span (Chin et al., 1984). It is generally believed that recalcitrant seeds never go into dormancy but instead continue their development and progress towards germination (Berjak et al., 1990). Well-documented aspects of recalcitrant seeds are desiccation-sensitivity
Review of Literature

Comprehensive Study on the Phenology, Morphology and Seed Germination (Berjak and Pammenter, 2001; Kermode and Finch-Savage, 2002) and mode of storability (Finch-Savage, 1992; Tompsett and Pritchard, 1993). According to Pammenter et al. (1998) and Pammenter and Berjak (1999; 2000a; b) desiccation sensitivity is probably an ancient character with tolerance having evolved independently a number of times and recalcitrance places constraints on the regeneration niches open to the species producing such seeds.

Although recalcitrant seeds shed with very high moisture content, they vary in the initial water content, extent of dehydration they tolerate, their response to drying rate, shortage of life span and response to low temperature (Pammenter and Berjak, 1999). Recalcitrance is presumed to be highly significant ecologically. High moisture content of the recalcitrant seeds is similar to vegetative tissue, which is sensitive to desiccation. According to Oliver and Bewley (1997) this character is ancestral and tolerance is evolved independently a number of times, including more than once in the angiosperms. von Techman and van Wyk (1994), Pammenter and Berjak (2000a; b) also agree with the view of Oliver and Bewley (1997).

As mentioned earlier, a characteristic feature of recalcitrant seeds is their short life span and it will place constraints on the range of environmental conditions in which regeneration through seeds can occur. Recalcitrant seeds are common in mesic tropical forests and these conditions would be
favourable for germination and seedling establishment and hence there has been no pressure driving the evolution of desiccation tolerance and seeds of these species, are not often found in soil seed bank since their life span is short and these seeds never show dormancy (Pammenter and Berjak (1999; 2000 a; b).

Garwood and Lighton (1990) suggested that seed respiration rates provide new insight into the physiology of recalcitrant seeds since viability apparently depends on the availability of oxygen as reported earlier by King and Roberts (1980) and Tompsett (1983).

Dussert et al. (2000) studied the relationship between seed desiccation sensitivity, seed water content at maturity and climatic characteristics of native environments of nine Coffea species and very highly significant correlation was found between the duration of seed development and the duration of rainy season in their native environments. Flowering in all Coffea species occurred only a few days after the main rain fall marking the end of the dry season and mature seeds were shed at the end of the rainy season. According to those authors, no significant correlation existed between the level of desiccation sensitivity as quantified by the water content or the water activity at which half of the initial viability was lost, and the duration of seed development or the seed water content at maturity. However, level of seed desiccation tolerance was significantly correlated with the number of dry
months following seed shedding. So a higher level of desiccation tolerance corresponds to an adaptation to drought.

Desiccation tolerance is an important functional trait and is an integral part of plant regeneration ecology (Tweddlle et al., 2003). Those authors opined that about 92% of spermatophyte species tolerate desiccation permitting the moisture content to reduce to low levels. In addition, the level of drying that recalcitrant seeds can tolerate vary due to range of other factors including seasonal differences in the extent of pre-shedding drying (Finch-Savage and Blake, 1994) and environmental features such as post harvest drying conditions (Berjak and Pammenter, 1994).

It has been recognized that moist tropical forest trees show high frequencies of desiccation sensitivity (Vazquez-Yanes et al., 1999; Farnsworth, 2000) while species from arid and highly seasonal habitats are overwhelmingly desiccation tolerant (Dickie et al., 1992, Hong et al., 1998). Similarly, desiccation sensitivity at the seed stage is more frequent among species having non-dormant seeds compared to dormant seeds (Farnsworth, 2000; Pammenter and Berjak, 2000 a; b; Dickie and Pritchard, 2002).

By analysing the data set of 886 trees and shrubs from 15 vegetation zones Tweddlle et al. (2003) agreed with many of the above views and suggested that seeds of species from moist habitats are desiccation sensitive than from highly seasonal or arid habitats. Those authors further opined that

**Comprehensive Study on the Phenology, Morphology and Seed Germination**
non-pioneer evergreen forest trees produce desiccation-sensitive seeds and desiccation sensitivity at the seed stage is more frequent in species having non-dormant seeds compared to dormant seeds.

In a study of ecological implications of 225 tree and shrub taxa consisting of 36 recalcitrant and 189 orthodox seeds from semi-deciduous tropical forest in central Panama, Daws et al. (2005) reported that desiccation sensitive seeds are larger than desiccation tolerant seeds and desiccation sensitive seeds germinate more rapidly resulting in reduced duration of seed exposure to predation and low investment in the physical defense and desiccation sensitive seeds are more efficient in using resource based on seed mass. On the other hand, seeds produced by desiccation – tolerant pioneer species rely on the occurrence of open (high-light) microsites for successful germination and seedling establishment. The less rapid germination and greater speed of seedling development period of the seeds of pioneer species may be advantageous in an environment of unpredictable rainfall. According to those authors, in habitats of benign, uniform climate that are continuously conducive to germination and seedling establishment, there may be no selection driving the evolution or maintenance of desiccation tolerance, particularly for large seeds that will dry slowly.

An important method to study germination biology of seeds is comparison of germination among groups of species classified with respect to

**Comprehensive Study on the Phenology, Morphology and Seed Germination**
various criteria including life pattern, family, geographical distribution, ecology, seed shape, weight, storage behaviour and colour (Grime et al., 1981). In a comparative study of seed germination biology of a local flora, those authors suggested that marked differences existed in the capacity of freshly collected seeds for immediate germination and dry seeds exhibited increased germination rate. Rate of germination showed a progressive decline with increasing seed weight and there was a positive correlation between the rate of germination and relative growth of seedlings. Another important observation was recurrent association between features of seed morphology and germination, which were related to ecological characteristics and therefore exist in several species.

Several factors in the environment- water, oxygen, light, temperature and many biotic factors determine whether or not germination occur and the rate at which it does so (Mayer and Poljakoff-Mayber, 1989; Bewley and Black, 1994). Dalianis, (1980) determined optimum temperatures for rapid germination, emergence and seedling elongation of Berseem and Persian clover in conjunction with studies of the effect of seed size and planting depth. The study revealed that seed size exerts no influence on germination, except that large seeds were inferior to other seed sizes in both species. However, there was a definitive superiority of large seeds over medium and medium over small in terms of seedling elongation rate and length. In
addition, large seeds were superior to medium and to small at every planting depth in terms of seedling emergence rate and at deep plantings in terms of emergence percentage. At shallow depths seed size had no effect in Berseem clover, but medium sized seeds were superior in Persian clover.

By studying germination biology of 105 species of Australian plants, Jurado and Westoby (1992) elucidated that germinability, propensity to germinate at different temperatures and germination speed are related to plant growth form, perenniality, seed size and seed dispersal mode and those authors opined that in arid environments with unpredictable climate, plants select to germinate at times which give the best chance for seedling establishment. Almost all species produced at least some seeds, which were dormant, consistent with the idea that risk spreading was important in arid zones. However, dispersal mode and plant perenniality were not found to be associated with germinability. Seeds of most species germinated rapidly relative to high rainfall environments, as might be expected in an environment where wet soils were usually temporary. Faster germination tended to be associated with low germinability, suggesting a spectrum of strategies from species that risk a small number of their seeds in many rainfall events, to those that germinate only in large rainfall events but then risk large number of seeds.
Studies on the effect of storage and temperature on the germination response of two morphologically different categories of *Cassia tora* seeds showed that they were physiologically different (Bhattacharya and Saha, 1997). Almost 100% viability was retained in both categories of seeds up to 1 year of storage. Thereafter the viability of one category of seeds was lost more rapidly than that of the other category. An important observation was that the temperature sensitivity of one category of seeds restricted the germination to regimes or seasons of favourable temperature only. This probably compensated for the lack of hard seededness and the shorter viability period and helped the seedlings to emerge in a season when chances of survival were better. The production of a large number of seeds of two categories multiplied the chances of establishment and also assured wide distribution in time and space.

A comprehensive study on ecology of seed germination by Baskin *et al.* (2004) revealed that in the seeds of annual weeds- *Capsella bursa-pastoris* and *Descurainia sophia* originating from high northern latitudes, low temperature inhibited dormancy-breaking in winter and so those authors hypothesized that the seeds that mature at high latitudes in late summer and/or early autumn would not germinate until they had been exposed to high summer temperatures. Consequently, germination would be delayed until the second autumn. According to those authors most seeds of these two annual

**Comprehensive Study on the Phenology, Morphology and Seed Germination**
weeds that mature in late summer do not germinate in the first autumn, but they may do so the following spring or in some subsequent autumn or spring.

Thapliyal and Phartyal (2005) suggested that germination of seeds is programmed over a period of time and germination patterns of seeds reflect adaptive response to the seasonal changes in their habitat. An investigation on dispersal and germination syndromes of tree seeds in a monsoonal forest in northern India by those authors revealed that in most tropical forests, 3 month monsoon period is the prime determinant of all biological processes including seed germination, seedling establishment and plant growth.

Based on the results of their investigation, Thapliyal and Phartyal (2005) suggested six patterns of seed germination 1) average germination percentage of fresh seeds lower than that of stored seeds, indicating an after-ripening requirement. 2) initial high germination percentage followed by low values, indicating a steep to moderate decline in viability following harvest; 3) no germination after 1 or 2 months of seed storage, due to complete loss of viability, indicating short seed longevity. 4) fresh seed germination in some species equaled the average germination value of stored seeds, indicating constant germination for one whole seedling cycle; 5) Germination of both fresh and stored seeds remained constantly low throughout the season, indicating a requirement for some kind of pre-treatment or having poor
quality of seeds; 6) initial high germination followed by decline and again increase, showing a seasonal rhythm of germination.

Seedling development and establishment also are dependent on ecology of habitat as well as metabolic potential of seeds. According to Molofsky and Augspurger, (1992), larger seeds produce seedlings, which emerge from a greater soil depth and are less affected by the smothering effects of leaf litter. Larger seeds produce seedlings with deeper roots so improving access to soil moisture during drought (Metcalf and Grubb, 1995). The metabolic effect is reported to have lower potential of relative growth rate in seedling and indicate the inherently lower metabolic rate and so the resources would be consumed more slowly, allowing longer survivorship of seedlings in the face of a variety of hazards (Cornelissen et al., 1996; Wright and Westoby, 1999; Bloor and Grubb, 2003). Another possibility opined by Kitajima (1996a; b) was related to seed mass and the functional morphology of cotyledons and their character showed general correlation between seed size and seedling performance that occurs via the correlation between seed mass and functional morphology of the cotyledons.

Significant variations occur in the shape and function of cotyledons. Shape vary from laminar and primarily photosynthetic in function, to being globoid and predominantly concerned with storage and in the extreme case where they are completely enclosed in the seed coat, entirely storage in

**Comprehensive Study on the Phenology, Morphology and Seed Germination**
function (Kitajima, 1992; Garwood, 1996). Small seed-masses are often associated with photosynthetic type cotyledons, while storage-type cotyledons occur most frequently among larger-seeded species (Wright et al., 2000). The seedlings of larger-seeded species perform better because they have more mobilizable reserves available to them during times of carbon deficit as in deep shade or for interim support while replacing photosynthetic tissue lost through herbivory or mechanical damage. A greater proportion of seed reserves in larger seeded species remains uncommitted during seedling deployment and is thus held in reserve to provide seedlings that germinate in hazardous environments (Westoby et al., 1996). However, Saverimuttu and Westoby (1996) suggested that the reserve effect of cotyledons explains the greater seedling longevity in larger seeded species. In larger seeded species, a relatively greater proportion of original seed mass is found to be retained in the cotyledons to act as reserves for the newly expanded seedling (Kidson and Westoby, 2000). Green and Juniper (2004 a; b) refuted the concept of reserve effect and stated that no evidence exists to demonstrate the correlation between better seedling performance and larger seeded species.

The terms cryptocotylar and phanerocotylar are used to describe the permanence of cotyledons within the seed coat or endocarp. Duke (1969) recorded phanerocotylar germination as a general characteristic for the family Annonaceae, and also pointed out that cryptocotylar probably takes place in
species with large seeds. Many authors use the word cryptocotylar when the cotyledons remain enclosed by the seed coat or endocarp, and phanerocotylar when the cotyledons emerge from these structures (Duke, 1965; 1969). The expressions epigeal and hypogeal germination are used to describe the conditions where the cotyledons are carried above or stay below ground surface, respectively, depending on the hypocotyl development (Rizzini, 1965; Kozlowski, 1972). Some authors consider the terms cryptocotylar and hypogeal to be synonyms (Duke, 1969).

In cryptocotyly, the seed may or may not be carried to above ground during germination; the situations in which the testa ruptures, the cotyledons develop chlorophyll, and the cotyledons remain at or below soil level or ensheathed in part by the testa. Cryptocotyly is part of syndrome of characters associated with certain modes of seedling development. Duke (1969) remarked that their first leaves are cataphylls. According to Ng (1978), the seeds of cryptocotylar species are larger and took longer time to germinate. Lack of endosperm and tree habit and large seeds are associated with cryptocotyly.

Phanerocotylar seedlings have either cotyledons or paracotyledons, the latter outnumber the former and alternate or opposite eophylls may be present. Garwood (1996) suggested classification of seedlings into five categories based on cotyledon's position and functions. Large amount of reserves favour
Review of Literature

growth under low-light conditions while small reserves and photosynthetic cotyledons favour fast growth in light-rich environments (Ng, 1978; Kitajima, 1996a; b; Garwood, 1996).

Ibarra - Manriquez et al. (2001) studied the seedling morphology of 173 trees and 37 lianas from a community perspective to identify major patterns of seedling functional types in a Mexican rainforest. Most common seedling type was PEF (Phanerocotylar Epigeal Foliaceous) followed by CHR (Cryptocotylar Hypogeal Reserve), PER (Phanerocotylar Epigeal Reserve), PHR (Phanerocotylar Hypogeal Reserve) CER (Cryptocotylar Epigeal Reserve). Animal dispersal syndrome of heaviest fleshy seeds was correlated with CHR type and PEF seedling associated with the lightest seeds of pioneer species. The results showed an evolutionary convergence of seedling types at the community level worldwide and the existence of a phylogenetic inertia in the evolution of initial seedling morphology. Those authors suggested that survival of the fittest seedlings depended on the seedling morphology or seedling types which consisted of size, function, position of cotyledons and the amount of maternal seed reserves. Based on phylogenetic signal tests, closely related species typically had similar cotyledon types, but did not have similar seed sizes, supporting that cotyledon morphology is phylogenetically more conservative than seed size (Garwood, 1996).
Species with photosynthetic cotyledons use light energy as an energy source earlier than those with reserve cotyledons (Kitajima, 2002). Reserve cotyledons, on the other hand provide resources to support seedling energy demands during times of stress and may be an adaptation to growing in low light (Ibarra-Manriquez et al., 2001).

Franceschini (2004) reported an unusual case of epigeal cryptocotylar germination found in Rollinia salicifolia Schltdl. (Annonaceae) and described and discussed the seedling morphology in relation to the terminology used for germination studies. The morphological characters shown by R. salicifolia seeds and seedlings - a non-chlorophyllous embryo, abundant endosperm, thick woody seed coat, thickened hypocotyl and non-photosynthetic haustorial cotyledons - are closely related to its epigeal cryptocotylar germination.

Maia et al. (2005) analysed the relation between seed size, seedling morphology and germination for 11 non-pioneer tree species typical of Amazonian Varzea floodplain forests and presented a classification of seedling morphology and establishment strategies. The seedlings were classified according to seed weight and size (length x width) and the position and function of their cotyledons. The most frequent seedling type was PEF (Phanerocotylar Epigeal Foliaceous) followed by CHR (Cryptocotylar Hypogeal Reserve), PHR (Phanerocotylar Hypogeal Reserve) and PER...
Review of Literature

(Phanerocotylar Epigeal Reserve), which also had the smallest seeds and the highest germination percentages.

Based on morphological and functional features, the seedlings of dicotyledonous plants were divided into 17 distinct types by Ye (1983). The most primitive type of dicotyledonous seedling is the ‘Polyalthe Type’. Its seedling morphology is similar to that found in the seedlings of Cycas and Ginkgo, and perhaps similar to those of seed ferns. According to Ye (1983), the "Magnolia" type is evolutionarily more advanced. From the Magnolia type several different evolutionary lines resulted in different seedling types. A number of evolutionary ‘dead ends’ arose from the ‘Polyalthe type’. These are restricted to families of Magnoliidae.

Paria and Kamilya (1999) suggested that seedling morphological characteristics of different taxa could be utilised in the context of Plant taxonomy. According to those authors, a good procedure for identifying plants depends upon keys in which some discriminating features are taken into account and in their investigations in Euphorbiaceae, seedling characters have been used in the construction of keys for identification. The preliminary analysis of the distribution of seedling characters in the Euphorbiaceae suggested that they may prove quite important in phylogenetic studies of the family.
Review of Literature

Seedlings of one species are usually uniform, although they may differ in measurements of parts and speed of development. The organs and characters of seedlings are limited in number, but their diversity is much and as such, specific combinations of morphological characteristics may be used for identification of species. In view of paucity of such data in Indian Flora, an attempt has been made to investigate the seedling morphology of Euphorbiaceae (Paria and Kamilya, 1999), Bignoniaceae (Paria et al., 1995), Asteraceae (Ahammed and Paria, 1996), Polygonaceae (Kamilya and Paria, 1993) and Leguminosae (Paria et al., 2006) which offered ample scope for the construction of artificial keys for identification.

Seed germination and seedling development have been studied in *Myrtus communis* to elucidate the presence of morphological and anatomical adaptations that enhance successful seedling establishment under biotic and abiotic stresses (Aronne and De Micco, 2004). Those authors suggested that on water scarcity, a dense ring of hairs was developed in the lower region of the hypocotyl, which helps in water absorption and also in anchorage. Early development of suberized layer of exodermis in the radicle and phenolics in the hypocotyl cortical parenchyma also were noticed. These characteristics are formed to a strategy of water absorption, anchorage and also act as defense against animal predation through phenolics. According to those authors, these features together with the absence of dormancy, fast
germination and high germinability can be considered advantageous in order to maximize reproductive success, seedling establishment and survival in Mediterranean environments.

Jain (1982) opined that adaptations, of seed/seedling to environmental changes or phenomena require that the behaviour of plants should be synchronized with change of the prevailing season. Examples include annual grassland communities possessing seeds with after-ripening requirement for germination which is linked with probability of summer rainfall and dormancy-cycling in buried seeds of annuals of humid temperate climates (Baskin et al., 1993; Baskin and Baskin, 1998; Baskin and Baskin, 2001).

An investigation undertaken by Hodgson and Mackey (1986) revealed that the major families in the Sheffield region of Central England are specialized to varying degrees with respect to three ecologically important attributes: growth rate, seed size and germination behaviour. These attributes help many species in evolutionarily advanced families to exploit highly productive and disturbed habitats and to exploit the less productive habitats by a large number of species of primitive families consisting of a greater proportion of rare species. Lesser number of heavier seeds with large reserves produced usually on apical or basal placenta will increase the probability of seedling establishment under unfavourable environmental conditions as in the shaded environment of woodland. Biennials tend to have
Review of Literature

heavier seeds than annuals. Seed weight is to some extent a function of plant height. Families with endospermous seeds usually produce large seeds in moist environment and the embryo is small, and a period of embryonic growth, with the seed in an imbibed state, may follow seed set and precede germination. Even though, two-celled form of proembryo development is characteristic of larger seeded families, it usually prevails in drier habitat and together. In dry habitats, if seed coat is impervious, a non-endospermic seed with a relatively large embryo is favoured. These conclusions reached above can be used to provide an idealized classification of seeds within a local flora. If the interrelationship between seed size and other attributes have a general relevance, the distribution of the familial character status may be used to predict lines of ecological specialization within the Dicotyledons.

Species with small seeds, small seedlings, thin photosynthetic cotyledons, fast germination, small adult stature and dispersal by small animals were associated with open habitats. Many of these relationships are well documented (Ng, 1978; Garwood, 1996; Kitajima and Fenner, 2000; Ibarra-Manriquez et al., 2001). According to Kitajima and Fenner (2000), Leishman et al. (2000) and Westoby et al. (2002) seed dispersal mechanism and cotyledon types and function are directly related each other and are dependent on ecological conditions. For example, photosynthetic cotyledons are advantageous in high light environment where small seed size can be
compensated for the faster autotrophic growth. Ibarra–Manriquez et al. (2001) opined that reserve cotyledons provide resources to seedling during time of stress and it is an adaptation to grow in low light.

A correlation between evolutionary and ecological aspects of early seedling morphology in East African Trees and shrubs species drawn by Zanne et al. (2005) revealed that seed size and cotyledon morphology are two key juvenile traits that have evolved in response to changes in plant species life history strategies and habitat associations. According to those authors, species with large seeds, large seedlings, thick storage cotyledons, slow germination, large-stature adults and dispersal by large animals were common in forest and gap habitats. An opposite suite of traits was common in open habitats.