REPRODUCTIVE BIOLOGY OF *Terminalia* SPECIES OF TROPICAL MOIST DECIDUOUS FORESTS OF KERALA

By

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THESIS

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Dedicated

to

the memory of my beloved parents

DECLARATION

I hereby declare that the thesis entitled "REPRODUCTIVE BIOLOGY OF *Terminalia* SPECIES OF TROPICAL MOIST DECIDUOUS FORESTS OF KERALA" is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Introduction

INTRODUCTION

Trees are vital component of our economy and environment. The successful cultivation of tree crops requires a detailed knowledge of their reproductive biology. In many crops, the marketable commodities are flowers, fruits and nuts which are the products of successful reproductive development. In most of the forest trees the most popular, economically feasible propagation option is by using seeds. Breeding programme aimed at tree improvement also requires knowledge about the reproductive biology of the species. Controlled pollination and stringent selection can be applied to improve a wide range of tree crops. The development of successful crossing techniques depends upon an understanding of the breeding system of the species. Above all the study of reproductive biology, the interaction between natural population structure,floral biology and vector responsible for pollination and seed dispersal are an essentiality for conservation of threatened and endangered species. It will also help to develop appropriate management strategies for both *in situ* and *ex isitu* conservation.

Terminalia is an important genus of moist decidous and decidous forests of India, particularly Kerala. In natural forest the genus is mainly represented by three species viz., *Terminalia paniculata, Terminalia tomentosa* and *Terminalia belerica. Terminalia paniculata* and *T. tomentosa* yields good quality commercial timber which is used for various construction purposes. *T. belerica* is a constituent of myrobalans with high medicinal importance. *Terminalia catappa* is another important species of

this genus, which is widely cultivated for its ornamental value. The kernels of the seed resemble almond and are eaten.

Eventhough most of the species are in demand for forestry programmes, the non availability of improved planting materials of the species is a problem. So far no serious tree improvement programmes have been undertaken in this genus mainly because of inadequate information on its reproductive biology. The current study on reproductive biology of *Terminalia* species of tropical moist decidous forests of Kerala was taken up with the objective of unravelling the knowledge pertaining to breeding system and breeding behaviour.

Review of Literature

REVIEW OF LITERATURE

Knowledge of reproductive biology and phenology of trees are very essential for efficient silvicultural and horticultural production. But compared to agricultural species reproductive biology research lagged far behind in tree crops. Providing controlled environmental conditions viz., suitable temperature, light and other such measures are possible in agricultural species. The situation in tree crops is different, many difficulties and complications inherent in trees are imposed by its perennial nature and large size which make tree crop research very cumbersome.

Terminalia Linn. is a genus which belongs to the family Combretaceae and this species of the genus are reported to be present in India. They are important constituent of the Indian decidous forests (Troup, 1986). Trees which belong to this genus are large to medium sized with leaves alternate or sub opposite frequently crowded at the end of each branch. The flowers are green or whitish spicate or panicled spike, hermaphrodite or upper flowers male and lower hermaphrodite. Fruits ovoid, drupaceous or winged (Anderson, 1875; Brandis, 1905 and Gamble, 1935). Except for a few studies like pollination mechanism in Terminalia (Srivastava, 1993) and reproductive behaviour of Terminalia (Srivastava, *et al.* 1996), not much works have been done with regard to tree improvement and reproductive biology of this genus so far. The available information related to the study are reviewed hereunder.

2.1 Phenology

Information on phenology or periodic events in trees is an essentiality for successful reproductive biology research. Information on phenology of a wide spectrum of plants were attributed to the studies and the observations of some keen investigators. Pioneer investigators in this fields include Croat (1969), (1975), Frankie (1974). Gentny (1975), Sasaki *et al.* (1980), Arjunan *et al.* (1995). Works on periodic events of trees in humid tropics were also conducted by Humes (1942), Koelmeyer (1959), Grat (1964), Smith (1970), Bergers (1972) and Foster (1973). Phenology of premontain rain forest of Pacific Columbia were monitored and recorded by Hilty (1980).

Phenological expressions were showing tremendous variation, as periodic events in plants were controlled by endogenous and exogenous factors. These variations are accounted to many climatic, genetic and environmental factors. Huxly and Eck (1974) reported that the periodicity of vegetative growth, flowering, fruiting and leaffall of 33 species observed varied considerably with respect to the change of climatic factors and the data fit the hypothesis that the exogenous control of vegetative flush by climatic factors is related with leaf ageing and exogenous leaf inhibitors. Role of different climatic factors in determining the phenology were studied by Sarvas (1962) and found that the temperature was the most important parameter which determined the late or early occurrence of a phenological events. Similar observations were also made by Winstein (1982) on *Pinus helpenris* in Israel.

Some species showed irregular nature in their phenology. Yakava (1977) observed irregular and random leaf fall with out any specific period. Completely irregular flowering, fruiting and other phenological events were seen in five out of the forty five species by Medway (1972). Artificial manipulations also were reportedly influencing phenology of species. Pruning in *Peltaphorum pterocarpum* resulted in temporary disturbance of the phenological events. A study on the effect of natural and artificial defoliation on flowering and fruiting of *Emblica officianalis* by Ram (1982) concluded that defoliation stimulate flowering and fruit set.

2.2 Juvenility in trees

Tree crops undergo a period of juvenility, during which they will not flower or fruit. Under natural conditions this period lasts between one and forty five years depending on the species and the environment (Ng, 1977; Hackett, 1985). Several morphological and physiological features are associated with juvenile phase and these include thorniness in citrus, vigorous upright growth in larch, pubescent leaves in pecan, differences in colour and leaf shape and waxiness or phyllotaxis from the mature foliage in some eucalyptus and pines (Longman, 1961; Scoort and Cameron, 1975; Crane and Iwakiri, 1981; Wetzstein and Sparks; 1986; Green wood, 1987).

The length of juvenile period is associated with the growth rate of seedlings. Reduction of juvenile phase can be achieved by growing seedlings under conditions which stimulate continuous or vigourous growth (Hackett, 1985). The time of flowering in Rhododendron can be halved by growing them under very long photo

period or at continuous light at temperature of 15-20°C (Doorenbos, 1955). Reduction of juvenile phase has been achieved using continuous light in *Betula vorrucosa, Mallus hupenhensis, Pinus resinosa* and *Picea glauca* (Longman and Wareing, 1959; Holst, 1961; Zimmerman, 1971). The length of juvenile period is also controlled strongly by genetic factors. Inheritance in Betula has been reported to be under polygenic control (Eriksson and Jonsson, 1986). In apple polygenic factors are said to determine inheritance in an additive manner (Visser, 1976).

2.3 Dormancy

Dormancy is a period during the life cycle of a plant when there is little or no visible growth. This phenomenon is noticeable more in the case of temperate trees and decidous species, which lose their leaves prior to dormant period. This enable them to withstand subzero temperatures. The capacity of resistance to low temperature varies among leaf and flower bud (Quamme and Gusta, 1987). Eventhough the actual mechanism of dormancy is not clearly known, three major mechanisms have been proposed (Lang, 1986; Lang *et al.*, 1985, 1987). Ecodormancy in which adverse environmental factors such as temperature extremes, nutrient deficiency and water stress are operating. Paradormancy is regulated by physiological factors out side flower buds such as apical dominance photo periodic response detected by the leaves or bud scale. Endodormancy is regulated by physiological factors inside the affected structure including chilling responses and photo periodic responses detected by the primordium itself.

There is considerable variation in the nature of expression of dormancy among cultivars of the same species. With regard to chilling requirement late blooming cultivars of apple was reported to have a long chilling requirement (Iezzoni and Hamilton, 1985 and Powell *et al.*, 1986). The length of period of chilling requirement for breaking dormancy is under genetic control (Saure, 1985). Selection and breeding can be a useful tool in obtaining new varieties of required suitability.

2.4. Reproductive biology

2.4.1 Flowering

Flowering of tree crops is a highly complex process involving many developmental stages. The physiology of flowering is still rather poorly understood (Bernier *et al.*, 1985). Trees interact with the environmental conditions at all times of the year and flowering is often closely related to seasonal climate changes.

2.4.1.1 Flower initiation

The first stage in flowering process is floral induction or evocation, when the vegetative meristem becomes programmed to change into a reproductive meristem. Flowering is a growth process and the nature of stimulus required to trigger this process is not known. There have been relatively few studies of floral induction in tree crops (Buban and Faust, 1982). The flowering process consists of a number of important stages, all of which must proceed successfully for the realization of yield potential. But usually floral initiation is recorded at the time of the macroscopic appearance of flower buds. In many cases this is inaccurate as floral initiation may occur weeks or months prior to the appearance of buds.

2.4.1.2 Flowering and environment

The extent of influence of environmental factors on the reproductive behaviour and expression in trees varies on account of several factors. Climatic range, species, growth habit and age of the trees are some among them. In contrast to many annual plant species, flowering in most of the woody perennials does not appear to be under photoperiodic control. But there are some exceptions like *Picea, Pinus, hibiscus,* apple and *Rhododendron.* In *Picea glaucca,* night breaks of red light will inhibit the production of female cones indicating that the flowering is under short day control (Duncan *et al.*, 1979). Similar observations were also made by (Longman, 1961; Mathews, 1963; Green Wood, 1978). Short days of 8 hours light which accelerated floral initiation in Rhododendron indicate that the effect is quantitative rather than absolute (Riley, 1969). In monoecious and dioecious species, which have single sex flowers, light intensity can have different effect on female and male flower initiation. High light intensity induced female flower initiation in walnut and pines, whereas low light intensity, often caused by shading with the canopy favoured male flower production (Mathews, 1963; Giertych 1977; Ryugo *et al.*, 1980).

2.4.1.3 Flowering and nutrition

Nutritional status of the tree is another important factor which determine flower initiation. In general fertilizer application particularly nitrogen improves flowering in most of the tree crops (Sarvas, 1962; Mathews 1963; Puritch and Vyse, 1972; Weinbaum *et al.*, 1980 and Edward, 1986).

2.4.1.4 Flowering and cultural activities

Other cultural activities influence flowering include gravity and girdling (Mathews, 1963; Jackson and Sweet, 1972; Owens and Blake, 1985). Horizontally and downwardly trained branches of Japanese larch and some cultivars of apple produce more flowers than upward pointing branches (Long man and Warieng, 1958 and Truomp, 1987). Burger (1972) reported that previous year drought promoted flowering in shorea.

2.4.1.5 Flowering and temperature

Temperature also controls floral initiation in trees. In temperate species relatively high temperature during summer and early autumn appear to promote flower initiation, where as in tropical species, a relative reduction in temperature is beneficial (Owens and Blake, 1985 and Sowth wick and Davenport, 1986). Flower induction in mango is more under relatively low temperature conditions of 19°C day and 13°C night (Shu and Sheen, 1987). The cold requirement for floral initiation in olive was noticed by Hacket and Hastman, (1967).

2.4.1.6 Flowering and growth regulators

The role of growth regulators in floral initiation in trees have made marked progress in recent years. Plant growth inhibitors such as chlormequat, Alar and TIBA (Tri-iodobenzoic acid) reduce vegetative growth and promote flowering of angiosperm tree species (Cathey, 1964; Crieley, 1969; Ramirez and Hoad, 1984 and Embree *et al.*, 1987).

2.4.2 Flower development

There is a wide variation in the structure of floral buds of tree crops. Floral buds may be produced either terminally or in the leaf axils, on current growth or on old wood. In avacado, the terminal meristem of floral bud generally remains vegetative, and floral initiation occurred in the axillary meristem of the floral bud (Scholefield *et al.*, 1985). Citrus is one of the most variable crops with regard to bud structure. The buds can be terminal or axillary and may contain flowers or mixture of flowers and leaves (Jackson and Sweet, 1972). Some tropical tree crops showing the phenomenon of cauliflory, the flower buds appear directly from the trunk with no accompanying leaves or shorts. Such condition in common in *Artocarpus* and *Theobroma*(Lent, 1966 and Sinha, 1975).

Angiosperm flowers are morphologically more complex than those of gymnosperms. The transition to flowering in angiosperm occurs when the short apex ceases to produce leaves and starts to produce floral parts (Lord and Eckard, 1985,1987). In walnut, transition occurs within four weeks of bud formation following short growth in summer (Ryugo and Ramos, 1979). Floral initiation follows 21 nodes in apple (Luckwill and Silva, 1971). At the earliest stage of development, the floral parts are undifferentiated mounds of tissue. The bud scale, the bud, the bract and the leaf are all homologous organ and have the same morphology during early stages of floral initiation. The major difference between the bracts and the scale is that the latter has flower primordium in its axil (Banno *et al.*, 1986).

2.4.3 Flowering pattern

Little work has been done on flowering pattern and floral biology of tropical forest trees. However, detailed investigations were carried out in fruit trees like mango (Singh, 1958, 1960), Jack (Sinha, 1975 and Joseph, 1983), Sapota (Nalwadi *et al.*, 1977), Nutmeg (Nazeem *et al.* 1981), Tamarind (Thimmaraju *et al.*, 1977) and Cashew (Shivanandam *et al.*, 1986).

There is marked variation observed among trees in expressing flowering patterns. Even individuals of the same species are said to exhibit marked variations. Bawa (1983) and Primark (1985) reported that this variability can be seen in populations and ecosystems and also according to the climatic conditions. Majority of the tropical trees are showing flowering patterns between two extreme conditions (Jansen, 1971; Henrich and Roven, 1972; Gentry, 1974). At one extreme, are the species with mass flowering individuals producing large number of new flowers each day over a week or less. At the opposite extreme, are the species with steady state individuals producing small number of new flowers daily or for many weeks. Details of flowering season of Indian trees were given by Troup (1986). Observations in Costaruiacan forest trees by Baker *et al.* (1983) showed a bimodal distribution in flowering pattern. Medway (1972) and Jansen (1974) reported that dipterocarps flowered synchronously once in 5 to 13 years. Teak, principal tree species in India, also showed marked variations in flowering patterns (Nanada, 1962; Darbul, 1976; Ramprasad *et al.*, 1990). Sahai and Tandon (1993) reported that this variation is quite pronounced with in and between trees.

2.4.4 Breeding system

Accurate assessment of the breeding system is possible only by detailed observation of flowers. The floral structure is often closely related with this function in many species. The structural and functional relationship of the female and male reproductive structures often controls the pollination biology and genetic make up of this population (Sedgly and Griffin, 1987).

In general, flowers are adapted for either self pollination (autogamy) or cross pollination (allogamy). Autogamy is favoured by hermaphrodite condition, simultaneous maturation of the male and female organs and spatial relation between stigma and anther also are factors which determine self pollination. Cross pollination is favoured by spatial separation of sexes, temporal separation of sexes and functional failure.

2.4.5 Monoecy and dioecy

In monoecious species, the female and male reproductive organs are seperated in different floral structures in the same plant. It is prevailing in gymnosperms, angiosperms, monocotyledons and dycoteledon temperate timber and nut crop species (Yampolsky and Yampolsky, 1922). In lichee and some species, three types of flowers are produced, the functional flowers with fully developed pistil but the anthers do not dehise, two types of male flowers, some with rudimentary pistil and some with pistils well developed but not functional (Mustard, 1960). Monoecious flowers produce more functional male flowers than functional female flowers, female flowers are 0.1% in Aesculeus (Coker and Totten, 1945).

In dioecious species, female and male reproductive organs are seperated in different floral structures on different plants. Self pollination is impossible in dioecious plants. Some genus like Aesculeus includes both monicious and dioecious species (de Tong, 1976).

2.4.6 Sex expression

Sex expression is very important with regard to reproductive behaviour of trees. In many species like *Carya illinoensis, Juglans cinerea, Populus trimuloides* and *Quercus rubra,* the flowers are both structurally and functionally unisexual from initiation through out the period of development (Sattler, 1973; Wetzstein and Sparks, 1986). Some functionally female lichee flowers have anthers which do not dehisce but many nevertheless contain pollen grains which show viability (Mustard *et al.*, 1953). Other genera with unisexual flowers bearing vestigial organs at some stage of development include Aesculus, Anacardium and Mangifera (Fuliano and Cuevas, 1932; Hardin, 1956; Ascenso and Mota, 1972). Genetic control of sex expression involving heteromorphic sex chromosome has been reported in a few species; but has not been equivocally demonstrated in tree crop genera (Westergard, 1958; Williams, 1964; Lionakis, 1985). In figs sex is determined by two closely linked pairs of alleles one pair controlling the female function and the other pair male expression (Storey, 1975). But in general the male-female sex ratio in wild trees and breeding progeny is approximately 1:1 (Flach and Cruickshank, 1969; Farmer and Pitcher, 1981).

Plant growth regulators are effectively used in the control sex expression in a number of tree crops. In general, auxin levels are higher in female than in male flower structures. The above fact has been established by Herlop-Harrison (1964); Hashizume (1969); Pharis and Kuo (1977) after conducting studies in *Salix caprea* and in many conifers. Ethelene releasing compounds has also been reported to be inducing femaleness. 2. Chloroethyl phosphoric acid (CEPA known as etheral), can induce the production of female flowers on male plants of *Morus nigra, Morus alba* and *Morus latifolia* (Jaiswal and Kumar, 1980 and Ogure *et al.*, 1980).

2.4.7 Anthesis and Anther dehiscence

Anthesis and anther dehiscence are found to vary considerably among species and even with in trees of same species. In nutmeg, the female buds took 154 days and the male buds took 84 days from emergence to anthesis (Nazeema *et al.*, 1980). The anthesis was occurred between 7 PM and 11 AM in male flowers and 9 PM and 3 AM in female flowers. Anther dehiscence occurred 25 hours before anthesis. In *Anacardium occidentale* anthesis occurred on 6 hours (Thimmaraju *et al.*, 1980). Pandy and Sharma (1984) reported that in Prunus species the anthesis started between 6 hours and 8 hours. In another study, Ramires (1984) reported that the anthesis in *Bauhenia ungulata* was found to be occurred between 17 and 19.30 hours and anther dehiscence occurred one hour later.

A study by Minhas (1985) in sapota revealed that flowers opened after 05 hours and reached its peak about 07 hours. Anther dehiscence occurred before anthesis suggesting protandrous conditions. Similar observations were made by Karnik and Gunjate (1984) in *Garcinia indica.*

2.4.7.1 Stigmatic receptivity

The angiosperm stigma characteristics were studied in detail by Baker *et al.* (1973) and Heslop-Harrison and Shivanna (1977). The receptive angiosperm stigma is covered by extra cellular secretion which may be copious or barely present and may contain carbohydrates, proteins, lipids, enzymes, phenolics and amino acids (Knox, 1984). In most of the species, maximum stigma receptivity occurs at or shortly after anthesis. Proteaceae and Myristicaceae members which show protandrous dichogamy are exceptions. In *Macadamia* full receptivity does not occur until two to three days following anthesis (Sedgley *et al.*, 1985) and in *Eucalyptus regnans* it occurs 10 to 14 days after flower opening (Triffin and Hand, 1979). The stigma may be receptive to pollen for only a few hours as in mango (Spencer and Kennard, 1955). But in cherry, stigma may receptive for up to 10 days following anthesis (Stossr and Anvari, 1982).

Stigmatic receptivity is tested by feeling the stickiness of the stigmatic surface and also by the peroxidase activity of the stigmatic surface (Galen and Plowright, 1987). Sticky stigmas are considered receptive. In the stickiness test, dry one is considered non receptive. In the peroxidase or enzyme activity test, the excised stigmas are plunged into freshly prepared, H_2O_2 solution or benzidiene solution. The bubbling at stigmatic surface or turning stigma surface brown is an indication of receptive stigma.

2.4.8 Pollen studies

Taxanomists and Paleontologists are attracted to the research on pollen grains due to its great significance in palynology. The science of pollen will also helps in the elucidation of radiation effects (Brewbaker, 1959), classification of angiosperms (Wodewoms, 1935) and also helps in identifying the disputed varieties or species (Nair, 1960, Nair and Mehra, 1961). The storage and germination of pollen grains play an important role in assisted pollination and hybridisation programme.

The amount of pollen produced per anther varies considerably even between varieties (Nair, *et al.* 1964). Studies on pollen morphology is also important with regard to floral biology and taxonomy. Rao and Khader (1960) made investigations on pollen morphology of six fruit plants. Moti *et al.* (1973) carried out investigations on the morphological characters of 101 mango varieties.

2.4.8.1 Pollen viability

Pollen viability has great importance in reproductive biology research and hybridization works. Alexander (1969) and Stanly (1974) suggested various methods for testing the viability of pollen grains including both germination and non germination assays.

2.4.8.1.1 Stain test

Different stains which give colour to viable pollen is often used as indices of viability. Zirkle (1937) described the method of mounting pollen grains in aceto

carmine. The pollen grains which stained well and well shaped were taken as fertile and unstained shrivelled ones as non viable and sterile. Alexander (1969) used Alexanders solution for staining pollen grains. Stanley and Linkens (1974) mentioned different stains such as aniline blue, potassium iodide, methyle green etc., for estimating pollen viability.

2.4.8.1.2 Germination tests

They are more accurate than stain tests in assessing the pollen viability. Sugar solutions are commonly used as media for pollen germinations Brink (1924) observed that when pollen was cultured in sugar or sugar agar medium, the pollen tubes were as long as or even longer than those found in nature. The optimum concentration of sugar and agar varies with species. In sapota the optimum concentration of 16 per cent sucrose and 0.7 per cent agar was found to be the best for pollen growth (Rao and Khader, 1960); 25 per cent sucrose and 0.5 per cent agar for mango (Singh, 1961); 30 per cent sucrose for cashew (Damodaran *et al.* 1966); 10 per cent sucrose for Jack (Gopinathan *et al.,* 1983) and 5 per cent sucrose for nutmeg (Bavappa and Banda, 1981).

2.4.9 Pollination

Pollination is the first male female interactive step in the reproductive process. It is the transfer of pollen from male reproductive structures to receptive stigmas or micropyles. Pollination management is essential and it will ensure that adequate pollen of appropriate genotypes were transferred during the pollination and optimal

quantity and quality fruit or seeds were produced. Excluding some parthenocarpic and autogamous species, the pollination process requires the intervention of a vector to effect pollen transfer. In nature, a wide range of pollen vectors are implicated in pollination (Faegri and Van der Pijl, 1979). These include abiotic agents of wind (anemophily) and water (hydrophily) as well as insects (entomophily), birds (Ornithophily) and mammals (Therophily). Insects and wind are by far the most significant pollinating agengs in tree crop species.

Srivastava (1993) reported the pollination mechanisms in the genus *Terminalia* Linn. Five orders of insects viz:, Lepidoptera with six of its species, Hymenoptera with six of its species, Hemiptera with two of its species, Coleoptera with two of its species, and Dipteral with six of its species were involved in their pollination. It was also observed that the pollen foraging insects operated between 7.30 and 12.00 hrs in the morning and 15.00 to 17.00 hrs towards the evening.

The size of the flower, spatial arrangement of pistil and stamens, accessibility of nectar and inflorescence structure all influence the plant-pollinator interaction (Wyatt, 1981). In general, the more exposed and accessible the nectar and pollen, the greater will the variety of flower visitors. More specialized zygomorphic flowers with a deep corolla enclosing the nectar as in *Gmelina arborea* needs more specialised pollinators because the visitor must harvest the flower in a very precise manner and be of a suitable size to contact both stigma and anther in the process. Only one pollen vector type utilizes the syconium of ficus (Faegri and Vanderpije, 1979).

The climate and weather conditions also affect the pollination. As the climate affect the timing and total period of flowering season and synchrony of flowering, it also affects pollen shed, effective pollination period and the foraging behaviour of vectors. The effects on population dynamics of pollinator on account of the climate too are important (Smith, 1970).

2.4.10 Fruit set

The term fruit set is used rather loosely in angiosperm literature and it refer either initial or final fruit set. Final fruit set is the number of seeds that remain on the tree at fruit and seed maturity. Initial fruit set occurs shortly after anthesis and involves swelling of the ovary. An analysis of the proportion of flowers setting fruit for 447 species of angiosperm has shown that the mean for woody perennial is significantly lower than that for either annuals or herbaceous perennials (Southerland, 1986). The final event in the initial fruitset process is the division of zygote to initiate embryo development. Flowers which do not set fruit may turn yellow and shed from the tree. Parthenocarpic fruit will set in the absence of fertilization and in some non parthenocarpic species limited swelling of unfertilised fruits can occur (Sedgley, 1980). Initial fruitset can be drastically reduced by adverse environmental conditions such as low temperature (Thompson and Liu, 1973).

Final fruitset is generally lower than the initial fruitset and is due to fruit drop during developmental period. The final fruitset value varies enormously between tree crops, tropical and subtropical species which have large number of small flowers

which produce only a few large fleshy fruits. Final fruitset value of mango and avocado ranges from 0.01 and 0.3 per cent (Chaplin and West wood, 1980). In contrast nonfleshy fruit crops such as Walnut and Almond may retain up to 100 per cent of their fruits to maturity. In most of the tree crops with multiple ovules, only will develop to seed maturity (Laun, 1986; Nactmura, 1986).

2.4.10.1 Ripening of fruits and seeds

Ripening is a genetically determined and regulated event which prepares the fruit or seed for dispersal. But the control mechanism in ripening varies on account of the species diversity and variation in morphology of the fruit (Brady, 1987). The physiological changes associated with ripening are not easily distinguishable from senescence. So ripening has defined as the changes that occur from the latter stages of growth and development, while senescence process are those which follow physiological or horticultural maturity (Watada *et al.*, 1984). Ripening is regarded primarily as manifestation of senescence in which intercellular organization begins to break down (Sacher, 1973). This disorganization leads to mixing of enzymes and their substraits and activity of hydrolases and enzymes responsible for the production of ethylene and pigments were also observed. The other hypothesis with regard to ripening is that it is the final stage of differentiation and this is thus a direct process requiring the synthesis of specific enzymes. Both types of mechanisms are involved but to different degrees in different fruits (Brady, 1987).

The works on ripening of fruit has been restricted to horticultural crops especially to temperate pome and stone fruits also to some extent as citrus, avocado, mango and pistachio (Hulme, 1970, 1971). The most readily apparent phenomena in the ripening processes are colour change which involves chlorophyll loss, resulting subsequent synthesis of new pigments, alternations in flavour, changes in acidity, astringency, sweetness and softening of the fleshy tissue (Rhodes, 1970). The concentration of sugar in fruit will be very high at the time of ripening in many species. Bollard (1970) cites that total sugar in dates, apples, peaches and figs comprises 63 to 81 per cent of total dry weight.

The ripening fruit exhibits characteristic changes in respiration rate over time (Rhodes, 1970). In majority of fruit crops such as apple, mango, peach, peccan and plums, the change from growth to senescence and ripening is marked by rapid rise in respiration rate, a peak or climacteric (Baile, 1960 and Rhodes, 1970). In contrast non climacteric species, such as cherry, citrus and fig. where the respiratory pattern shows a slow drift downwards after the fruit is detached are generally ripen on the tree itself.

2.4.10.2 Indices of ripeness

Ripeness in fruits were determined using several methods and these methods varied depending upon the fruit type and requirement. Harvest indices have been based on all major changes that occur during maturation and ripening of fleshy fruits (Hulme, 1970, 1971). The visual assessment of the appearance is the simplest

method. The change in colour from green to yellow, orange or red is ineffective in many crops such as apple, mango, apricot and pear (Delwiche and Baumgardner, 1985; Meddicott *et al.*, 1986). A general dulling of the skin is an indicative of maturity in avocado in combination with yellowing of the pedicel. Fruit softening and loosening from the tree are used as indicators of maturity in a variety of fruits (Jackson, D.I., 1986). The browning of testa in apple and avocado depends up on the relationship between seed and fruit maturity (Jakson, 1986).

There are also several approaches to quantify the ripening process. The number of days required to reach fruit maturity from full bloom is a reliable indicator in some climates (Fanic, 1979; Jakson, 1986) and is used in apple in some part of U.S.A. and Australia. Heat units measured as the accumulated degree above a designated minimum temperature are also reliable for prediction of maturity (West Wood, 1978).

Materials and Methods

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

The present study was carried out in the deciduous forests of Vazhachal Forest Division and in the main campus of Kerala Agricultural University. Vazhachal Forest Area lies between 10°23' north latitudes and 76°9' and 76°52' east longitudes. The main campus of Kerala Agricultural University which is located at Vellanikkara in Thrissur district of Kerala, lies between 10°32' north latitude and 76°10' east longitude.

3.1.2 Climate

The area enjoys a warm humid climate having a mean rainfall of 2980 mm. The mean maximum temperature ranges from 24°C to 30°C and the mean minimum temperature range was 15°C - 20°C.

3.1.3 Physiography

The forest area selected in Vazhachal for the study was highly rugged and undulating physiography wherein all kinds of aspects were met with. The study area in Kerala Agricultural University Campus was plane having an altitude of 22 to 25 m above mean sea level.

3.2 Method

3.2.1 Species

The following four species of *Terminalias* were selected for the study.

	Location
1. *Terminalia paniculata* (Maruthi)	Deciduous forests of
2. *Terminalia tomentosa* (Thenbavu)	Vazhachal Forest Division
3. *Terminalia* belerica (Thanni)	
4. *Terminalia* catappa	Kerala Agricultural University campus

Ten trees each of the four species were marked and serially numbered. The trees selected were middle aged, healthy and without any serious defects. The selected trees were observed for a period of twelve months starting from June 1996 to July 1997.

3.2.2 Phenology

Phenology of the four species of *Terminalias* were studied. The important periodic events observed were leaf shedding, dormancy, flushing, flowering and fruiting. The study areas were visited every month and the phenological stage of selected trees were recorded. The data obtained were used to prepare phenograms of the four species.

3.2.3 Reproductive biology

Studies on the reproductive biology of the four *Terminalia* species were carried out. Wooden frames of one square meter were fabricated and placed over the crowns

of each tree. The number of wooden frames placed on each tree depends up on the crown size of the tree. Approximately 5 per cent of the total crown area of the tree was covered by the wooden frames. The following observations were recorded from these selected areas.

3.2.3.1 Morphology

The morphology of the inflorescence and flowers were studied in detail, using a hand lens. Sections of flowers were taken and drawings of floral parts, inflorescence and flowers were prepared. Floral diagrams of the four species were also prepared.

3.2.3.1.1. Inflorescence character

Twenty five mature spikes were tagged on each tree and the number of flowers on each spike was counted. The number of male flowers and number of hermaphrodite flowers present on each spike were also recorded. The mean values were calculated from the data, separately for the four species.

Similarly length and breadth of spikes and individual flowers were taken in centimetres using a scale and the mean values were calculated.

3.2.3.2 Floral biology

The floral biology viz., anthesis, anther dehiscence, stigma receptivity and pollen fertility of the four *Terminalia* species were found out.

3.2.3.2.1 Anthesis

Preliminary observations showed that flower opening takes place during evening hours in *Terminalia paniculata* and *T. tomentosa* and during morning hours in *T. belerica* and *T. catappa*. In order to know the exact time of anthesis, mature spikes were tagged and flower buds on it were observed at half hourly intervals from 16.00 hrs onwards for *T. paniculata* and *T. tomintosa* and 6.00 hrs onwards for *T. belerica* and *T. catappa*.

3.2.3.2.2 Anther dehiscence

The period of anther dehiscence was studied by tagging mature spikes and observing the flower buds on it. Anthers of the flowers were examined using a hand lens. Preliminary observations indicated that anther dehiscence occurred after anthesis of flowers in the four *Terminalia* species. Later observations were made at half hourly intervals, starting shortly after anthesis of the flowers.

3.2.3.2.3 Stigma receptivity

The onset and duration of stigma receptivity was determined in the field by testing stigma for the production of peroxidaseae (Galen and Plowright, 1987). Stigmas aged (0-36 hrs) from floral opening were gathered from flowers closed in bags and plunged into vials containing 6 per cent w/v of hydrogenperoxide. The presence of bubbling on the surface of the stigma surface indicates peroxidaseae activity and considered receptive.

3.2.3.2.4 Pollen fertility

Opened flowers were collected shortly after anthesis and prior to anther dehiscence. The pollen was collected in acetocarmine (one per cent) glycerin mixture kept on a slide and covered with a clean cover slip. The slides were kept undisturbed for thirty minutes to allow the pollen grains to take the stain properly, before examining it under the microscope. The fertility was calculated as the percentage of normal well stained pollen grains to the total number of pollen grains in each microscopic field. Ten such fields were observed in each slide. The average was worked out and expressed as percentage.

The experiment was repeated by *in vitro* germination method using 4 per cent sugar + 0.5 per cent agar as the medium.

3.2.3.3 Flower production

The number of flowers produced by a tree during the study period of twelve months was found out separately for the four species. The number of spikes produced inside the sampled area (area covered by 1 m^2 wooden frames) was recorded. Flowering intensity (mean number of flowers produced inside one square meter) for the four species was thus worked out.

The data on crown height and crown width were used to work out the crown area of each tree. Average crown area of a single tree of the four species was also found out. This information was used to work out the average flower production by a tree.

3.2.3.4 Flowering pattern

Flowering pattern of individual trees of the four species was studied. Scores from 0 to 100 were given based on the number of opened flowers on each day after the onset of flowering.

(a) *Median flower opened day*:

It is an arbitrary day in which exactly half of the flowering activity has occurred. The day correspond to the score of 50 will give the median flower opened day.

(b) *50 per cent flowering*

It represents the peak flowering period. The period around the median flower opened day during which 50 per cent of the flowering activity happened. The period between days corresponds to the score of 25 and 75 will give the 50 per cent flowering.

3.2.3.5 Pollination time

To understand about the time of pollination of *Terminalias*, the longevity of opened flowers and the period of insect activity around the opened flowers were observed.

The longevity of opened flowers were found out by observing flowers from anthesis onwards upto the shedding or drying of floral whirls. The mean period of longevity of opened flowers was calculated separately for the four species. The insect activity around opened flowers from anthesis to the entire life span of the flowers were observed and data were recorded.

3.2.3.6 Self pollination

To know the extent of self pollination in *Terminalias,* inflorescence were selected and covered one day prior to anthesis for preventing any pollen contamination from out side. The inflorescence were shaken well to facilitate pollen distribution and self pollination. The extent of initial fruit set (swollen ovaries formed), seed maturity and germinative capacity of the seeds produced by self fertilization were found out.

3.2.3.7 Fruit set

3.2.3.7.1 Initial fruit set

To understand the initial fruit set in *Terminalias,* 25 mature spikes were tagged on each tree. The number of swollen ovaries formed on each spike was recorded. The ratio of swollen ovaries formed to that of the number of flowers observed expressed in percentage will give the extent of initial fruit set. The average value of initial fruit set was calculated for the four species.

3.2.3.7.2 Seed maturity

The swollen ovaries on tagged spikes were observed at monthly intervals at the initial stages of fruit development and observed weekly during the final stages. The different stages of fruit development from initial fruitset to seed maturity were recognized from the change in colour and size of the fruit. The mean number of days required from initial fruit set to each fruit developmental stages were found out. The germinative capacity of seeds at each stage was also studied.

The extent of fruits that reached the final stage of fruit development and became mature were found out as percentage total of the swollen ovaries.

3.2.3.7.3 Reproductive capacity

It represents the extent of germinable seeds produced with respect to the total number of flowers produced. It was estimated from extent of initial fruit set, seed maturity and germination percentage.

Results.

RESULTS

The results of the present series of investigations on reproductive biology of *Terminalia* species seen in tropical moist decidous forests of Kerala are presented hereunder.

4.1 Phenology

The phenology of the four species of *Terminalias* during the study period is illustrated in Figure 1 to 4.

4.1.1 Leaf shedding

All the four species of *Terminalias* showed change in leaf colour during leaf fall. In the case of *Terminalia catappa*, the leaf colour changes from green to red or yellow at the time of leaf fall while in *Terminalia belerica* the leaves turned to yellow colour at the time of falling. In *T. paniculata* and *T. tomentosa* the leaf colour changed from bright green to dull greyish green before the leaf fall.

Eventhough leaf fall in small numbers occurred regularly in all the four species, it occurred in significant quantity once or twice during the year.

In *Terminalia catappa* mass leaf shedding occurred twice during the annual period. The first major leaf shedding commenced from March onwards and it reached its peak during mid April. The second leaf shedding period was from the mid September and extented upto December. The peak period was during November and December. The trees became completely leaf less during this period.

Fig. 1. Phenogram of *Terminalia catappa*

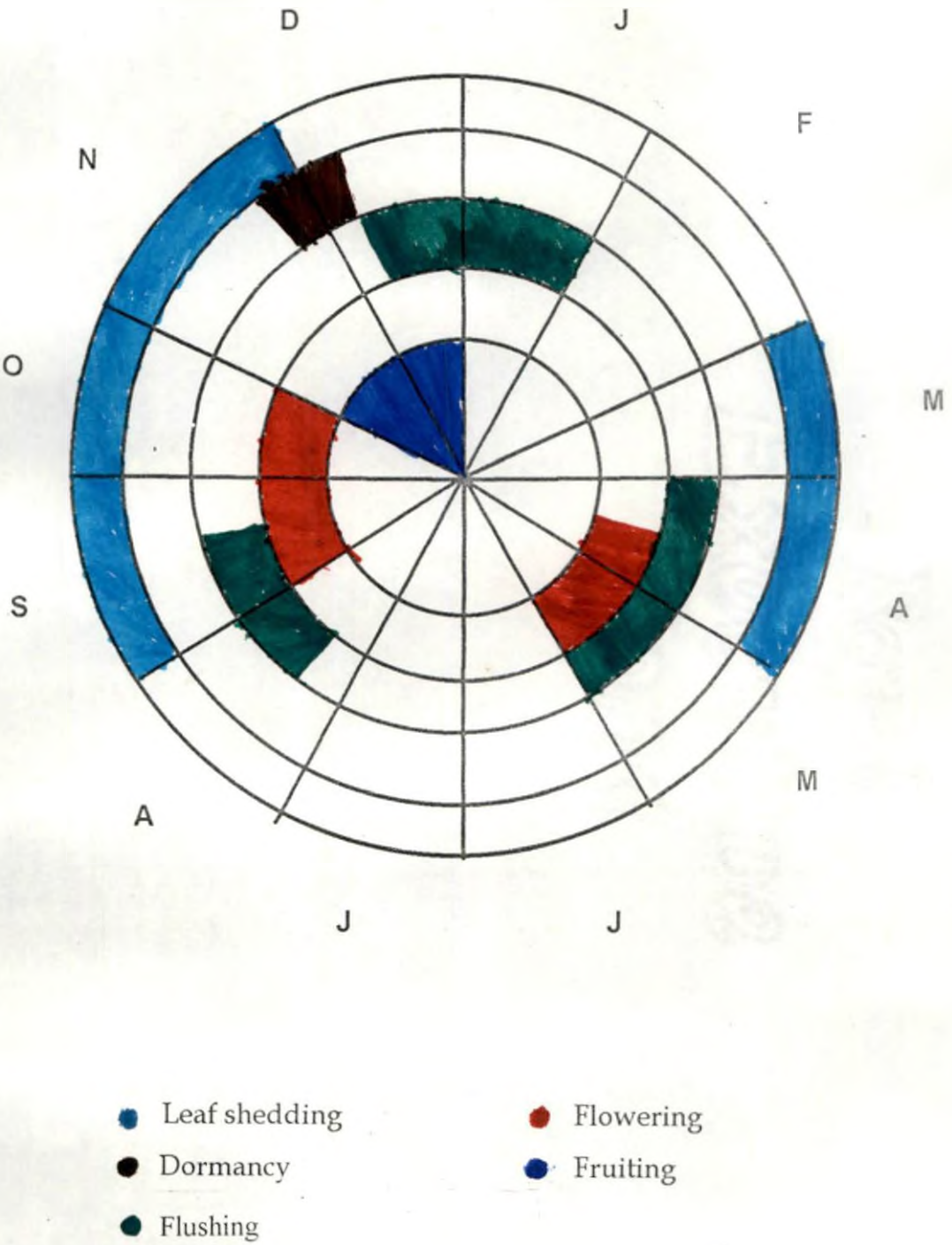


Fig. 2. Phenogram of *Terminalia paniculata*

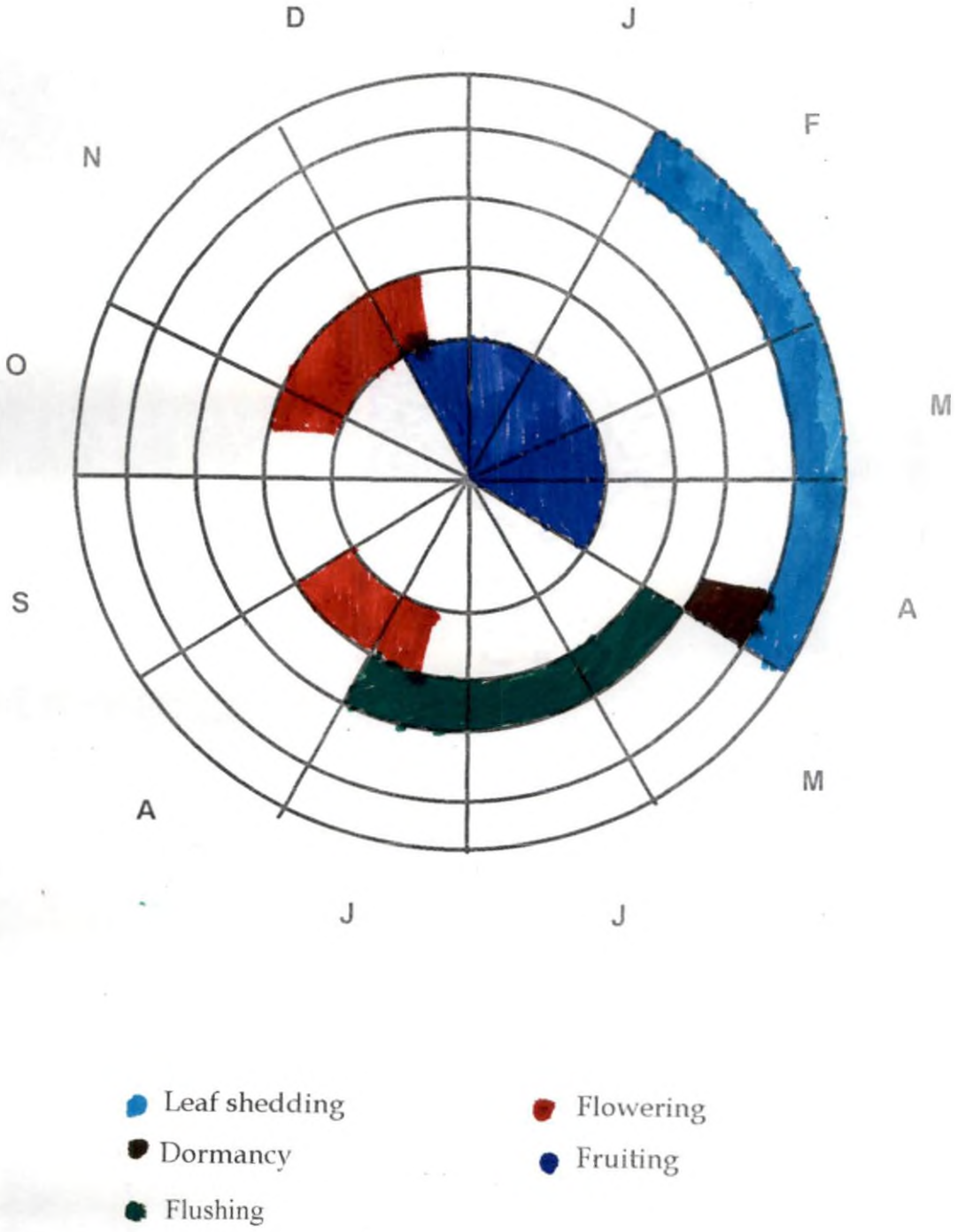


Fig. 3. Phenogram of *Terminalia belerica*

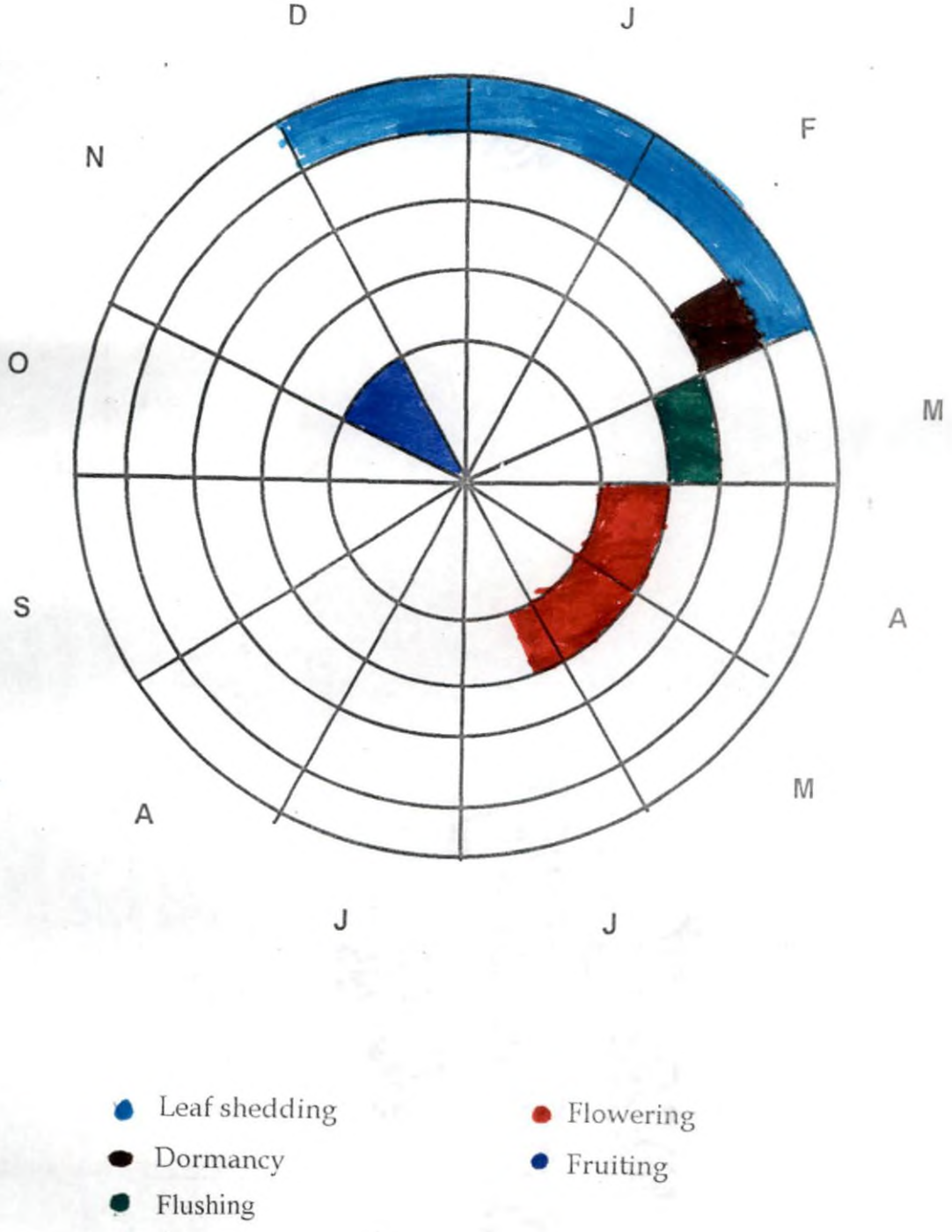
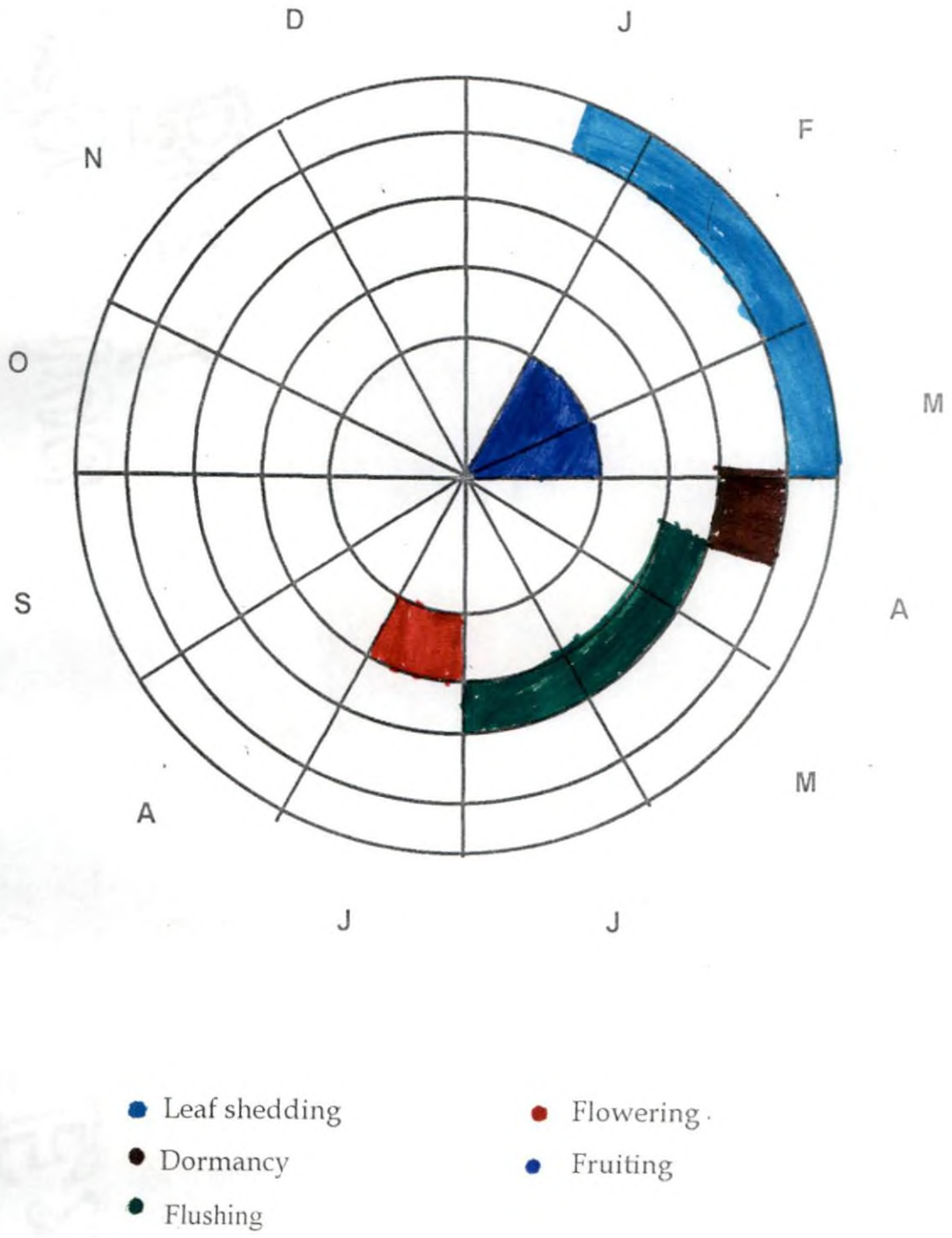


Fig. 4. Phenogram of *Terminalia tomontosa*



In *Terminalia belerica* the leaf shedding commenced from the month of December onwards and reached its peak during the month of February. The trees became leafless during the end of February or March.

In *Terminalia tementosa* also there exists only a single leaf shedding period. The leaf shedding started from the mid January and reached its peak during the middle of March and the trees became completely leafless by end of March.

The major leaf shedding activity in *Terminalia paniculata* started from the end of January and continued up to May. The leaf fall reached its peak during April and the tree became completely leaf less by the end of the month.

4.1.2 Dormant period

The four species showed a specific dormancy period during their annual life. It usually occurred during the end of leaf shedding period and prolonged till the new flushes originate after the leaves were completely shed. In *Terminalia catappa* the dormant period occurred during the month of November and December. The dormant period of *T. paniculata* was occurred during April. The period of dormancy in *T. belerica* was observed during the end of February, while in *T. tomentosa* it was occured during the end of March and beginning of April.

4.1.3 Flushing

The flushing pattern of *Terminalias* vary from species to species. In *Terminalia catappa,* three flushing peaks were observed, the first one began from the month of April onwards and it extented upto June. The second flushing peak was observed from the mid August which extended up to the mid September while the third flushing occurred after the dormant periods which was from the mid December and extented up to February. In *T. belrica* the major flushing event occurred just after the dormant period, the flushing started from the month of March and extented upto mid May. Two flushing periods were observed in *T. paniculata.* The first one occurred just after the dormant period and it was started from the month of March and extended up to April. While the second flushing occurred from the midst of October to the midst of November. The flushing in *T. tomentosa* was started from the month of April and extented up to July. In all the four species, the new flushes were light green in colour and produced in large numbers.

4.1.4 Flowering

The flowering period of the four *Terminalia* species occurred either along with the flushing or followed by the flushing. In all the four species, the inflorescence originated as light green protuberance. The onset of flowering in *T. catappa* occurred during April-May and it extented up to the end of October (Fig. 3). Two distinct flowering seasons were observed in *T. paniculata* (Fig. 4). The first flowering occurred during July to September and the second during November-December. The flowering period of *T. belerica* was from April to July and that of *T. tomentosa* from the mid May to August.

4.1.5 Fruiting

Two distinct periods of fruiting were observed in *Terminalia catappa,* one during June to August and the other during November to January. In the case of *T. paniculata,* it was observed during December to May. The fruiting period was during November to the middle of January in *T. belerica* and February to April in *Terminalia tomentosa.*

4.2 Reproductive biology

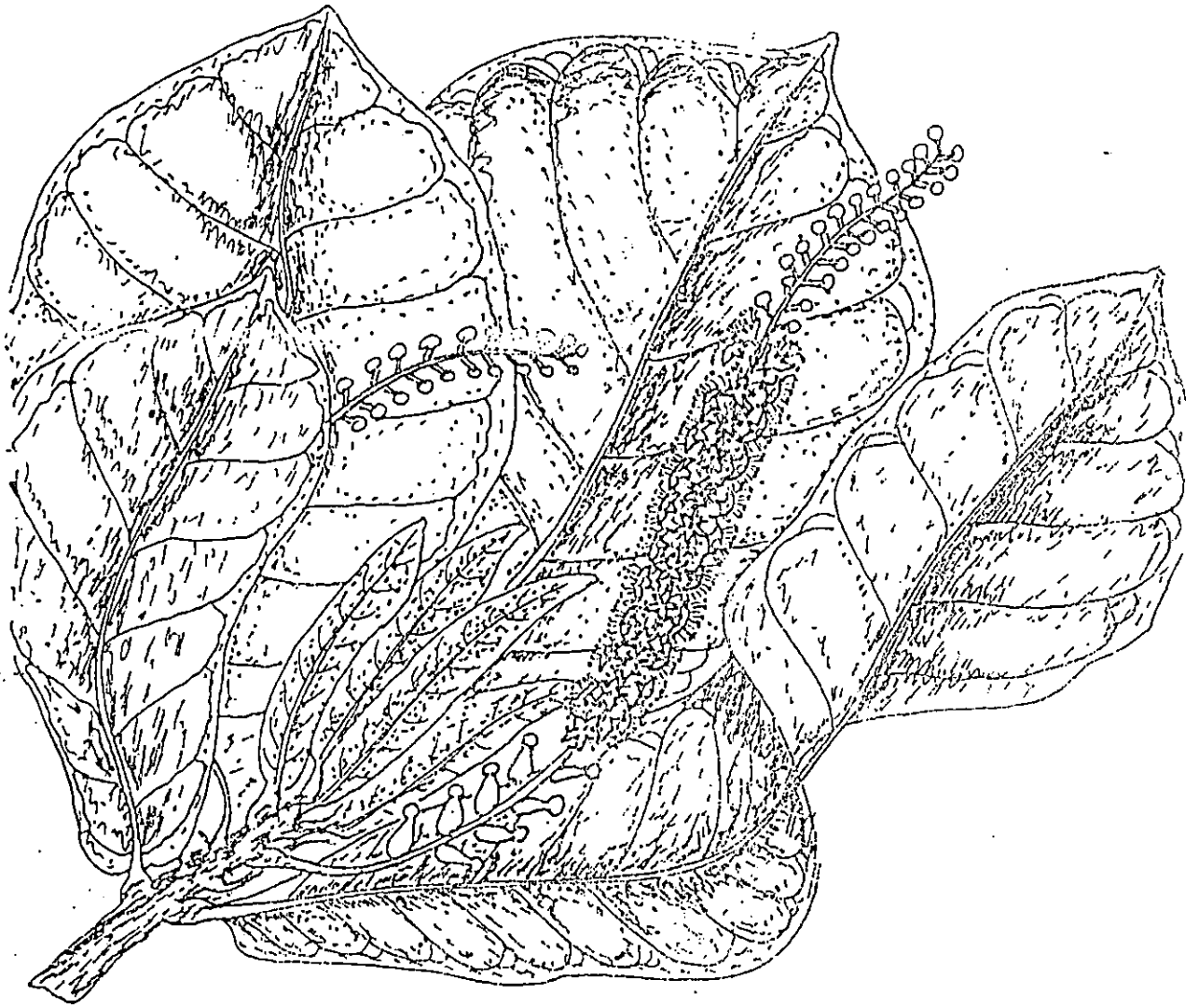
4.2.1 Morphology

The morphological descriptions of *Terminalias* are depicted in Fig.5 to 8. The inflorescence of *Terminalia catappa* were simple spikes and they usually originate from leaf axils (Fig.5). In *T belerica* also the inflorescence were spikes but the flowers were not very close (Fig.6) unlike the other *Terminalias.* The inflorescence of both *T. paniculata* and *T. tomentosa* were panicled spikes. In *T. tomentosa,* each panicle consists of eight spikes (Fig.7), whereas in *T. paniculata,* inflorescence is compound panicles (Fig.8) and the number of spikes on each inflorescence may vary.

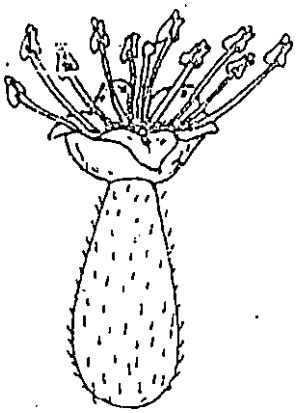
All the flowers on the inflorescence of *Terminalia paniculata* and *T. tomentosa* were hermaphrodite whereas in *T. belerica* and *T. catappa* the flowers on the lower part of inflorescence were hermaphrodite while others were male.

The floral morphology of all the four species resembles greatly. The colour of flowers were creamy yellow in *Terminalia paniculata, T. tomentosa* and *T. catappa* and greenish yellow in the case of *T. belerica.*

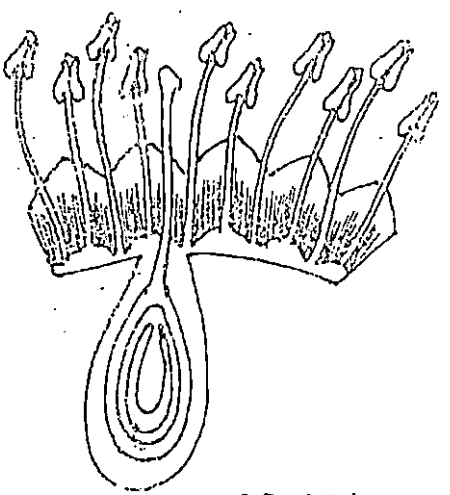
Fig. 5. Morphological descriptions of *Terminalia catappa*



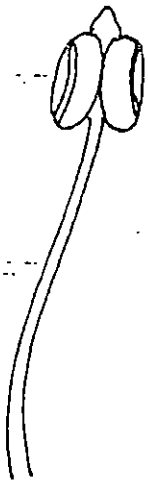
a. Habit



b. Flower

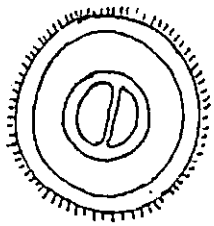


c. LS of flower

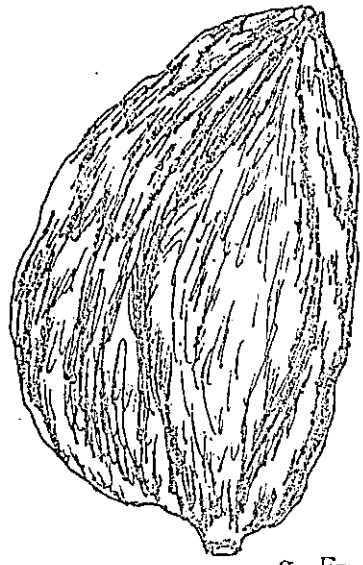


d. Stamen

e. Stigma

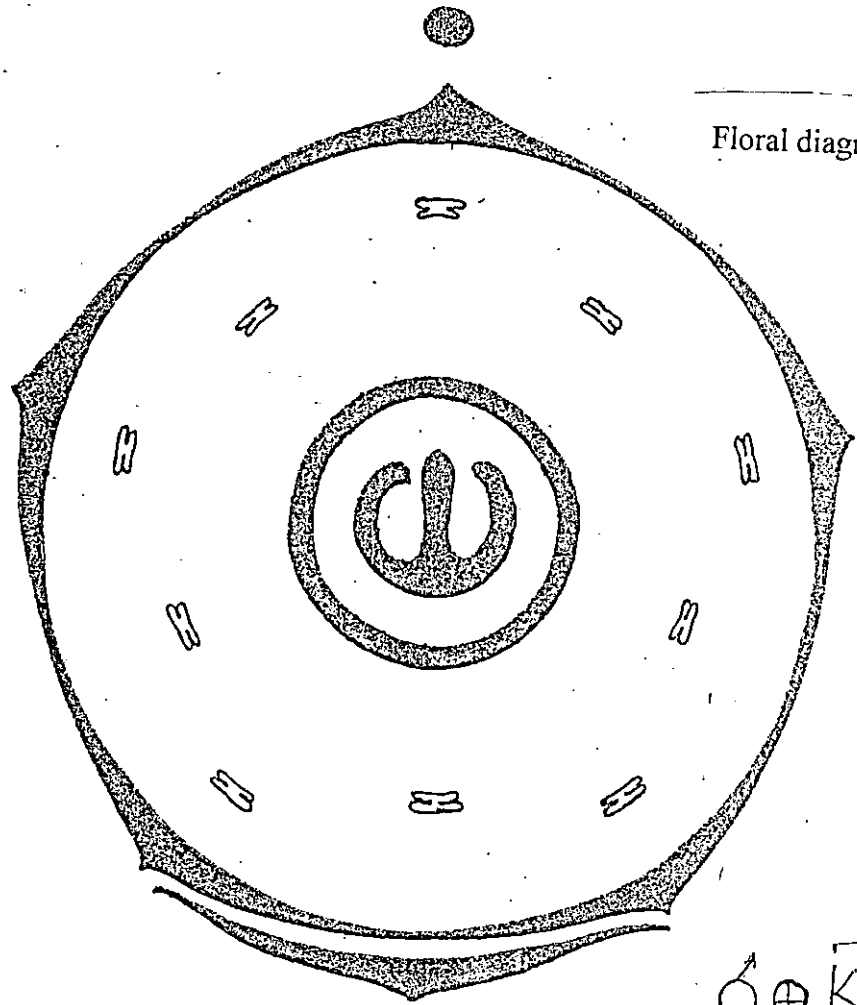


f. CS of ovary



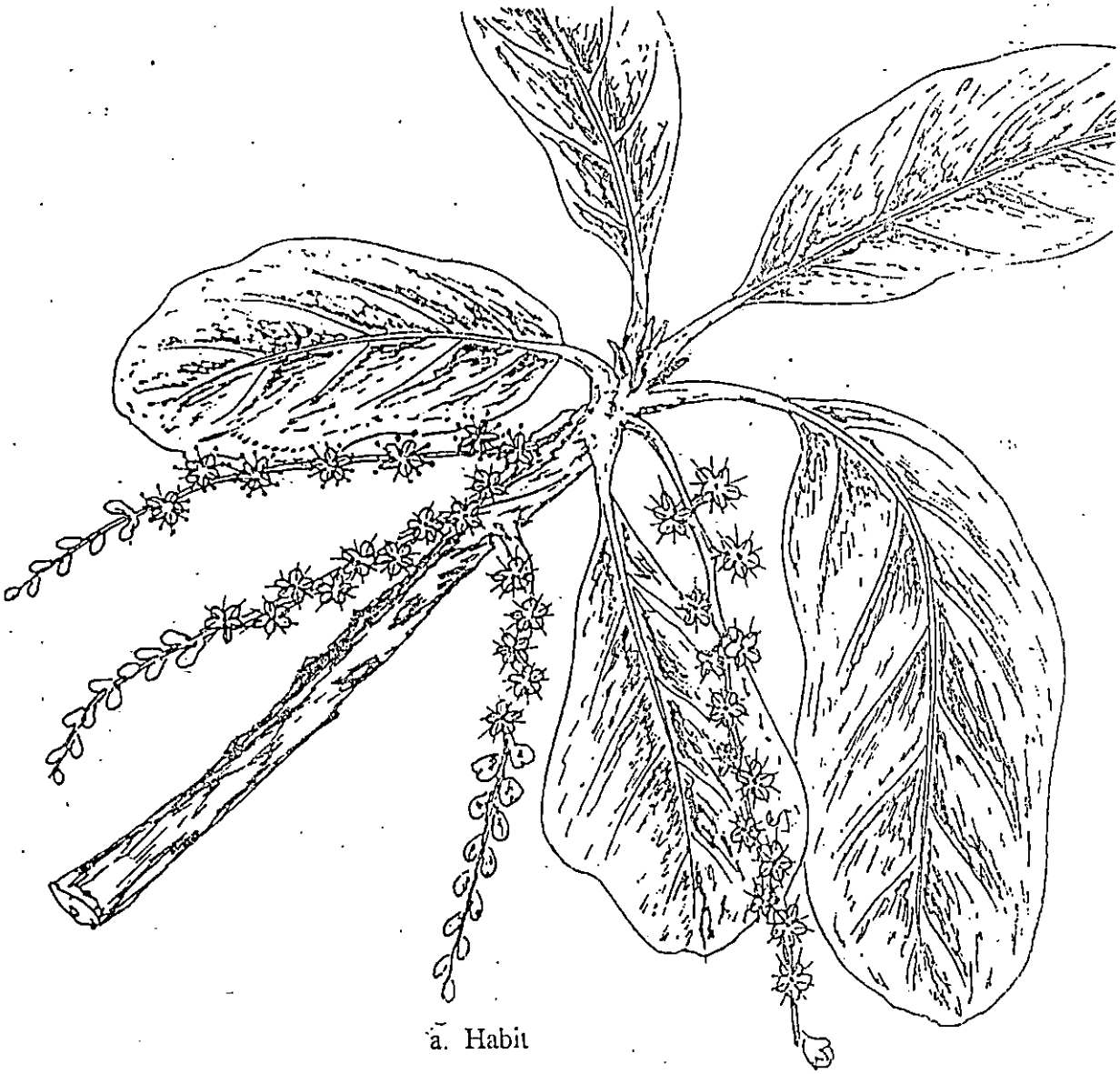
g. Fruit

Floral diagram

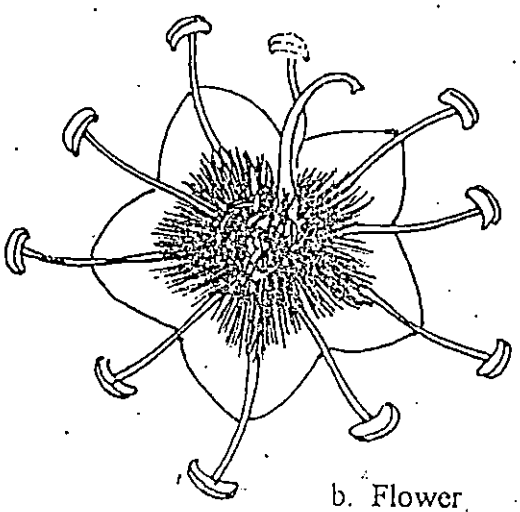


$\female \oplus \overline{K_{(5)} C_0 A_{5+5} G_1}$

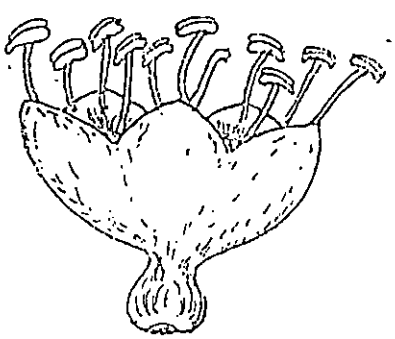
Fig. 6. Morphological descriptions of *Terminalia bellerica*



a. Habit

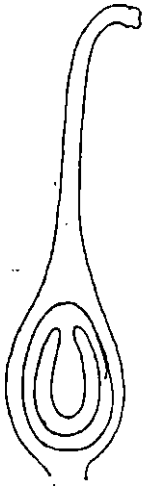


b. Flower



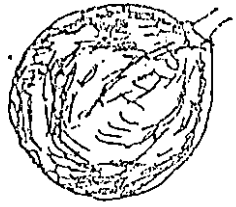
c. LS of flower

d. Stamen



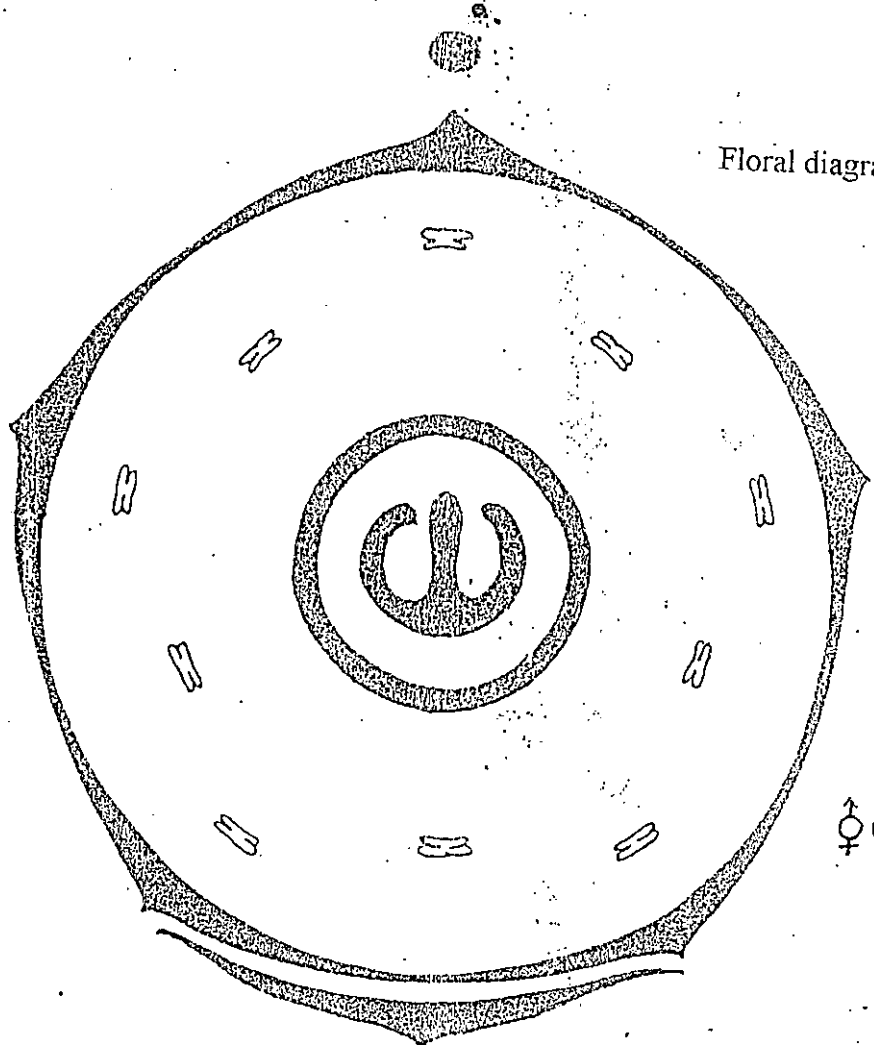
e. Stigma

f. CS of ovary



g. Fruit

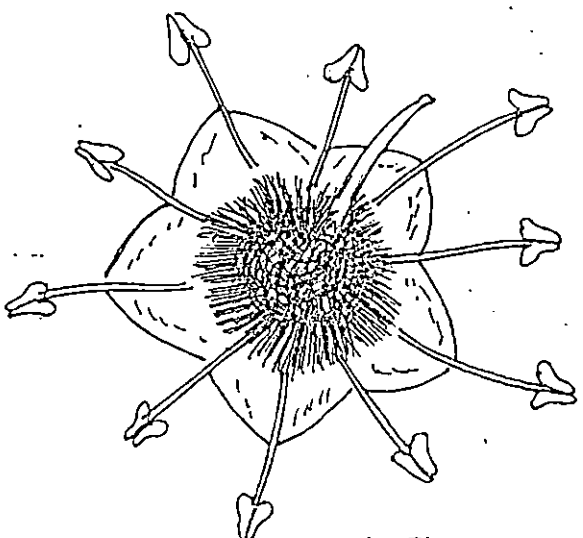
Floral diagram



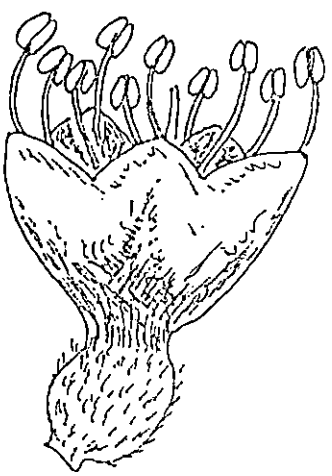
$\hat{\varphi} \oplus \overline{K_{(5)}\,C_0\,A_{5+5}}\,\underline{G_1}$

Fig. 7. Morphological descriptions of *Terminalia paniculata*

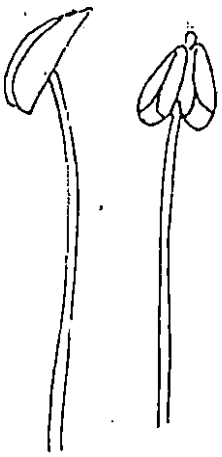
a. Habit



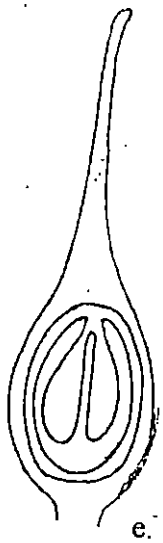
b. Flower



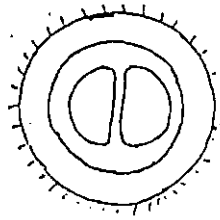
c. LS of flower



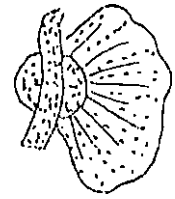
d. Stamen



e. Stigma

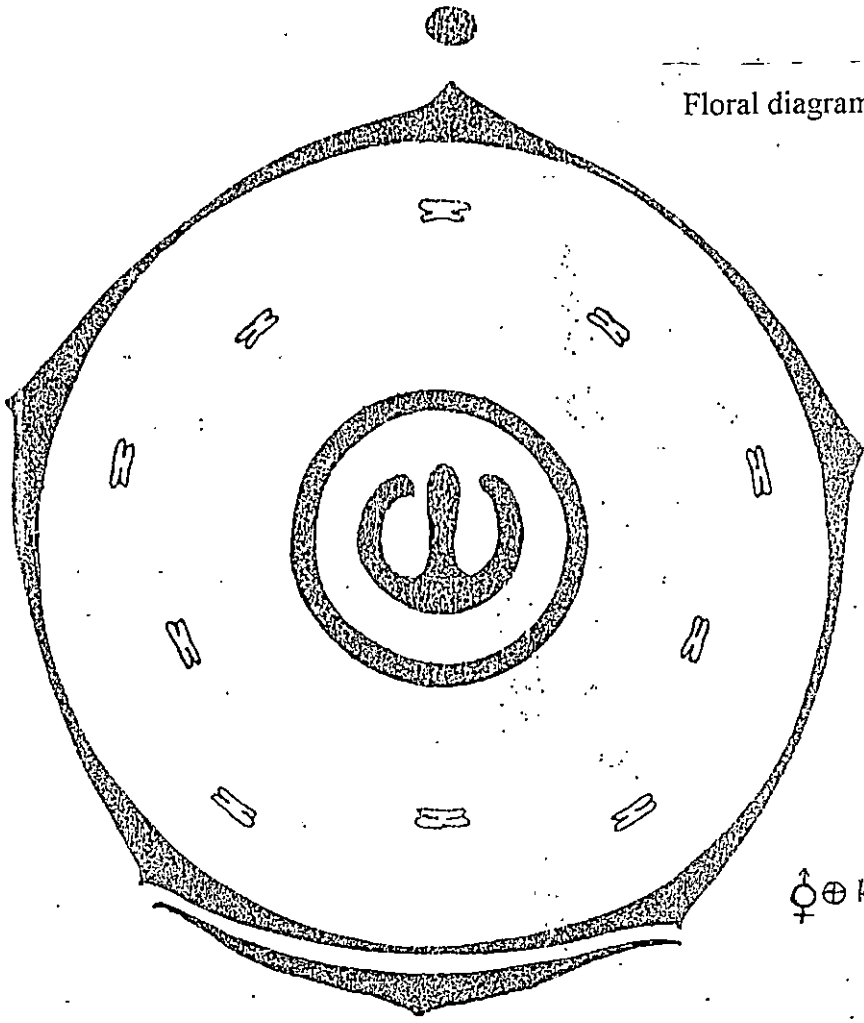


f. CS of ovary



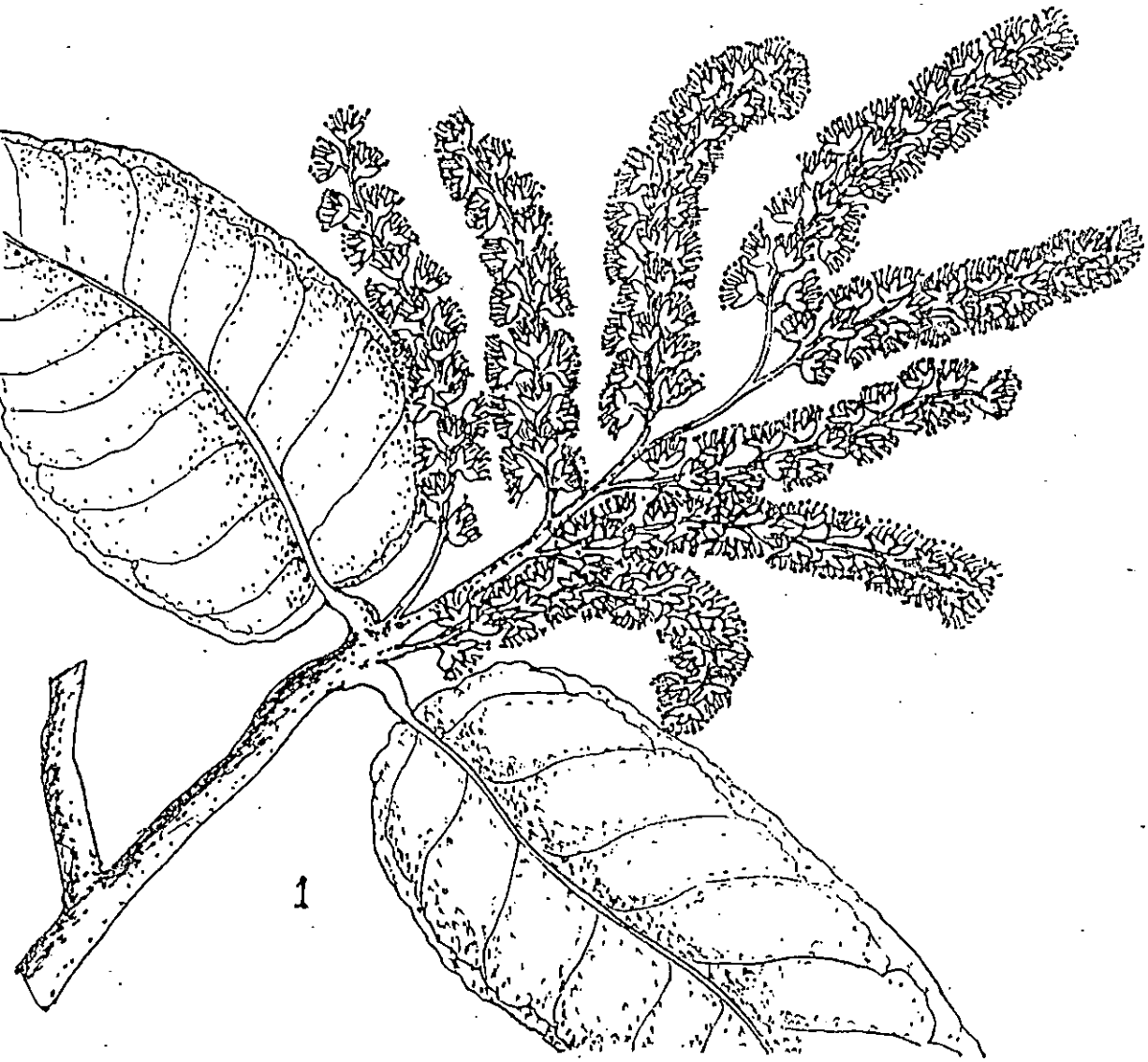
g. Fruit

Floral diagram

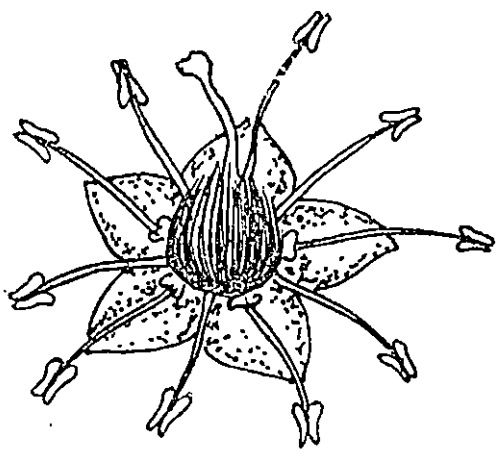


$\Q \oplus K_{(5)} C_0 A_{5+5} \underline{G}_1$

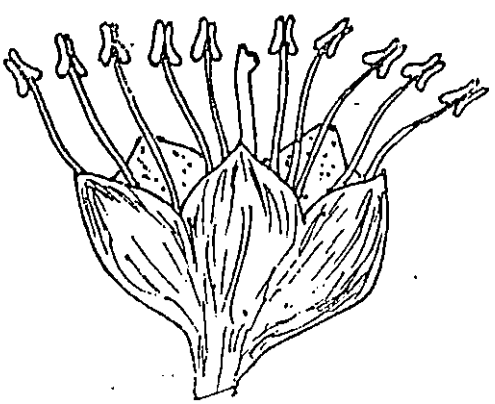
Fig. 8. Morphological descriptions of *Terminalia tomentosa*



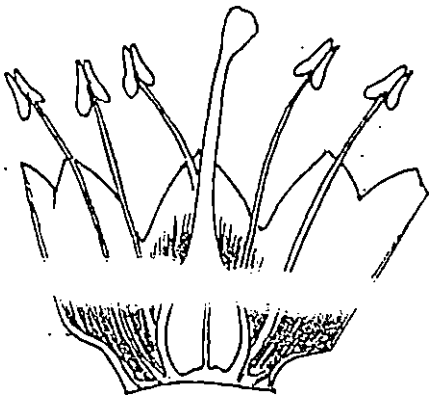
a. Habit



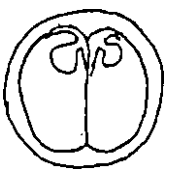
b. Flower,



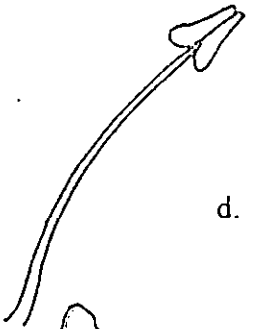
3



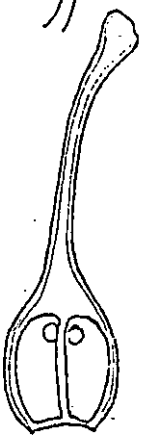
c.. LS of flower



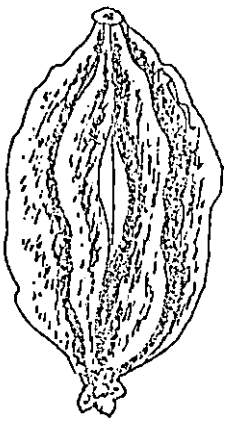
f. CS of ovary



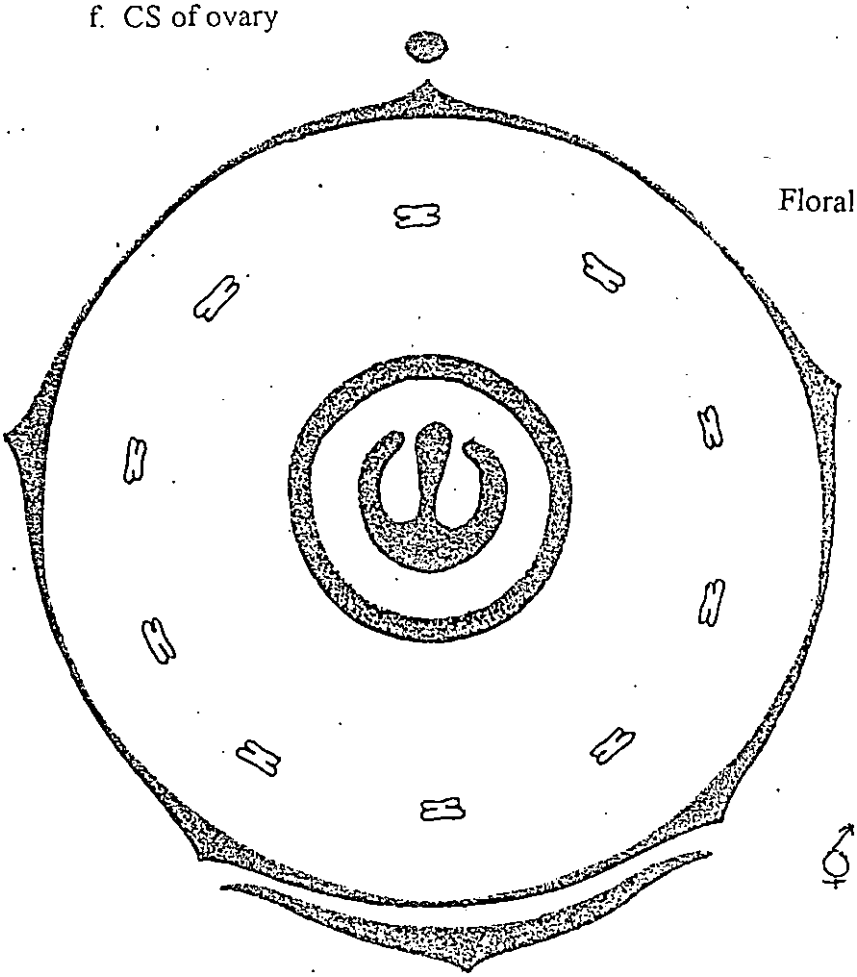
d. Stamen



e. Stigma



g. Fruit



Floral diagram

$\delta \oplus K_{5)} C_0 A_{5+5} \overline{G}_1$

The calyx tube of *Terminalias* was ovoid or cylindrical and constricted above. The ovary aestivation was valvate with five short triangular lobes. Petals were zero. The stamens were ten in number and inserted on the calyx lobes (the epigynous disc within them densely hairy), biseriate, the five lower opposite to the calyx teeth and the five upper longer and alternate with the calyx teeth filaments subulate or filiform, exserted. Ovary is inferior and single celled. The number of ovules varied from 2 to 3 and pendulous from the apex of the cell. Style subulate often thickened and villous at the base. The stigma was simple.

The fruits of the species varied in size and shape. The fruits of *Terminalia paniculata* and *T. tomentosa* were winged. In *T. paniculata* the fruits were with three unequal wings and in *T. tementose,* they were with five equal and acute wings. The fruits of *T. belerica* and *T. catappa* were not winged. The fruits of *T. catappa* were 2 to 3 angled.

The fruits were indehiscent and coriaceous. Seeds solitary exalbuminous and convolute.

4.2.1.1 Inflorescence character

The observations of the inflorescence character of *Terminalias* are furnished in Table 1. The inflorescence of *T. catappa* and *T. belerica* were simple spikes where as the inflorescence of *T. tomentosa* and *T. paniculata* were panicled spikes. In *T. catappa* the average number of flowers per spike were 77.22, and out of which 6 flowers on the lower part of the spikes were hermaphrodite.

Table 1 Inflorescence characters of *Terminalias*

Sl. No.	Species	Type of inflorescence	Average No. of flowers in a spike			Average size of spikes		Average size of flowers			
			Herma-phrodite	Male	Total	Length (cm)	spread (cm)	Length (cm)		Spread (cm)	
								H	M	H	M
1	*T. catappa*	Simple spike	6	71.22	77.22	13.7	1.66	1.34	1.07	1.09	0.97
2	*T. belerica*	Simple spike	6	41.01	47.01	9.73	1.4	1.09	0.89	0.84	0.79
3	*T. paniculata*	Panicled spike (Compound panicle with 5-46 spikes)	55.3	-	55.3	8.71	1.34	0.98	-	0.88	-
4	*T. tomentosa*	Panicled spike (8 spikes in a panicle)	65.71	-	65.71	10.01	1.36	1.18	-	0.97	-

H - Hermaphrodite M - Male

The remaining 71.22 were male flowers with defective ovary. The average length of a spike was 13.7 cm with their mean spread of 1.66 cm. The average length and spread of hermaphrodite flowers were 1.34 cm and 1.07 cm respectively and that of male flowers were 1.09 cm and 0.97 cm respectively. There were 47.01 flowers on an average on each spike of *T. belerica*, with 41.01 male flowers on the upper part and 6 hermaphrodite flowers on the lower part. The average size of the spikes was 9.73 cm and 1.4 cm in length and spread respectively with length of flowers of 1.09 cm and 0.84 cm respectively, for the hermaphrodite flowers. The spikes of *T. paniculata* were with 55.3 flowers (all hermaphrodite). Each spike on an average have 8.71 cm length and 1.34 cm spread. The flowers on an average were 0.98 cm in length and 0.88 cm in spread. The spikes on the inflorescence of *T. tomentosa* were having 65.71 hermaphrodite flowers on an average and the spikes have 10.01 cm and 1.36 cm length and spread, respectively. The average size of flowers were 1.18 cm and 0.9 cm in length and spread, respectively.

4.2.2 Floral biology

4.2.2.1 Anthesis

The observations recorded at half hourly intervals on the anthesis of flowers of four species of *Terminalias* are furnished in Table 2. In *Terminalia catapp,* and *T. belerica,* the flower opening commenced during the morning hours. In *T. catappa* anthesis started from 6.30 hrs onwards and the maximum number of flowers (56 per cent) opened between 7.00 to 7.30 hrs and the flower opening continued up to 8.00 hrs. The peak period of anthesis in *T. belerica* occurred

Table 2 Anthesis of *Terminalias*

Species	Time hours	Number of flowers	Number dehisced	Percentage of total
	6.00		0	-
	6.30		13	17
T. catappa	7.00	77	43	56
	7.30		15	19
	8.00		6	8
	6.30		0	-
	7.00		12	26
T. belerica	7.30	46	24	52
	8.00		4	9
	8.30		6	13
	16.30		4	7
	17.00		27	46
T. paniculata	17.30	59	16	27
	18.00		8	14
	18.30		4	7
	16.30		4	6
	17.00		12	18
T. tomentosa	17.30	66	39	59
	18.00		4	6
	18.30		7	11

between 7.30 to 8.00 hours, when on an average 52 per cent flowers were opened. Only a very small number of flowers opened before 6.30 hour and after 8.30 hours.

In *Terminalia paniculata* and *T. tomentosa,* anthesis of flowers occurred during the evening hours. In *T. paniculata,* the flower opening commenced from 16.30 hours onwards and continued upto 18.30 hours. The peak period of anthesis (46 per cent) occurred between 17.00 and 17.30 hours. In *T. tomentosa* also, the flower opening started after 16.30 hours and reached its peak (59 per cent) between 17.30 and 18.00 hours. In both the species only very small number of flowers opened after 18.30 hours.

4.2.2.2 Anther dehiscence

The observations on anther dehiscence of the four *Terminalia* species are presented in Table 3. Anther dehiscence occurred few hours after anthesis in all the four species. In *Terminalia catappa* and *T. belerica,* anther dehiscence commenced one hour after anthesis. Anther dehiscence started from 7.00 hours onwards in *T. catappa* and reached its peak (51 per cent) between 8.30 hours to 9.00 hours. In *T. belerica* the anther dehiscence started from 7.30 hours onwards and reached its peak (37 per cent) between 8.30 hours and 9.00 hours. In both the species, anther dehiscence occurred at a very low level after 9.00 hours.

Anther dehiscence of *Terminalia paniculata* commenced from 17.30 hours onwards and reached its peak (41 per cent) between 18.00 hours and 18.30 hours.

Table 3 Anther dehiscence of *Terminalias*

Species	Time hours	Number of flowers observed	Number dehisced	Percentage of total
	7.00		0	-
	7.30		2	3
T. catappa	8.00	78	28	36
	8.30		40	51
	9.00		7	9
	7.00		0	-
	7.30		6	9
T. belerica	8.00	49	13	27
	8.30		18	37
	9.00		12	24
	17.00		0	-
	17.30		16	28
T.paniculata	18.00	58	24	41
	18.30		16	28
	19.00		2	3
	17.30		0	-
	18.00		12	18
T. tomentosa	18.30	67	30	45
	19.00		10	15
	19.30		15	22

Anther dehiscence in very little amount has occurred after 19.00 hours in *T. paniculata.* In *T. tomentosa,* anther dehiscence has started from 18.00 hour onwards which was about 1.30 hours after the anthesis. Anther dehiscence reached its peak (45 per cent) between 18.30 hours to 19.00 hours. About 80 per cent of the anther dehiscence in *T. tomentosa* occurred between 18.00 hours and 19.30 hours the rest occurred after 19.30 hours.

4.2.2.3 Stigma receptivity

The data on the onset and extent of stigma receptivity are presented in Table 4. All the four species of *Terminalias* showed maximum stigma receptivity at the time of anthesis. At the age of 0-1 hour from anthesis, in *Terminalia catappa,* the stigma receptivity was 82 per cent and it reduced to 75 per cent and 54 per cent respectively for 1 to 2 hours and 2 to 4 hours aged stigmas. The stigma, receptivity was only 10 per cent for stigmas aged 8 to 24 hours and above 24 hours aged stigmas no receptivity was observed. The stigma receptivity of *T. belerica* was highest at the age of 0-1 hour (85 per cent) and it declined to 81 per cent and 66 per cent respectively at the age of 1 to 2 hours and 2 to 4 hours. In stigmas aged more than 4 hours, the receptivity declined to 3 per cent. In *T. paniculata* the highest stigma receptivity (89 per cent) occurred at the age of 0-1 hours. It sharply declined to 22 per cent at the age of 4 to 8 hours after anthesis. The stigma receptivity was very low (2 per cent) as the age of the stigmas were 8 hours or more. *T. tomentosa* also showed a similar trend. The stigma receptivity was maximum (94 per cent) at the age of 0-1 hours and it sharply declined to 66 per cent and 10 per cent respectively at the

Table 4 Stigma receptivity of *Terminalias*

Species	Age of excised stigma (hrs.)	Number observed	Number recep-tive	Recep-tivity
	0-1		102	82
	1-2		94	75
T. catappa	2-4	125	67	54
	4-8		53	42
	8-24		12	10
	24-36		-	-
	0-1		106	85
	1-2		101	81
T. belerica	2-4	125	82	66
	4-8		40	32
	8-24		4	3
	24-36		-	0
	0-1		111	89
	1-2		100	80
T. paniculata	2-4	125	54	43
	4-8		27	22
	8-24		3	2
	24-36		-	-
	0-1		117	94
	1-2		83	66
T. tomentosa	2-4	125	66	53
	4-8		12	10
	8-24		-	-
	24-36		-	-

age of 1 to 2 hours and 4 to 8 hours. No receptivity was observed in stigmas aged more than 8 hours.

4.2.2.4 Pollen fertility

The observations on pollen fertility of *Terminalias* are presented in Table 5. The average fertility of pollen grains of *Terminalia catappa* was 55 per cent in the stain test. On an average 46 per cent pollen grains of the species germinated in the germination test using agar and sugar. In *T. belerica*, 60 per cent of the pollen grains were stained in the stain test and 48 per cent on an average germinated in the *in vitro* germination test.

The fertility of pollen grains determined by stain test in *Terminalia paniculata* was 51 per cent and in the *in vitro* germination test, it was 49 per cent, slightly less than the fertility observed in stain test. In *T. tomentosa* the result of the stain test showed that 63 per cent of the pollen grains were fertile. In the germination test of pollen grains of *T. tomentosa,* the pollen tube growth was observed in 55 per cent of the pollen grains.

4.2.3 Flower production

The average number of flowers produced by individual trees of four species of *Terminalias* are presented in Table 6. In *Terminalia catappa,* an individual tree produced on an average 26.5 spikes per meter square of crown area and it consisted of 2046.3 individual flowers. The average crown area of a single tree of the species worked out was 23.6 m^2. The total number of flowers produced on an individual tree

Table 5 Pollen fertility and viability of *Terminalias*

Species	Total number of pollen observed	Number stained/ germinated	Percentage of pollen stained/ germinated
T. catappa			
(a) stain test	1976	1093	55
(b) germination test	376	173	46
T. belerica			
(a) stain test	2214	1336	60
(b) germination test	319	152	48
T. paniculata			
(a) stain test	1217	617	51
(b) germination test	233	115	49
T. tomentosa			
(a) stain test	2310	1460	63
(b) germination test	163	89	55

Table 6 Flower production of terminalias

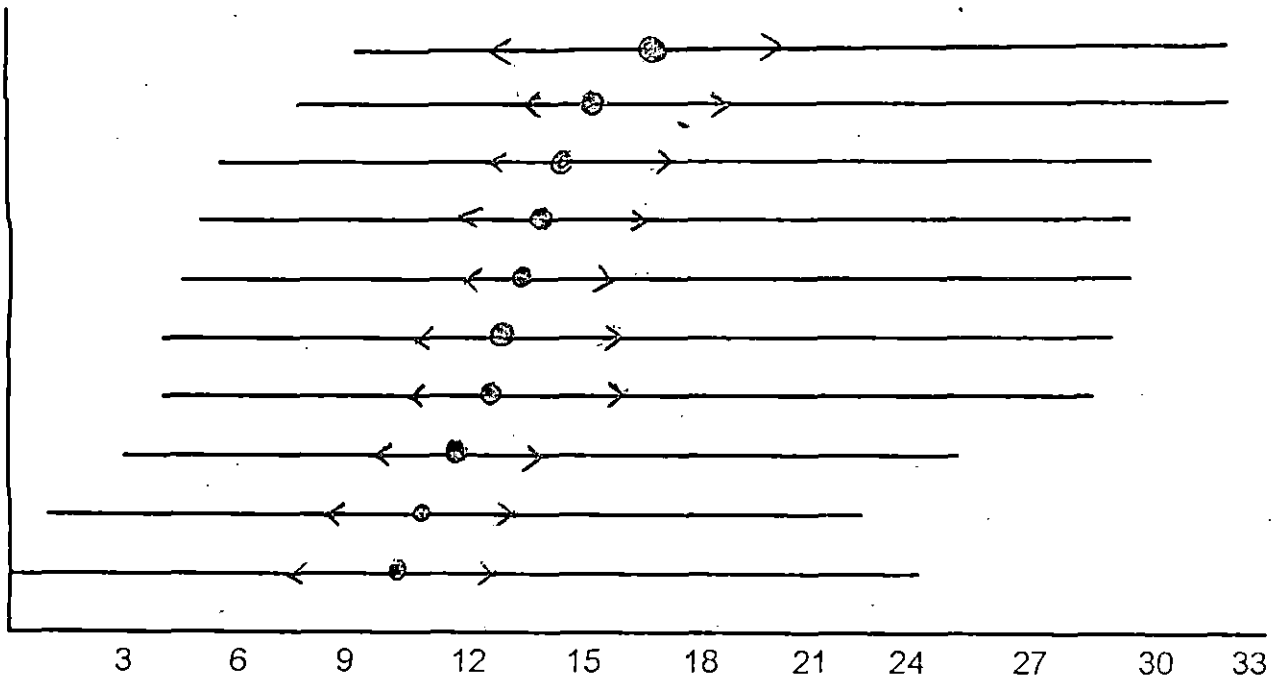
Sl. No.	Species	Average No.of flowers per spike	Average No. of spikes/m^2	Average No. of flowers/m^2	Average crown area in (m^2)	Total No. of flowers produced by an individual tree
1	*T. catappa*	77.22	26.5	2046.3	23.6	48293
2.	*T. belerica*	47.01	78.8	3704.4	48.8	180774
3.	*T. paniculata*	55.3	628.5	34756.1	39.8	1383290
4.	*T. tomentosa*	65.71	256.3	16841.5	42.6	717447

calculated were 48,239 during the twelve months. *T. belerica* produced 78.8 spikes/m^2 of crown area and the average number of flowers produced in one square meter was 2046.3. The average crown area of an individual tree of *T. belerica* was 48.8 m^2. The number of flowers produced by a single tree was worked out and on an average it was 1,80,744 flowers. Individual trees of *T. tomentosa* and *T. paniculata,* produced higher number of flowers than the other two species. In *T. paniculata* the average number of spikes produced in one square meter area was 628.5 and the average number of flowers produced were 34,756.1. The crown area worked out was 39.8 m^2 for a single tree and the number of flowers produced was 13,83,290. *T. tomentosa* produced 256.3 spikes in one meter square of crown area on an average, which consisted of 16841.5 flowers. The average crown area of the species was 42.1 m^2 and the number of flowers produced by a single tree worked out was 7,17,447.

4.2.4 Pattern of flowering

The pattern of flowering of *Terminalias* were studied in detail. The pattern of flowering of individual trees of *Terminalia belerica* are diagrammatically presented in Fig.9. The flower opening in each individual continued for about 24 to 28 days in *T. belerica* and it extented about 33 days from the onset of flower opening. The median flower opened day occurred 8 to 23 days after the onset of flowering and the 50 per cent flowering (peak flowering period) occurred at 5 to 8 days. The diagrammatic description pattern of flowering *T. tomentosa* (Fig. 10) showed great similarity with that of *T. belerica*. The flower opening continued for a period of 21 to 25 days on each individual trees. The median flower opened day was occurred

Fig. 9. Flowering pattern of *Terminalia belerica*

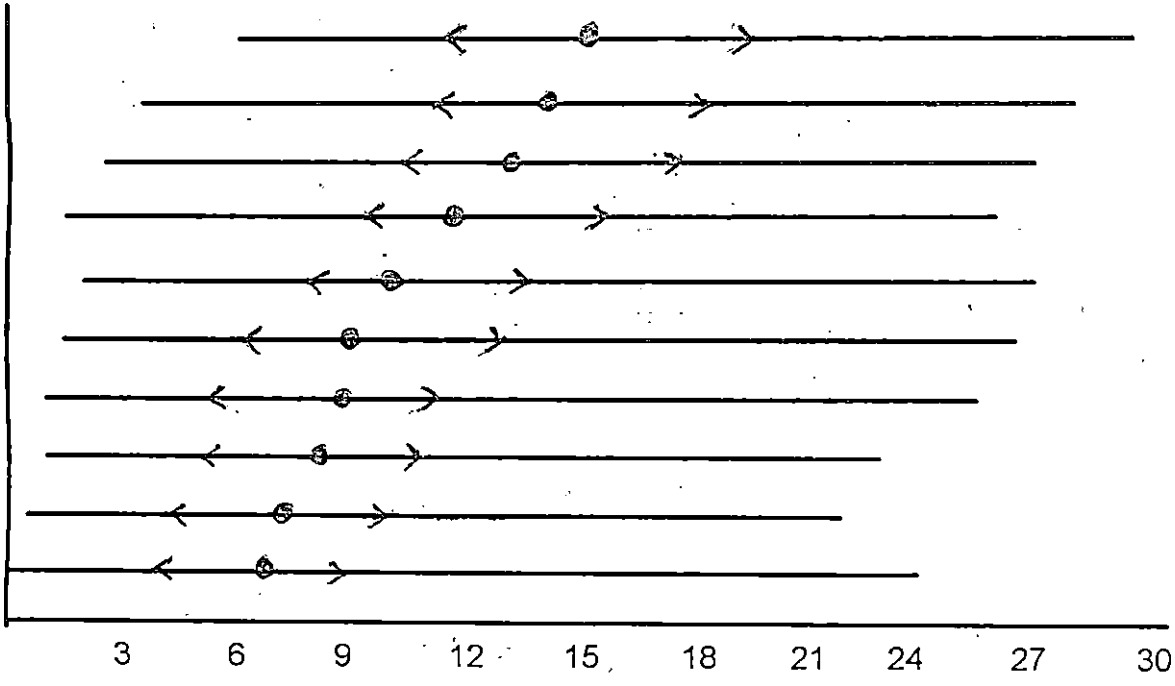


No. of days after the onset of flower opening

- flower opened day
- ∘ median flower opened day
- < > 50 per cent flowering

(Trees are arranged according to the rank order in which their median flower was opened)

Fig. 10 Flowering pattern of *Terminalia tomontosa*



No. of days after the onset of flower opening

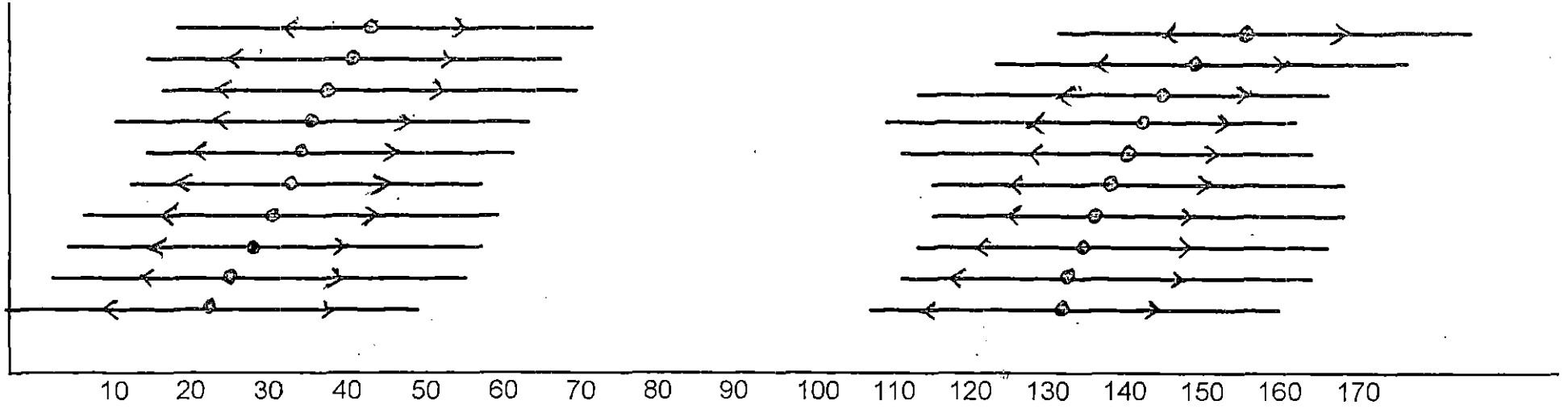
- flower opened day

o median flower opened day

<> 50 per cent flowering

(Trees are arranged according to the rank order in which their median flower was opened)

Fig. 11 Flowering pattern of *Terminalia paniculata*

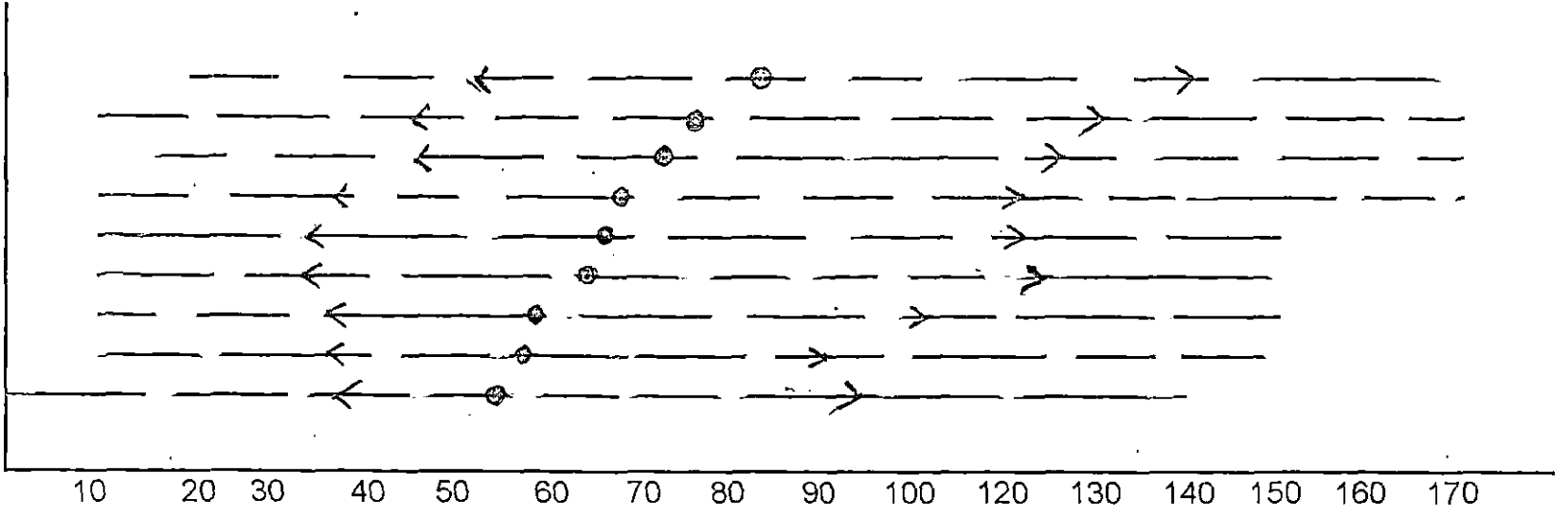


No. of days after the onset of flower opening

- flower opened day
- • median flower opened day
- <> 50 per cent flowering

(Trees are arranged according to the rank order in which their median flower was opened)

Fig. 12 Flowering pattern of *Terminalia catappa*



No. of days after the onset of flower opening

- \- flower opened day
- • median flower opened day
- <> 50 per cent flowering

(Trees are arranged according to the rank order in which their median flower was opened)

about 8 to 18 days after the onset of flowering and 50 per cent flowering was occurred in the range of 6 to 11 days.

Terminalia paniculata and *T. catappa* showed rather different pattern in their flowering activity. In *T. paniculata* (Fig. 11), two distinctive seasons of flowering were observed. The flower opening continued for about 40-45 days in each individual. The median flower opened day and the peak flowering (50 per cent flowering) occurred in 13 to 15 days after the onset of flower opening. The two flowering seasons were separated by a period of two months in this species.

Figure 12 represents the pattern of flowering in *Terminalia catappa*. Flower opening extented for about 150 to 160 days in *T. catappa* with several breakage or discontinuity. The flowering peak (50 per cent flowering) also extented 40-50 days on each individual trees around the median flower opened day.

4.2.5 Self pollination

The results of the study on self pollination of *Terminalias* are presented in Table 7. In *Terminalia tomentosa* and *T. belerica,* no fruit set was observed in flowers where self pollination was executed. In *T. catappa,* 21 per cent initial fruit set was observed but all the fruits were fallen with in few weeks before reaching maturity. The self pollination study in *T. paniculata* showed that it achieved an initial fruit set of 37 per cent and about 12 per cent of them reached the mature stage. But no germination was obtained from seeds produced by self pollination.

Table 7 Extent of self fertilization in *Terminalias*

Sl. No.	Species	Extent of initial fruit set (%)	Extent of fruit maturity (%)	Germination (%) (matured seed)
1.	*T. catappa*	21	0	0
2.	*T. belerica*	0	0	0
3.	*T. paniculata*	37	12	0
4.	*T. tomentosa*	0	0	0

4.2.6 Pollination time

The observations of the studies on pollination time of *Terminalias* are furnished in Table 8. The average longevity of opened flowers was 32.8 hours in *Terminalia catappa* and the anthesis was occurred from 6.30 hours in the morning. The maximum duration of stigma receptivity was 24 hours and peak period of insect activity observed from 7.00 - 8.00 hours. *T. belerica* too showed similar trend. The average longevity of opened flowers was 34.7 hours and the anthesis occurred at 6.30 hour onwards during the morning hours. The stigma was found to be receptive for about 24 hours after the flower opening. The peak period of insect activity was from 7.00 - 8.30 hours during the morning hours. The peak pollination occurred during this period.

In *Terminalia paniculata* and *T. tomentosa,* the pollination occurred during evening hours shortly after anthesis. The mean longevity of opened flowers was 28.3 hours and 25.9 hours respectively for *T. paniculata* and *T. tomentosa*. The anthesis also commenced from 16.30 hours in the evening in both the species. The maximum period of stigma receptivity was 24 hours and 8 hours respectively for *T. paniculata* and *T. tomentosa*. The peak time of insect activity around opened flowers occurred during 17.00 - 19.30 hours in both the species. The period of maximum pollination in this two species was occurred from 17.00 - 19.30 hours.

4.2.7 Fruit development

The stages of fruit development of *Terminalias* were studied in detail and the observations are presented in Table 9. The fruits of *Terminalia catappa* changed their

Table 8 Pollination time in *Terminalias*

Sl. No.	Species	Anthesis (h)	Longevity of opened flowers (h)	Max. duration of stigma receptivity (h)	Peak hour of insect activity	Effective pollination time
1.	*T. catappa*	6.30	32.8	24	7.00-8.30	7.00-8.30
2.	*T. belerica*	6.30	34.7	24	7.00-8.30	7.00-8.30
3.	*T. paniculata*	16.30	28.3	24	17.00-19.30	17.00-19.30
4.	*T. tomentosa*	16.30	25.9	8	17.00-19.30	17.00-19.30

Table 9 Stages of fruit development in *Terminalias*

Sl. No.	Species	No. of days from anthesis	Colour	Fruit size at maturity		Germination obtained at maturity	Remark
				Mean length (cm)	Mean breadth (cm)		
1.	*T. catappa*	<35	Light green	3.23	1.81	72%	The seed was matured when fruit colour changed from yellow, red to black (60-65 days age onwards)
		35-55	Dark green				
		55-65	Yellow, Red				
		>65	Black				
2.	*T. belerica*	< 120	Green	2.53	1.41	68%	The seed was matured when changed from yellowish or geryish green to greyish brown (160-170 days age onwards)
		120-150	Dull green				
		150-170	Yellowish or greyish green				
		> 170	Greyish brown				
3.	*T. paniculata*	< 80	Light green	1.41	0.72	22%	The seed was matured when fruit colour changed from reddish brown to brown (110-120 days of age onwards)
		80-100	Pale yellow light brown				
		100-120	Reddish brown				
		> 120	Brown				
4.	*T. tomentosa*	< 120	Light green				The seed was matured when the fruit colour changed to brown (200-210 days of age onwards)
		120-190	Light yelllow, brown	3.45	2.32	38%	
		190-210	Reddish brown				
		> 210	Brown				

colour from light green to dark green and then to yellow or red and ultimately became black. The seed maturity occurred with in 60 to 65 days after the initial fruit set. The fruit size at the time of maturity was 3.23 cm and 1.81 cm in length and breadth respectively. In *T. belerica,* the fruits took about 160 to 170 days to attain seed maturity. The fruit colour changed from greyish green yellow to greyish brown at the time of maturity. The mean length of the fruit was 2.5 cm and mean breadth was 1.41 cm. The mean germination obtained was 68 per cent for mature seeds. The fruit colour changed from reddish brown to brown during maturity in *T. paniculata.* The fruits took about 110 to 120 days to attain seed maturity. The average size of fruits of *T. paniculata* at the time of maturity was 1.41 cm in length and 0.72 cm in breadth. The mean germination obtained at the time of seed maturity was 22 per cent. In *T. tomentosa* also the fruit colour changed from reddish brown to brown during seed maturity. *T. tomentosa* fruits took about 200 to 210 days for attaining seed maturity. The mean size of the fruits were 3.52 cm and 2.32 cm in length and breadth respectively and the mean germination obtained was 38 per cent at the time of seed maturity.

4.2.8 Fruit set

The extent of initial fruit set, extent of seed maturity and reproductive capacity of the four species of *Terminalias* were studied and the data are presented in Table 10. The extent of initial fruit set was 5 per cent in *Terminalia catappa*, 9 per cent in *T. belerica,* 63 per cent in *T. paniculata* and 73 per cent. In *T. catappa* the extent of seed maturity was 35 per cent followed by *T. belerica* (31%), *T. tomentosa* (22%) and *T. paniculata* (17%). The reproductive capacity of the species were 1.26 per cent for *T. catappa*, 1.89 per cent for *T. belerica*, 2.36 per cent for *T. paniculata* and 6.38 per cent for *T. tomentosa.*

Table 10 Extent of fruit set and reproductive capacity of *Terminalias*

Sl. No.	Species	Mean No. of flowers per spike	Mean No. of swollen ovaries per spike	Extent of initial fruit set (%) (a)	Number of swollen overies observed	Number drop before maturity	Number matured	Extent of seed maturity (%) (b)	Germination percentage of matured seed (c)	Extent reproduction capacity (%) a x b x c
1	*T. catappa*	77.22	3.9	5	262	171	91	35	72	1.26
2	*T. belerica*	47.01	4.1	9	279	193	86	31	68	1.89
3	*T. paniculata*	65.71	36.9	63	1058	883	175	17	22	2.36
4	*T. tomentosa*	55.3	495	73	896	694	202	23	38	6.38

Discussion

DISCUSSION

Cultivation of tree crops using improved planint materials are essential for the success of any afforestation programme. Information about the reproductive biology of the species is a pre-requisite for undertaking tree improvement programmes. Hence the present series of studies were taken up with the objective of understanding the phenology and the reproductive biology of *Terminalia* and a result of the study will provide necessary information for undertaking such programmes in this species. The salient results of the studies on the reproductive biology of *Terminalia* species of tropical moist decidous forests of Kerala are discussed hereunder.

5.1 Phenology

5.1.1 Leaf shedding

The major leaf fall event in *Terminalias* were noticed after the rainy seasons from November to June. The habit of large scale leaf shedding evolved as a mechanism to overcome adverse conditions was very well observed in these species also. The leaf fall period was centred along with the hottest months in the case of *Terminalia paniculata, T. catappa* and *T. tomentosa* where as in *T. belerica,* the leaf shedding was completed in February, ie. just before the summer season. Troup (1986) has noticed similar leaf shedding pattern in many Indian species. Gopakumar (1995) has also observed leaf fall during the hottest months in many decidous tree species including *T. paniculata* and *T. tomentosa.* Chbots and Hicks (1988)

suggested that decidous habit could be an adaptation to tide over the water stress periods. This hypothesis holds good in this study also, as the observed species cut down their transpiring surface by adapting leaf fall during the water stress period.

5.1.2 Flushing

Trees renew their foliage in periodic flushes. The leaf renewal and leaf shedding in trees are often tuned with the climate of the area so that the species could utilize the optimum conditions for their advantage and there by achieve maximum photosynthetic production. In this study also, the major flushing activity was observed to be started before the rainy season and the trees were in its maximum foliage during the period when the moisture and sunshine were the highest. Janzen (1967) suggested that by producing new leaves before the rainy season, the trees will be able to expose their foliage to the photosynthetically active radiation and can readily synthesise carbohydrates. In general the flushing activity of *Terminalias* also were well in obeyance to the above mentioned principle.

5.1.3 Dormant period

The observed species experienced a short and distinct dormancy period. Dormancy is a mechanism to overcome certain adverse conditions. The species included in the study showed dormancy during the dry months. The trees were completely leafless at least for a short period during the dormant period (Fig. 1 to 4). The dormancy was observed during the month of December in *Terminalia catappa* and during February in *T. belerica*. The dormant period was observed in April and

in April-May respectively in the case of *T. tomentosa* and *T. paniculata*. The variation observed in the occurrence of dormant period suggested that along with water stress, the principle causative factor physiological factors or other environmental factors may also influence the species in determining its dormancy. The hypothesis of ecodormancy, metadormancy and paradormancy (Lang *et al.*, 1987) occurring at different levels in the species could be the reason for the differential expression of the dormant period among the four observed species.

5.1.4 Flowering period

The flowering in tropical tree species are influenced by water stress and many tropical trees have been reported to flower after the dry season (Kozlowzki and Kramer, 1979). In the present study also, three of the observed species, ie. *Terminalia, catappa T. belerica* and *T. tomentosa* the flowering was observed after the month of April. It is suggested that drought might have induced flowering in these species. But the flowering periods observed in *T. paniculata* has shown variation to the above mentioned trend. The first flowering during July to September and second flowering during November to December and it was after the commencement of monsoons suggested that a hot season followed by rains required for the flowering in *T. paniculata*.

Rathke and Lacey (1985) had correlated a number of abiotic factors with flowering time like seasonal availability of conditions favourable for pollen transfer, availability of pollinators, competitive effects on seed set. The above mentioned

reasons also might have contributed for the variation in flowering period observed among the *Terminalia* species.

5.1.5 Fruiting period

Species specific variation in fruiting phenologies were noticed in many trees (Sedgley and Griffin, 1985). In the present study also variation in fruiting phenology among the species wsd observed. In the case of *Terminalia paniculata* and *T. tomentosa,* the fruiting period was observed along the dry season as their winged seeds were able to be dispersed well in the prevailing wind. Two fruiting seasons were observed in *T. catappa* and the fruiting season of *T. belerica* was from February to April. The fruiting pattern of trees has strong bearing on its natural regeneration, and the seeds are often shed during the dry season which provide suitable condition for their dispersal (Richard, 1975). The present study also, this might be the principle behind the variation in fruiting period among the observed species.

5.2 Reproductive biology

5.2.1 Morphology

Significant similarity in inflorescence morphology were noticed among the observed species. The inflorescence of *T. catappa* and *T. belerica* were simple spikes. The lower most six flowers on the spikes were hermaphrodite and the others were male flowers (Fig. 5 and 6). But in *T. tomentosa* and *T. paniculata* the inflorescence were panicled spikes (Fig. 7 and 8) and all the flowers were hermaphrodite in nature. In most of the other characters such as number of calyx,

aestivation, arrangement of stamens, stigma, ovary etc. the four species showed similar characters. Troup (1986) also noticed similar morphological pattern in other members of the genus.

5.2.3 Flower production

All the observed species produced large number of flowers. *Terminalia tomentosa* and *T. panlculata* produced higher number of flowers than *T. belerica* and *T. catappa*. The mean number of flowers produced in one square meter crown area was the lowest in *T. catappa* (2046.3) and the highest in *T. paniculata* (16841.5). Similar variation in flower production was noticed by Srivastava *et al.* (1996) in *Terminalia arjuna* and *T. tomentosa*. Flower production in large numbers is a mechanism to attract many type of opportunistic pollinators with density dependent foraging behaviour (Janzen, 1967). Large number of flowers produced in *Terminalias* also might be for attracting pollinators.

5.2.4 Flowering pattern

Tropical trees exhibit flowering between two extreme patterns, at one extreme are the species with mass flowering individuals producing large number of new flowers each day over a week or less and at the opposite extreme are the species with steady state individuals producing small number of new flowers daily or for many weeks (Janzen, 1971 and Gentry, 1974). In the present study also the flowering pattern showed considerable variation. The analysis of the occurrence of median flower opened day and 50 per cent flowering in the species suggested that, in

Terminalia tomentosa and *T. belerica* the flowering activity was completed with in a short period and can be considered as mass flowering type of species. But in *T. paniculata,* two flowering seasons were noticed and it extent about two months. The flowering pattern of *T. paniculata* thus resembles much to the intermediate type, ie. between the mass flowering and steady state type. The flowering pattern of *T. catappa* was prolonged and discontinuous. It can be considered as steady state type of flowering. The difference in flowering pattern is to achieve many objectives. Regulation of pollen flow, foraging behaviour of pollinators, rate of fruit development in response to resource availability and habitat affect the flowering pattern (Bawa, 1982). This may be the reason of variation among the observed species also.

5.2.5 Anthesis and anther dehiscence

Anthesis and anther dehiscence occurred either at the morning or at the evening hours in *Terminalias*. The anther dehiscence was observed after the anthesis in all the four species. Bawa (1983) suggested many adaptations to facilitate the success of pollination and fruit set in trees. As the insect activity is maximum during the evening and morning hours, by synchronising the anthesis and anther dehiscence along with the peak period of insect activity may enhance the entomophilous pollination. Srivastava (1993) also obtained similar results and observed various pollen foraging insects operating around flowers of *Terminalia arjuna, T. paniculata* and *T. tomentosa* during the evening hours.

5.2.6 Stigma receptivity

Similar pattern in stigma receptivity was noticed in the four *Terminalia* species. They showed maximum receptivity when the stigma was fresh and just after the anthesis. Generally 0 to 1 hour old stigmas showed more than 80 per cent receptivity. Thereafter, stigma receptivity reduced considerably. It was very less for stigmas aged more than 8 hrs. and even no receptivity was noticed in old stigmas. The stigma receptivity pattern suggested that even though the flowers were open for more than 24 hrs. maximum successful pollination might have occurred with in a few hours after the anthesis and the stigma was fresh.

5.2.7 Pollen fertility

The pollen fertility studies showed no significant variation among the four *Terminalia* species. The range of pollen fertility obtained was 51 to 63 per cent in the stain test and 46 to 55 per cent in the germination test. Earlier studies also have shown that pollen fertility determined by germination tests were slightly less than fertility determined by the stain tests (Sherly, 1995).

5.2.8 Pollination time

In all the species, pollination was observed with in a few hours after the anthesis. Eventhough the flowers remain open for about 25 to 32 hours, the peak insect activity was limited to a few hours only and significant pollination was occurred only during this time. The anthesis and effective pollination was observed either during the morning or at the evening hours and it is conformity with observations of Srivastava (1993) in *Terminalia arjuna* and *T. tomentosa*. It might be due to the fact

that morning and evening hours are more congenial for insect activity and maximum insect activity was observed during this period. So synchronising the breeding activity during morning and evening hours will help to get maximum results.

5.2.9 Self fertilization

The results on the self fertilization studies suggest that self fertilization is not effective in these species. The failure of all the species in producing viable fruits clearly indicate that *Terminalias* are not favouring self fertilization.

5.2.10 Fruit set, fruit development and seed maturity

The proportion of flowers setting fruits are significantly lower in tree species (Soulherland, 1986). All non parthenocarpic species requires successful pollination and fertilization for formation of fruits and this in turn depends on many factors such as the climate, pollinators and floral biology of the species (Sedgley, 1980). In the present study, the extent of initial fruitset observed ranged from 73 to 5 per cent. The highest fruit set was observed in *Terminalia tomentosa* and the lowest in *T. catappa.* The low initial fruit set in *T. belerica* and *T. catappa* was due to the presence of large number of functionally male flowers with aborted ovary.

The fruit development in tree species involves different developmental phases. In the four species of *Terminalias* in the present study also the different fruit developmental phases and seed maturity can be easily distinguishable from the colour change of fruits. In *Terminalia catappa* the fruit colour was changed from yellow to

black, where as it became brown in the case of *T. paniculata* and *T. tomentosa* at the time of seed maturity. The fruit colour was greyish brown at the time of seed maturity in the case of *T. belerica.* Fruit colour change is a dependable indice to determine the seed maturity in *Terminalias.* It is the readily apparent phenomenon in the ripening process which involves chlorophyll loss and subsequent synthesis of pigments (Rhodes, 1970). Jakson (1986) also reported browning of pericarp as a good indices in determining seed maturity in many tree crops.

All the fruits which were set initially wouldn't be retained until the final developmental stage, a large portion of them will be dropped before attaining the seed maturity. In the observed *Terminalia* species also the extent of seed maturity range was 17 to 35 per cent. Similar to the seed maturity, only a portion of the mature seeds are germinable and will involve in the germination process. The regeneration potential of the species is largely depends upon the extent of seed maturity and germination percentage (Sedgley and Griffin, 1987). The extent of reproductive capacity of the species, determined by its seed maturity and reproductive capacity in the observed species were with in a range of 6.38 to 1.26. The trend earlier noticed in the genus *Terminalia* by Srivastava (1993) is also in conformity with the present study.

Summary

SUMMARY

A study was carried out in Vazhachal forest division and Kerala Agricultural University campus on the reproductive biology of the four *Terminalia* species viz. *Terminalia catappa, Terminalia belerica, T. paniculata* and *T. tomentosa* with the objective of understanding the phenology, flowering, floral biology, morphology, self fertilization, pollination time, fruit set and seed maturity of these four species. The results of the study are summarised below:

1) In *Terminalias* the leaf shedding period occurred during the dry months and leaf colour change was observed prior to the leaf fall. The period of dormancy was noticed at the final stage of the major leaf shedding activity and was over before the rainy season.

2) Flushing in *Terminalia* species facilitate the utilization of the high moisture availability during the rainy season and flowering was observed along the flushing. Fruting period showed considerable variation on account of the difference in flowering time, fruit development and maturation period.

3) The inflorescence of *Terminalia catappa* and *T. belerica* was simple spikes, whereas that of *T. tomentosa* and *T. paniculata* was panicled spikes. The flowers on the spikes of *Terminalia paniculata* and *T. tomentosa* were all hermaphrodite, whereas in *T. belerica* and *T. catappa*, the lower most six flowers only were hermaphrodite and the others were male.

4) The anthesis and anthedehisence were observed during the morning hours in *Terminalia catappa* and *T. belerica*, and during the evening hours in *T. paniculata* and *T. tomentosa,* which will facilitate high insect activity and maximise pollination. The stigma receptivity was the highest at the time of anthesis and just after it, the receiptivity reduced considerably with the age of stigma. The fertility of pollen grains ranges from 63 to 43 per cent and maximum value was observed in *T. tomantosa.*

5) The flower production of *Terminalias* ranged from 2046 to 16841 flowers in one square meter of crown area with the lowest and highest values were observed in *T. catappa* and *T. paniculata* respectively. The longevity of opened flowers vary from 74 to 36 hours and the peak pollination was noticed within two hours of flower opening. Self fertilisation was not successful in the species.

6) Mass flowering was observed in *Terminalia belerica* and *T. tomantosa* whereas it was intermediate type in *T. paniculata.* In *T. catappa* steady state type of flowering pattern was noticed.

7) The fruit development undergo different phases and can be easily distinguished from the colour change. The seed maturity also can be understood from the colour change of their fruit. The number of days required for attaining seed maturity was 60 to 65 days in *T. catappa*, 110 to 120 days on *T. paniculata*, 160 to 170 days in *T. belerica* and the maximum 200 to 210 days was noticed in *T. tomentasa.*

8) The extent of initial fruit set and seed maturity varied considerably among the four species. The extent of reproductive capacity was maximum (6.38 per cent) in *Terminalia tomentasa* and the minimum (1.26 per cent) was noticed in *T. catappa.*

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APPENDIX I

Number of flowers per spike of *Terminalias*

Tree No.	Species			
	T. catappa	*T. belerica*	*T. tomentosa*	*T. paniculata*
1	77.9	46.8	66.0	54.7
2	76.3	46.9	65.9	55.7
3	76.6	45.8	66.4	56.0
4	76.8	47.9	66.2	55.6
5	77.6	47.6	65.0	55.8
6	78.8	46.9	64.9	54.9
7	76.5	46.7	66.1	55.0
8	76.5	45.9	65.4	56.6
9	76.7	47.6	65.0	54.9
10	77.9	47.9	65.8	56.6
Mean	77.2	47.0	65.7	55.3

APPENDIX II

Crown size and number of spikes per meter square of the *Terminalia*

Sl. No.	Crown size (m^2)				Number of spikes/m^2			
	T. catappa	*T. belerica*	*T. paniculata*	*T. tomentosa*	*T. catappa*	*T. belerica*	*T. paniculata*	*T. tomentosa*
1	18.5	45.4	40.2	43.7	19.7	79.6	576.3	287.3
2	26.6	46.9	36.7	38.4	26.3	84.3	816.5	217.5
3	29.2	51.3	41.1	43.2	28.4	65.7	643.7	312.9
4	20.9	50.6	35.7	39.9	21.7	92.3	475.6	181.6
5	21.7	40.3	43.2	45.2	32.1	57.5	534.2	169.5
6	24.3	49.7	39.5	38.1	21.1	60.3	617.9	217.4
7	19.8	54.2	44.3	47.3	28.4	91.3	719.6	293.2
8	24.7	38.9	36.9	38.9	36.3	90.5	497.4	169.5
9	24.1	58.2	41.3	41.9	24.3	86.3	693.5	284.2
10	25.7	52.5	39.1	49.4	26.7	80.2	710.3	187.6
Mean	23.6	48.8	39.8	41.2	26.5	78.8	628.5	256.3

REPRODUCTIVE BIOLOGY OF *Terminalia* SPECIES OF TROPICAL MOIST DECIDUOUS FORESTS OF KERALA

By

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ABSTRACT OF THE THESIS

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ABSTRACT

An investigation was carried out in Kerala Agricultural University campus and Vazhachal Forest Division on the reproductive biology of *Terminalia* species of tropical moist deciduous forests of Kerala with the objective of understanding the phenology, floral biology, morphology, flowering, self fertilization, pollination time, fruit set and seed matruity of its species. Four species of *Terminalia* viz., *Terminalia paniculata, T. tomentosa, T. catappa and T. belerica* were observed for a period of twelve months starting from June 1996 to July, 1997.

The study revealed that leaf shedding and dormancy occurred in dry months and flushing occurred after the dormant period facilitate the utilization of high moisture available during the rainy season. The inflorescence of *T. paniculata* and *T. tomentosa* was panickled spikes and in *T. catappa* and *T. belerica* it was simple spike. All flowers were hermaphrodite in *T. paniculata* and *T. tomntosa* but in *T. catappa* and *T. belerica* the only lowermost six were hermaphrdite and others were male flowers with defective overy. Mass flowering was observed in *T. belerica* and *T. tomentosa*, but steady state type of flowering activity was observed in *T. catappa* and intermediate type of flowering pattern was noticed in *T. paniculata.* The anthesis and antherdehiscence occurred during the morning and evening hours in *Terminalias* facilitate high insect activity and maximum pollination. The stigma receptivity was high at the time of anthesis and it declines sharply with its age. The fruit development phases and seed maturity were distinguishable from the colour change of their fruits. The extent of fruit set seed maturity and reproductive capacity of *Terminalias* suggested that only very small proportion of the flowers producerd were transformed into viable fruits.