KFRI Research Report No. 225 ISSN 0970-8103

POLLINATION ECOLOGY OF TEAK IN KERALA

K. Mohanadas
George Mathew
E.P. Indira

Kerala Forest Research Institute
Peechi - 680 653, Kerala, India

January, 2002

KFRI Research Report No.225

Pollination Ecology of Teak in Kerala

K. Mohanadas
George Mathew
(Division of Entomology)

E. P. Indira
(Division of Genetics)

Kerala Forest Research Institute
Peechi 680 653, Kerala, India

January 2002

PROJECT PROPOSAL

1. Project No. : KFRI 292/98

2. Title of the project : Pollination Ecology of Teak in Kerala

3. Principal Investigator : K. Mohanadas
   Entomology Division

4. Co-investigators : George Mathew
   Entomology Division
   : E. P. Indira
   Genetics Division

5. Objectives:
   1. To study the various aspects of pollination in teak in dry and moist zones in Kerala,
   2. To study the role of insects in pollination,
   3. To evaluate the effect of insect assisted pollination in boosting seed production , and
   4. To study the breeding system in teak.

6. Study area : KFRI campus

7. Date of commencement : January 1998

8. Scheduled date of completion: December 2000

9. Funding agency : Kerala Forest Department (Development)

CONTENTS

ABSTRACT

In Kerala, flowering of teak trees generally coincides with the SW monsoon during May-June although sporadic flowering may occur towards the end of March at some locations. On an average, each tree bears more than 300 inflorescence. The number of flowers in an inflorescence varies from 5,000 to 7,000 and it takes 30-40 days for the flowering to complete in a single inflorescence. Usually, only less than one per cent of the initial number of flowers results in fruiting. The flowers open by 6.30 am and drop off by 7 pm. Anthesis occurs from 8 am to 12 am. The stigma normally become receptive between 8 am and 2 pm. Studies using fluorescent microscopy have shown that teak prefers cross-pollination although a certain amount of selfing could also be observed. Observations have also shown that the same tree that rejected selfing till 3 pm allowed it afterwards.

The flowers at all the four-positions in the inflorescence viz., P1, P2, P3 and P4 were found to be receptive to pollination although, maximum fruit setting was found in the P1 and P2 positions. Insects were found to play a major role in pollination. Pollination by insects was observed to commence in the morning and continued till noon after which the insect activity decreased. Maximum insect visit coincided with the anthesis. The insects observed on the teak inflorescence, belonged to the orders Hymenoptera, Coleoptera, Lepidoptera, Diptera, Thysanoptera, and Hemiptera. Maximum number of species recorded belonged to Lepidoptera, most of which were butterflies. Based on the

quantity of pollen carried and potential to effect pollen transfer, the solitary bees, *Halictus tectonae* Narendran & Joberaj, *Nomia elliotii* Smith, *Anthophora niveo-cincta* Smith and *A. zonata* Lin. as well as the wasps *Eumenes flavopicta Blanch* and *Rhynchium brunneum* (Fabr.) were to be the main pollinators. Although the domesticated bee *Apis indica* Fabr. was also observed to be attracted to teak flowers, they were not observed in sufficiently large numbers in the trials conducted to evaluate their role in boosting pollination through introduction of colonies in plantations.

While most of the insects were observed visiting different inflorescence on a single tree, the solitary bees and wasps were found to move from tree to tree visiting different inflorescence. Thus, most of the insects contributed to selfpollination rather than crosspollination. Isolation of flowers from pollinators showed marked reduction in fruit setting.

Factors leading to premature fruit fall was also investigated and a fungus *Phomopsis* sp. was also found to be the major cause. Fortnightly application of Mancozeb 75 WP (0.25%) on the inflorescence from the early flowering stage to fruit formation was found to give effective control of the infection.

1. INTRODUCTION

Teak (*Tectona grandis* Linn.) is one of the most valuable and widely planted tree species in south Asia (Kaosa-Ard, 1981). In India, natural teak forests are found up to 24° N latitude extending as far as the Western Aravallis of Rajasthan. Being highly adapted to a wide range of climatic and edaphic conditions, teak is preferred for large-scale plantation programs all over India. Approximately 9,91,560 ha have been planted with teak in India (Pandey and Brown, 2000). The important teak growing States in India are Kerala, Tamil Nadu, Karnataka, Madhya Pradesh and Maharashtra. In Kerala, about 76,000 ha have been planted with teak (KF and WLD, 1999).

Low fruit production and poor germination rates have already been reported to be the major problems in teak propagation (Anmol Kumar and Kumar, 1992; Bedell and Vijaya Chandran, 1994). With a view to ensure adequate supply of good quality seeds, seed orchards have been established in Kerala. However, the quantity and the germinability of seeds produced were found to be too low to meet the current demands.

Only less than one percent of the initial lots of flowers present in each inflorescence develop into fruits. Insect assisted cross-pollination will be helpful in order to enhance seed productivity in teak orchards. For this, a thorough knowledge of the floral biology, breeding system, as well as factors affecting fruit maturation and is required. It was in this context that the present investigation was undertaken to study the breeding system and various aspects of pollination in teak.

2. REVIEW OF LITERATURE

Since 1969, several investigations have been made on the factors affecting fruitsetting in teak, inorder to develop strategies to enhance seed production. The most important of such studies have been those on the reproductive biology (Bryndum and Hedegart, 1969; Hedegart, 1973; Egenti, 1978; Nagarajan *et al.*, 1996; Palupi and Owens, 1996; Tangmitcharoen and Owens, 1996; Bila *et al.*, 1999). Owens (1993) has discussed in detail the constraints in seed production in temperate and tropical forest trees. Juvenility, clonal variation, genotype verses environmental interactions, insufficient number of pollinators, attack by insect pests, rain damage as well as premature fruit abortion due to unknown physiological reasons have been reported to be the main reasons for low fruit setting in many tree species including teak (Hedegart, 1973; Neelay *et al.,* 1983; Sirikal, 1992; Rawat, 1994).

Karmacharya and Singh (1992) have studied production and nutrient dynamics of reproductive components of teak in the dry tropics. Based on a study carried out in 14 to 30- year- old teak tree stands, they have shown that flower production per tree was positively correlated to tree size. The annual production of reproductive components (flowers, peduncles, and fruits) in the 14-year-old stand was 245 kg/ha and 1122 kg/ha in the 30-year-old stand. Despite massive annual flower production, only about 0.5- 0.7 per cent of the flowers developed into fruits. Immature fruit abscission in the 14 and 30 year-old stands was from 34 and 58 per cent respectively. Availability of nutrients in the reproductive parts was also found to vary with season. For instance, in both stands, relatively greater amounts of dry matter and nutrients were present in the reproductive parts during September compared to other months.

Teak flowers being protandrous, the male gametes attain maturity before the female gametes. Within a few hours of flower opening, anthesis (shedding of pollen) takes place. Although 78 per cent of the flowers were open pollinated, the rate of fruit setting was found to be low (3.5%) suggesting that there are other factors as well which influence the fruit set (Owens, 1993). Investigations on the receptivity of stigma, development of embryo, rate of growth of pollen tube as well as pollination success have indicated a high proportion of selfing.

Dabral (1976) made observations on fruit formation right from flowering to fruit maturity in 20 to 50 year-old teak trees at four sites in Chandrapur District in Maharashtra. The fertilized fruits in the early stages of development have four ovules, one in each of the four locules and emptiness (of one or more empty testae) developed at the time of lignification of the endocarp. Availability of accumulated food reserves in the tree as well as site factors were found to be important in the development of seed emptiness. Other aspects such as age or infestation by insect pests, especially the teak skeletonizer *Eutectona machaeralis* (Wlk.) were not found to affect the rate of seed set.

Neelay *et al.,* (1983) investigated the role of insects in fruit setting in teak orchards in Mohghata in Maharashtra. *Pagyda salvalis* Walker (pyralid pest affecting inflorescence and fruit), *Leptocentrus taurus* Fabr. (sap sucking bug) and *Dichocrocis punctiferalis* Guen. (fruit borer) are the major insect pests that cause direct or indirect fruit loss. Trials using various insecticides have shown that application of Thiodan (endosulfan) 0.25 per cent or Nuvacron (monocrotophos) 0.025 per cent with the hormone Naphthalene Acetic Acid at 40 PPM gave best results in controlling these pests (Neelay *et al.,* 1983). Subramanian and Seethalakshmi (1984) examined pollen sterility as a factor affecting seed production in teak in Maharashtra. However, since the percentage sterility was found to be insignificant, it was not considered as an important factor affecting seed set.

Bryndum and Hedegart (1969) and Hedegart (1973) studied the role of insects in pollination of teak. Based on a study carried out in Thailand they stated that 'intra-tree flight' was the habitual nature of insects visiting teak, which leads to selfing. These studies have also shown that teak is an insect pollinated species with a high degree of selfincompatibility.

Mathew *et al.* (1987) studied the insect pollinators of teak in Kerala. Seventeen species of insect pollinators were recorded, of which 13 were hymenopterans and two each of dipterans and lepidopterans. Among the hymenopterans, the solitary bees *Prosopsis pratensis* Guerst, *Allodope marginata* Sm. and *Halictus* sp., were the most potential pollinators. The study showed that these insects were active during the cooler morning hours (8-10 am) than the rest of the day. They also suggested the possibility of enhancing pollination by the introduction of colonies of domestic bees.

Manish and Mishra (1991) studied the relationship between the tree growth (gbh) and seed emptiness. It was found that seeds collected from trees of higher girth classes showed less seed emptiness compared to seeds from trees of lower girth classes. The former also gave better germination percentage. The germinability of seeds from trees of 161-200 cm gbh was 39.25 per cent and for trees of 40-80 cm gbh, 27 per cent.

Anmol Kumar and Kumar (1992) worked on teak seed improvement in Maharashtra by establishing seed orchards. The overall performance of clones raised in the seed orchard was found to be quite satisfactory.

3. MATERIALS AND METHODS

3.1. Breeding system in teak

3.1.1. Flowering and fruiting

Regular observations on flowering, anthesis, stigmatal receptivity, fruit setting, etc. were made on selected teak trees in the KFRI Campus at Peechi (4 trees) and in the Chinnar Wildlife Sanctuary (2 trees) during the entire flowering period. The trees were 25 to 35 years old, growing among other natural moist deciduous tree species. Occasional observations were also made on four other trees selected at Vellanikkara, Olarikkara, Trichur and Karuvannur. In order to reach the inflorescence, two scaffold towers have been erected at Peechi; at other places, ladders were used.

On each tree, periodical observations were made from 6 am to 6 pm to collect information related to the floral activities such as flower opening, anthesis and shedding of flowers. The viability of pollen grains was tested in 14 per cent sucrose solution (Egenti, 1978) using samples collected at various intervals. Stigmatal receptivity was tested at hourly intervals from 6 am to 4 pm by staining with 1 per cent aqueous solution of Nile blue sulphate and warming in 1 per cent acetic acid. The staining pattern of lipids on the stigmatic surface was set as an indicator for the stigma receptivity. For this, 10 flowers each was collected from the first, second, third and fourth order branches (P1, P2, P3, P4) of the inflorescence. In order to find out whether enough pollination had occurred naturally, the pollen load was estimated at the end of the day in rainy as well as sunny weather conditions by

observing the entire stigmatic surface and counting all the pollen grains adhering to it.
The effects of flower position on fruit set as well as the per cent fruit setting were also estimated. For this, 10 inflorescences collected from each of the 10 experimental teak trees were examined and the number of buds, flowers, and premature fruits formed were recorded.

3.2. Pollinator activity

The foraging activity of various insects visiting the teak inflorescence was closely observed from the scaffold towers. Initially the observations were made continuously from morning to evening, and subsequently, the observations were limited to specified hours when the insects were found to be most active. The foraging time, frequency of insect visit and the number of individuals of each species visiting the inflorescence were noted. Samples of insects were collected using a sweep net and observed under a microscope for presence of pollen on their body parts in order to assess the pollen carrying capacity of the insects. The insects collected were later preserved for confirming their identity.

The role of insects in pollination was studied by recording insect activity by emasculating whole inflorescence and exposing them to pollinating insects. Observations were also made on unemasculated normal inflorescence. In both cases, flower density was noted prior to observation and insect activity observed for the entire day. At the end of the day, stigmas from both the manipulated and normal inflorescence were excised and observed under the microscope for stigmatic pollen load.

3.2.1. Artificial pollination studies

The role of insect foragers in pollination was evaluated in order to explore the possibility of enhancing the fruit setting rate.

i. Role of insects in pollination

For studying this, two sets of inflorescence were selected, of which one set was covered with nylon nets in order to prevent the entry of insects, while the other was left open for natural pollination. At the end of the day, 15 stigmas were excised from each set of inflorescence and pollination success and pollen load estimated by counting the number of pollen grains present on the stigmas.

ii. Artificial self-pollination

The flowers were emasculated and dusted with pollen of the same tree at peak pollination time and the result of self pollination recorded.

iii. Artificial cross-pollination

The flowers were emasculated before anthesis and they were pollinated with pollen from other trees and the result of crosspollination recorded.

iv. Index of self-incompatibility

This index was estimated by using the method suggested by Zapata and Arroyo (1978).

v. Role of domesticated bees in pollination

In order to evaluate the role of domesticated bees in enhancing pollination in teak, beehives (containing active bees) were kept in the vicinity of teak trees that were in bloom and pollinating activity observed.

3.2.2. Pollen tube formation in self and cross-pollinated flowers

In order to assess the success of pollination, pollen tube growth in self- and cross-pollinated flowers was studied. The procedure for preparing material for microscopy was as follows. The pistils excised from self and cross-pollinated flowers were fixed in acetic alcohol and stored in 70 per cent alcohol. They were transferred to 4N sodium hydroxide and left overnight. The cleared pistils were then rinsed with double distilled water and kept in decolourised aniline blue overnight. The stained pistils were washed in water and mounted in glycerin and observed under fluorescence microscope for pollen tube growth (Kho and Baer, 1968, Shivanna and Rangaswamy, 1992). The style and stigma from selected self- and cross- pollinated flowers were collected at hourly intervals for up to 24 hours after pollination and the pollen tube germination studied *in vivo* by staining the material for fluorescence microscopy using aniline blue.

4. RESULTS AND DISCUSSION

4.1. Breeding system in teak

4.1.1. Flowering

In Kerala, the peak flowering season is during rainy season (June - September), although in a few cases erratic flowering was observed during the summer months as well. The flowering season has been reported to be similar in other countries also. In Thailand, flowering was reported from June to August which is also a rainy season (Tangmitcharoen and Owens, 1996). In Indonesia, flowering begins during the rainy season and the fruits attain maturity during the dry season (Palupi and Owens, 1996). In Mozambique, flowering begins in the middle of rainy season in January and lasts up to April (Bila *et al.*, 1999). These show that teak generally flowers during the rainy season and the fruits mature in the subsequent months.

The number of inflorescence present on the trees was found to vary. The average longevity of an inflorescence was about a month. In an inflorescence, the flowers are categorized into four maturity (age) groups viz., flowers at first order branching (P1), second order branching (P2), third order branching (P3) and fourth order branching (P4) (Fig.1). Seventy per cent of flowers were from P3 and P4

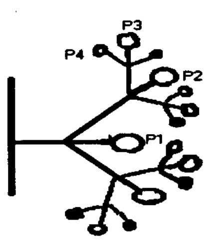

Fig. 1 Position of flowers (P1, P2, P3 and P4) in a portion of the teak inflorescence

positions. The flowers are arranged as compound dichasial cyme and remains open throughout the day till they fell off in the evening (around 7 pm) after which the petals and stamens abscise leaving the calyx and style for some more time. Nectar produced in the lower half of the corolla tube was available from early morning hours till afternoon.

4.2. Effect of position of flowers on fruiting

In any inflorescence, fruiting was observed mainly in the P1and P2 flower positions. No fruiting was observed in P3 and P4 flower positions. The peripheral part of the inflorescence remained mostly vacant. Based on observations made on two different teak trees, the per cent fruit set on different flower positions was worked out as follows:

Tree No. 1: P1 (41%), P2 (35%), P3 (18%) and P4 (6%)

Tree No. 2: P1 (68%), P2 (31%), P3 (1.2%), and P4 (1.4%).

Data presented here clearly show that the flowers at positions P3 and P4 were less productive than flowers at the other two positions. Peripheral flowers of massive inflorescence in general have been reported to function as pollen donors (Styles, 1972; Wilson and Bertin, 1979; Bawa and Webb, 1984; Holtsford, 1985; Ganeshaiah and Uma Shaanker, 1998). The flowers in P1 position matured first followed by P2, P3 and P4. In teak, the fruits initiated early in the inflorescence are known to have a lower probability of aborting than the fruits initiated later. Similar situation has been reported in other trees like in *Yucca whipplei* as well (Udovic and Aker, 1981).

4.3. Pollen load

There was marked difference in the degree of pollination during the flowering season. During the early flowering season (3rd week of

February to the 3rd week of April) when only a few trees were in bloom, many of the flowers were not pollinated. However, in the peak season (June to September), more than 80 per cent of flowers were pollinated (Table1). During this season, especially on sunny days, around 95 per cent of flowers were found to be pollinated with an average number of 8.25 pollen grains per stigma. However, on rainy days only 45 per cent of the flowers were found to be pollinated, with a low pollen load of 1.9 (Table1). The reason for the poor pollination percentage during rain may be due to the reduced anther dehiscence and stigma receptivity. The insect activity was also found to be low during rains.

Table1. Pollen load on stigmas during different seasons

Date of observation	No. of stigmas observed	No. of stigmas with pollen grains	Average No. of pollen grains on stigma	Percentage of stigmas pollinated	Percentage of stigmas not pollinated
3rd week of February	20	13	3	65	35
2nd week of March	30	16	3	53	47
3rd week of March	30	24	6	80	20
4th week of March	30	24	4	80	20
1st week of April	17	16	9	94	6
July (during sunny days with intermittent showers)	20	19	8.25	95	5
July (during rainy days)	23	10	1.95	45	55

4.4. Stigma receptivity

As has already been stated, teak flowers open by 6.30 am and fall off by 7.00 pm. The stigmatic secretions contain lipids, amino acids and perhaps sugars. Lipid staining with aniline blue sulphate tested stigmatic receptivity. Intense staining was observed with samples collected from 10 am to 2 pm. Intense staining is an indication of maximum stigma receptivity. The stigma became receptive after 8 am and it showed maximum receptivity by 12 am after which the receptivity started to decrease. Stigma receptivity was almost identical in flowers at different positions (P1, P2, P3, & P4) of the inflorescence. Tangmitcharoen and Owens (1996) have also reported 11am to 1pm as the most receptive period.

4.5. Pollen tube formation in self and cross-pollinated flowers

Fluorescent microscopical studies have indicated that pollen germination and stigma penetration occurred within 45 minutes of pollination. The pollen tubes were observed in the stylar region by one hour and there was no inhibition of pollen tube growth either in self-pollinated or cross-pollinated flowers. The entry of the pollen tubes into the ovules through micropyle occurred within 5 to 6 hours. In most self-pollinated flowers the pollen tubes were found to be coiled around the ovary indicating failure in making an entry (Fig.2), while in cross-pollinated flowers, there was no obstacle for the entry of pollen tubes into ovules (Fig. 3). Tangmitcharoen and Owens (1996) noted similar pollen tube abnormalities in their studies where, up to 20 per cent of the self-pollinated flowers developed abnormalities in pollen tube penetration which was attributed to late, acting gametophytic self-incompatibility. The findings of the present study show that teak prefers cross-pollination with a certain percentage of self-incompatibility. The index of self-incompatibility (ISI) was worked out during this study and the value obtained was 0.4, which indicates partial self-incompatibility.

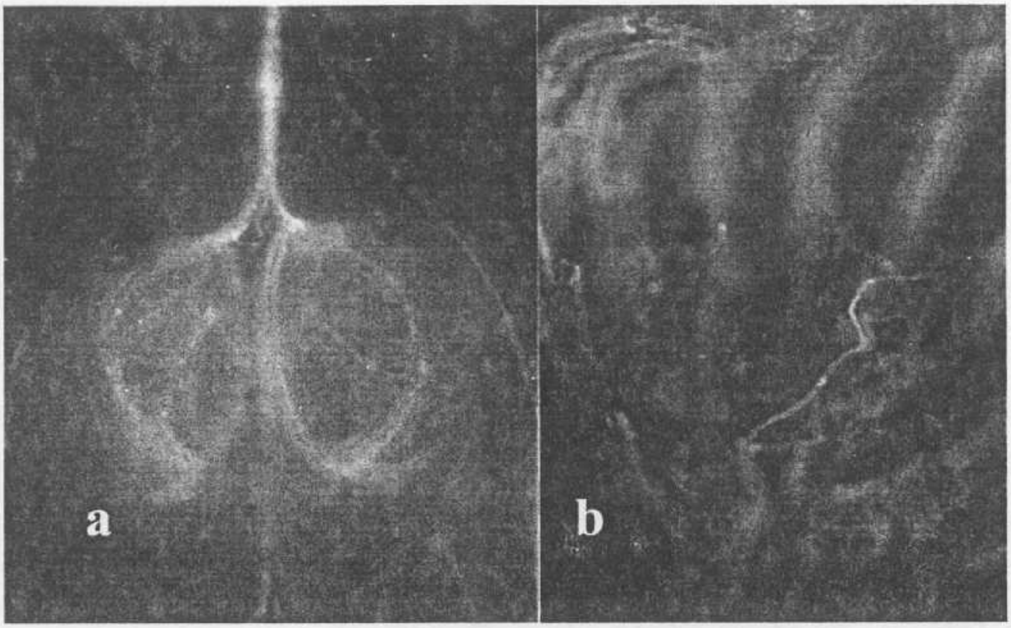

Fig.2.a & b Unsuccessful pollen tube coiling around the ovary failing to make an entry through the micropyle

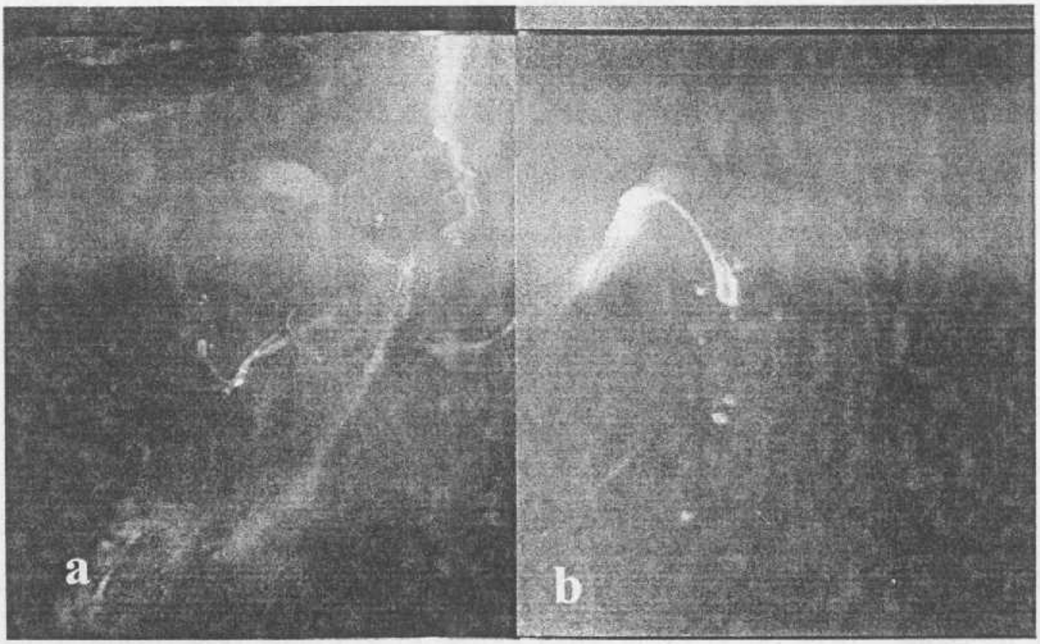

Fig.3. a & b Successful instance of pollen tube development. Note the pollen tube entering through the micropylar region

4.6. Insects visiting teak inflorescence

The open flower structure as well as the richness in pollen and nectar attracts diverse groups of insects to teak inflorescence. Observations on insect activity on teak flowers have shown an increasing trend from morning to noon (9 am-12 am) coinciding with the increase in temperature. Insect activity showed a gradual decrease towards the evening.

Altogether 60 species of insects were recorded in this study (Appendix 1&2). They belonged to 42 families under 6 orders *viz.*, Lepidoptera (28 spp.), Hymenoptera (15 spp.), Hemiptera (4 spp.), Diptera (7 spp.), Coleoptera (4 spp.) and Thysanoptera (2 spp.). Maximum number of species recorded belonged to Lepidoptera, most of which were butterflies. Of these, the skippers *Tagiades litigiosa*, *Potanthus* sp., and *Udaspes* sp., were found to be the active visitors, visiting several flowers in quick succession. However, they are not considered as true pollinators as they were not found to carry pollen grains on their body parts.

The hymenopterans collected belonged to Apidae (bees), Eumenidae, Sphecidae (wasps) and Formicidae (ants), of which the wasps contained maximum number of species. The bees were found to be active mostly during morning hours and the dominant ones were the stingless bee, *Apis florea* Fabr., the dammer bee, *Melipona iridipennis* Dall. and the Indian bee, *Apis indica* Fabr. besides four species of solitary bees- *Anthophora zonata* (Lin.), *A. niveocincta* Smith., *Nomia elliotii* Smith and *Halictus tectonae* Narendran & Joberaj. Most of the bees except *M. iridipennis,* were present only in small numbers. Of these, the solitary bees were found to be very active, visiting several inflorescence on the same tree in a short time carrying appreciable loads of pollen on the under side of their abdomen and on their hind legs.

4.6.1. Foraging pattern of insects and their role in pollination

As has been stated earlier, the hymenopterans by virtue of their size, number and morphological adaptations were found to be efficient pollinators, while certain other groups of insects like Lepidoptera, Diptera and Coleoptera which do not have elaborate adaptations to make efficient contacts with the stigma were considered to be only as nectar 'stealers'. Foraging by nectar stealers has been reported to render the flower less attractive to efficient pollinators (Young, 1981). Since a large number of inflorescence (150-200) are available on a single tree, most of the insects were found to feed at the flowers belonging to the same tree. The wasps, which were found to move very fast among the inflorescences of a single tree as well as of the adjacent trees, were the only exception. This means that most insect foragers restricted their activity to a single tree, resulting in intra inflorescence pollen transfer. Rainy conditions that normally prevail during the flowering season of teak have also resulted in reduced insect activity and thereby of less cross-pollination. In the case of emasculated inflorescences, the insects were found to be moving among the flowers feeding on nectaries.

Although four colonies of *Apis indica* were kept in the vicinity of the trees under observation, no proportional increase in the number of honeybees visiting the teak flowers could be observed which indicate that teak flowers are not very much preferred by them.

4.7.Fruit formation

The effect of selfing and cross-pollination on fertilization and fruit maturation is represented in Table 2. The unfertilized ovules are known to persist only for about 10 days. The number of fertilized ovules present in artificial pollination (self and cross) were counted at periodic intervals after two weeks of pollination. Eighty five per cent of fruits developed by self pollination and eighty two per cent of fruits developed by cross-pollination were found to be aborted within a period of 4 months. It was found that even if a greater percentage of fruit setting occurs initially (56 per cent), in assisted cross-pollination, the survival rate of fruits would be low due to the high abortion rate. Palupi and Owens (1996) suggested that fruit set depends mainly on food resource and that scarcity of food resources may lead to fruit abortion. It has also been reported that the tendency for fixed abortion is for natural selection at zygotic level either through competition among embryos or by direct control from the maternal plant (Casper and Wiens, 1981).

Observations made in this study indicate that only about 1per cent fruit setting occurred through natural pollination. Through artificial self-pollination, 4 per cent fertility could be induced. The selfing experiment showed a fruiting percentage of 6 per cent and 2.67 per cent respectively in the successive years and in artificial cross-pollination, 10 per cent fruiting could be obtained. This clearly shows that insufficient pollination is one of the reasons for the low fruit productivity in teak as suggested by Hedegart (1973) and Tangmitcharoen and Owens (1996). Hedegart (1973) has reported varying fruiting percentage of 0.2 and 1. 3 through natural pollination in different years while through artificial crosspollination it was increased to about 12.

Table 2. Effect of artificial (self and cross) pollination in fruit setting

Period after pollination	*No. of fruit setting through self pollination	*No. of fruit setting through cross pollination	Percentage of fruiting in self pollination	Percentage of fruiting in cross pollination	Percentag e of fruits aborted in selfed fruits	Percentag e of fruits aborted in cross pollinated fruits
2 weeks	13	28	26	56		
21 month	8	17	16	34		
2 months	6	11	12	22		
3 months	3	6	6	12		
4 months	2	5	4	10	85	82

* Out of 50 number of flowers

Fluorescent micrographs as well as artificial pollination experiments indicate that selfing is accepted to a certain extent (Kho and Baer, 1968). In the present study, it was found that the teak tree, which rejected selfing up to 3 pm, accepted it afterwards (Fig.4). In inflorescence isolated from insect foragers using nylon nets, 20 per cent of the stigmas were self-pollinated naturally (Table 4) which also shows that a low percentage of selfing occurs in teak.

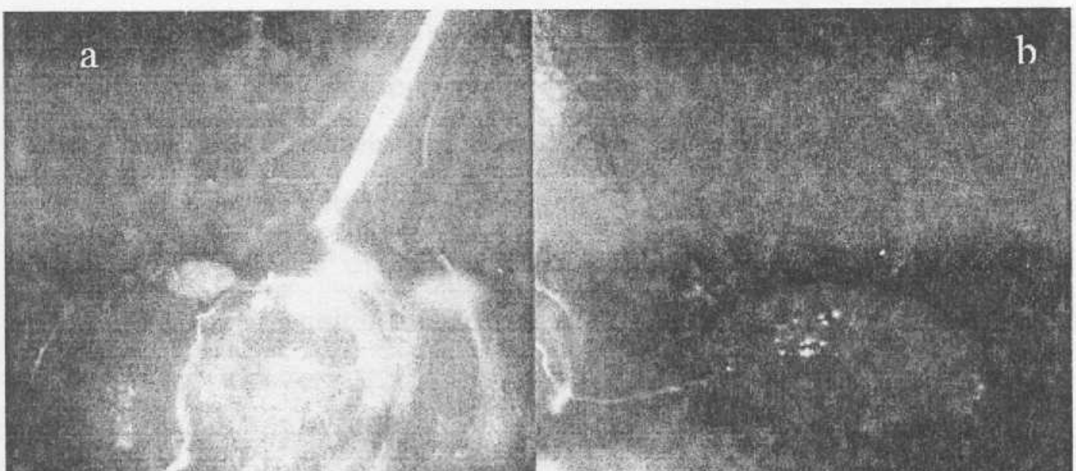

Fig.4. a. pollen tube formation: & b. pollen tube entry in selfing at late hours after breaking the self incompatibility barrier

The number of seeds per fruit was also found to vary considerably. Out of the 160 fruits examined in the cutting test, 59% (95 fruits) had no seeds, 36% (57 fruits) had one seed, 4% (seven fruits) had two seed each, 0.6% (1fruits) with three seeds. No fruit possessed four seeds. In another lot of 65 fruits, 88 per cent had only one seed, 11 per cent with two seeds and two per cent with three seeds. One of the reasons for the poor seed formation in teak might be the low pollen-ovule ratio, as found in many cases. Another reason might be the incidence of fungal infection to the fruit that lead to a blockade in seed filling as discussed under 4.9.1. Once the fruit stalk gets infected, it becomes non-functional and as a result, conduction of nutrients to the locule is affected leading to emptiness of second, third and fourth position locules.

4.8. Isolation of flowers from pollinators and its effect on fruit setting

The role played by insects in pollination of teak was further investigated by examining the pollen load on stigma under natural conditions by emasculating and covering flowers in the inflorescence with nylon nets. Data on flower density and average pollen load per stigma are given in Table 3. In the case of emasculated inflorescences, 80 per cent of the flowers did not receive even a single pollen grain. However, a small proportion of flowers (20%) was found to be pollinated, which was attributed to the entry of smaller insects that could sneak through the meshes of the net effecting transfer of pollen. In the uncovered and unemasculated inflorescences more than 87 per cent flowers were pollinated and in uncovered and emasculated inflorescence 77 per cent were pollinated. This shows that a small percentage of flowers (10%) were pollinated by pollen from the same inflorescence (Table 4).

In the emasculated flowers, the stigmas contained only a few pollen, which were probably brought from the adjacent inflorescences. In the normal flowers, the pollen load was high due to the activity of insect pollinators. The percentages of bare stigmas in these flowers were comparatively less and the average pollen load per stigma was high.

These results indicate that insects are important pollinators of teak. However they mostly effect pollination using pollen collected from the inflorescence of the same tree, rather than using pollen from inflorescence of other trees in the plantation which indicates that insect aided pollination is not strictly cross-pollination, rather it is selfing.

Table 3. Flower density and average pollen load per stigma in emasculated and unemasculated flowers

	Total No. of flowers emasculated on different inflorescence	Flower density of intact inflorescence at 1 m distance from the emasculated flowers	Percentage of bare stigma	Average pollen load per stigma
Emasculated flowers	14	270	57	1.7
	20	50	80	0.45
	30	250	23	2.9
Unemascul--ated flowers	Total No of stigma observed	Flower density of intact inflorescence studied	Percentage of bare stigma	Average pollen load per stigma
	17	200	5	8.23
	20	150	35	5.5
	30	100	20	4.12

Table 4. Per cent pollination in emasculated / covered inflorescence

Treatments	No. of stigmas observed	Stigmas with pollen load	Average No. of pollen grains on stigma	% of stigmas pollinated
Inflorescence covered with nylon nets	15	3	3	20
Inflorescence not emasculated, not covered	15	13	9	87
Inflorescence emasculated and not covered	30	23	2.9	77

Table 5. Comparative fruit setting in covered and open inflorescence

Tree location and inflorescence observed		Fruit setting in cloth bag	Fruit setting in net bag	Fruit setting in open Inflorescence
KFRI campus	R1	0	9	145
	R2	0	5	95
	R3	0	9	60
Olarikkara	R4	2	45	238
	R5	3	3	180
	R6	1	4	120
Average		1	**13**	**140**

R= Replication

4.9. Fruit abortion in teak

Premature fruit fall is an important factor leading to low seed production in teak. Our observations have shown that a large number of flowers in teak inflorescences withered off at an early stage (Table 6). Among various factors leading to fruit abortion incidence of fungal attack or insect attack was the most important one. Other than the pest and disease infestation, scarcity of food resources and abnormalities of endosperm development are also known to induce a tendency for fixed abortion for providing opportunity for selection at zygotic level (Palupi and Owens, 1996; Casper and Wiens, 1981).

4.9.1. Incidence of fungal infection

In the case of fungal attack initially the flowers appeared to be brown coloured and later showed symptoms of fungal attack. The developing fruits also showed similar symptoms and showed premature shedding. Two species of fungi viz., *Colletotrichum* sp. and *Phomopsis* sp. could be isolated from the affected flowers and fruits. Of these, the latter was found to cause maximum damage (Mohanadas *et al.,* 1999). The impact of fungal attack on seed setting was assessed by collecting the entire flowers and fruits that fell prematurely in a wide mouthed cloth bag kept below the inflorescence.

Table 6. Comparative data on premature abscission of flowers in two trees

Stages of premature abscission	Tree 1 Total number of flowers in an inflorescence	Loss in percentage	Tree 2 Total number of flowers in an inflorescence	Loss in percentage
Total flower nodes observed	**5600**		**395**	
Button- stage fruits; Fruit size 1-1.5cms	29	0.5	0	0
Whole flowers *	59	1.1	0	0
Stamens-Petal system	329	6	125	32
Flower as a whole with all parts dried and crumpled *	1472	26	86	22
Flower falling with pistil and calyx alone *	1725	31	51	13
Very young flower buds	233	4	40	10
No. of fruits initially set	55	0.98	10	3
Number of flowers missing	2027	36	208	53

* Fungal infection by *Phomopsis* sp.

In order to study the distribution of this disease in various teak plantations, a survey was carried out at various locations in Kerala. It was found that the infection was rather widespread in several teak plantations in Kerala and the percentage of attack varied from 3 to 97 (Table 7). Fungal pathogens have already been reported to regulate the reproductive output in many tropical plants (Augspurger, 1990).

Table 7. Incidence of fungal infection to teak fruits at various locations in Kerala

Date of observation	Location	Infection of fruits (%)
31 July 1999	Karuvannur (Trichur Dist.)	22
"	Olarikkara (")	49
12 August 1999	Trichur (")	36
"	Mannuthy (")	11
"	Thottappady (")	11
19 August 1999	Irinjalakkuda (")	48
01 Sept. 1999	Wadakkanchery (")	87
06 Sept. 1999	Shornur (Palakkad Dist.)	52
07 Sept. 1999	Mannarkkad (")	65
"	Kuzhalmannam (")	9
"	Alathur (")	3
06 Sept. 1999	Pandikkad (Malappuram Dist.)	73
"	Nilambur (")	90
28 Sept. 1999	Mullumala (Kollam Dist.)	98
"	Achenkovil (")	98
"	Aryankavu (")	42
"	Konni (")	97

4.9.1.1.Control of fungal infection

The role of fungal infection in the premature abscission of the reproductive parts as well as its persistence in the developing fruits causing premature fruit fall calls for necessary attention. A preliminary trial using the fungicides Bavistin, Fytolan and Mancozeb (Indofil M45) at 0.1 per cent and 0.25 per cent concentrations were carried out. The treatments were carried out at fortnightly intervals starting from the early flowering season till seed maturation so as to cover the different stages of the inflorescence such as buds, flowers and developing fruits. The effectiveness of the chemical treatment on fruit development was assessed by

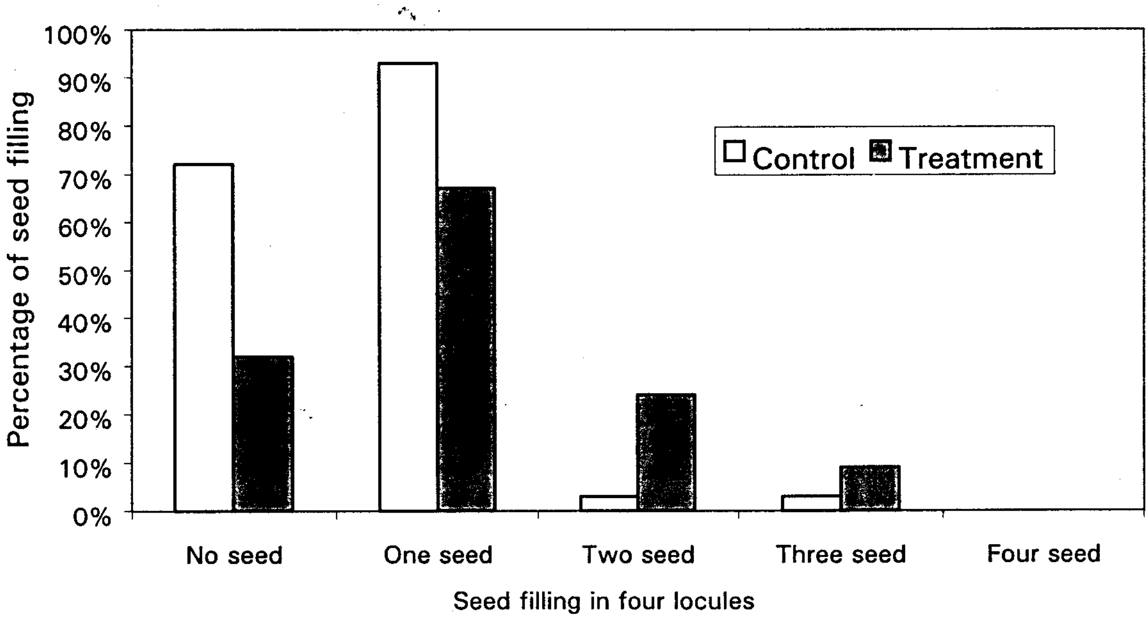

Fig.5. Effect of mancozeb 75%WP treatment in seed filling in teak

carrying out a cutting test using mature fruits collected both from the treated and control inflorescences. Of the various treatments, the one using Mancozeb 75% WP (Indofil M 45) at 0.25 per cent concentration gave the best result (Fig. 5). Treatments with Bavistin and Fytolan were not found to be very effective. Following chemical application, the infection subsided becoming 10 per cent by the 45th day compared to the control in which the infection showed a progression attaining 40 per cent by the 45^{th} day and 100 per cent on the 120 day. The studies have shown that for the effective control of the fungal infection, application of the fungicide right from the beginning of flowering till the fruits mature, is necessary.

4.9.2. Infestation by insect pests

Besides fungal attack, incidence of various insect pests have also been recorded (Appendix 2). In the case of fruits, incidence of a sap sucking bug *Tingis beesoni* Drake (Hemiptera: Tingitidae) was the most serious. Adults and immature stages of this bug were found to feed inside the inflated persistent calyx. As a result of injury caused by this insect, the mesocarp of the immature fruits develop callous growth and the affected seeds subsequently fall off. The bugs *Pochazia fuscuta* Fab. , *Flata* sp., and *Tessaratoma* sp., have also been reported to feed on the flower buds and premature fruits. However, the damage caused was not serious. Caterpillars of *Aphomia* sp., *Dichocrocis punctiferalis* Guenee, *Cleora* sp., *Potanthus* sp., and *Euproctis scintillans* Walker were found to feed on flower buds, flowers or on the mesocarp of premature fruits.

5. CONCLUSIONS

Investigations on the breeding system, the role of pollinators in fruit setting as well as factors affecting seed formation in teak were made in this study.

With a few exceptions, flowering in teak starts from June to August. Rarely, flowering has been observed from the 3rd week of February in some areas. On an average, there are more than 300 inflorescences on a single teak tree. Each inflorescence contains 5000 to 7000 flowers. The life span of a flower is 12.5 hours (from 6.30 am to 7 pm.). In a single inflorescence, flowering is completed in 30 to 40 days. Altogether, it takes about 5 months for maturation from the bud to fruit stage.

In each inflorescence, the flowers are located at four positions (P1, P2, P3, and P4) and all the flowers in these positions were found to be receptive to pollinators. The stigma becomes receptive from 8 am to 2 pm. The maximum fruit setting was noticed in the P1 and P2 positions. Studies have indicated that teak is an insect pollinated species that prefers cross-pollination, although in a few cases selfing occurs. Fluorescent microscopy and artificial pollination experiments have also indicated that teak is a self-incompatible species promoting cross-pollination. Selfing occurs very rarely by breaking the self-incompatibility barrier.

Altogether 60 species of insects were recorded as visiting teak inflorescence. Of these, the identity of 29 species could be established. Of the various groups of insects recorded, Hymenoptera, Coleoptera, Diptera, Lepidoptera, Thysanoptera, and Hemiptera formed the major groups of insect visitors. Among these, the hymenopterans were found to be the most affective in pollen transfer because of their structural adaptations thus playing a vital role in pollination. It was also observed that while majority of the insects contributed to selfpollination the solitary bees *Halictus tectonae, Nomia elliotii, Anthophora niveocincta and A. zonata* as well as the wasps, *Eumenes flavopicta* and *Rhychium brunneum* helped in cross-pollination. Prevention of insect pollinators from reaching the flowers using nylon net or cloth bags resulted in very low fruit setting. Insect activity during sunny days was observed from morning to noon. On rainy days, there was considerable reduction in the insect activity, which resulted in poor pollination leaving up to 85 per cent of stigma bare with no pollen.

The possibility of enhancing pollination rate by managing the pollinator population was also investigated. For this, colonies of the honeybee *Apis indica* were introduced in the study area. However, the bees were not found to visit the teak flowers very frequently and even when present, their number was very low to have much application in boosting pollination.

The study has also shown that infection of flowers and fruits by the fungal pathogen *Phomopsis* sp. is the major cause for low fruit setting in teak. Fortnightly application of Mancozeb 75WP(0.25%), from the early budding stage till maturation of the fruit was found to give effective control of the disease.

6. ACKNOWLEDGEMENTS

We are grateful to Dr.K.S.S. Nair (former Director) and Dr.J.K. Sharma (Director) for their interest in this study. We thank Dr. M. S. Muktesh Kumar, Dr. C. Mohan and Dr. V.V.Sudheendra Kumar for editorial scrutiny; Dr. T.C. Narendran, Dept. of Zoology (Calicut University) and Dr. D.N. Raychoudhuri (University of Calcutta) for identifying several insects collected in this study; Dr. E. J. Maria Florence and Shri K.K. Radhakrishnan for identification of the pathogens and Shri Subash Kuriakose for photography. We thank Shri Anand Gopinath, Research Fellow, for his dedicated work both in the lab and in the field. Thanks are also due to Smt. D. Sumangala Amma and Shri K. C. Joby for word-processing the report. This project was sponsored by the Kerala Forest Department under the Development Fund.

7. REFERENCES

Anmol Kumar and Kumar, A. 1992. Teak seed improvement achievements and problems. *Ind. For.,* 118(8): 525-533.

Augspurger, C.K. 1990. The potential impact of fungal pathogens on tropical plant reproductive biology. *In:* Bawa. K. S. and Marley (eds.) *Reproductive Ecology of Tropical Forest Plants*.

Bawa, K.S. and Webb, C. J. 1984. Flower, fruit and seed abortion in tropical forest trees: Implications for evolution of paternal and maternal reproductive patterns. *Amer. J. Bot.,* 71(5): 175-182.

Bedell, P.E. and Vijayachandran, S.N. 1994. Observations on fruits and seeds of individual clones of Walayar teak seed orchard. *J. Trop. For.*, 10: 107-113.

Bila, D. Lindgren, D. and Mullin, T.J. 1999. Fertility variation and its effect on diversity over generations in a teak plantation (*Tectona grandis* L.f.). *Silvae Genet.*, 48: 109-114.

Bryndum, K. and Hedegart, T. 1969. Pollination of teak (*Tectona grandis* L.f). *Silvae Genet.,* 18: 77- 80.

Casper, B. B. and Wiens, D. 1981. Fixed rates of random ovule abortion in *Cryptantha flava* (Boraginaceae) and its possible relation to seed dispersal. *Ecology,* 62: 866- 869.

Dabral, S.L. 1976. Emptiness in teak (*Tectona grandis* L.f.) fruits. *Ind. For.,* 102 (4): 247-253.

Egenti, L C. 1978. Pollen and stigma viability in teak (*Tectona grandis* L.f.) *Silvae Genet.,* 27(1): 29-32.

Ganeshaiah, K.N. and Uma Shaanker, R. 1998. Fruit and seed set in tropical trees: Evolutionary Constrains and Proximate

Mechanisms. *In*: Mandal, A.K. and Gibson, G.L. (eds.) *Forest Genetics and Tree Breeding*. CBS Publication.

Hedegart, T. 1973. Pollination of teak (*Tectona grandis* L.f.) Silvae *Genet*. 22(4): 124-128.

Holtsford, T. P. 1985. Non fruiting hermaphroditic flowers of *Calochortus leicstlinii* (Liliaceae): potential reproductive functions. *Amer. J. Bot.,* 72(11): 687-1694.

Kaosa-ard, A. 1981. Teak (*Tectona grandis* L.f.) its natural distribution and related factors. *Natural History Bulletin of Siamese Society,* 29: 55-79.

Karmacharya, S.B. and Singh, K.P. 1992. Production and nutrient dynamics of reproductive components of teak trees in dry tropics. *Tree physiology,* 11(4): 357-368.

KF&WLD (Kerala Forest and Wildlife Department) 1999. Forest Statistics, Table 10. Forest Plantation Divisions and Species wise area. 19-24, 99 pp.

Kho, Y O and Baer, J. 1968. Observing pollen tube by means of fluorescence. *Euphytica* 17: 298-303.

Manish M and Mishra M. 1991. Effect of tree growth on emptiness in teak fruits. *Vaniki Sandesh* 15 (3): 6.

Mathew, G, Mathew, P. K. and Mohanadas, K. 1987. Preliminary studies on insect visitors to teak (*Tectona grandis* L.f.) inflorescence in Kerala, India. *Ind. For.,* 113(1): 61-64.

Mohanadas, K, Gopinath, A, Florence, E. J. M, Radhakrishnan, K.K. and Indira, E P.1999. Fungi cause 'June Drop' in Teak. *Evergreen,* 43:14.

Nagarajan, B, Varghese, M Nicodemus, A., Sasidharan, K.R., Bennet, S.S.R. and Kannan, C.S.1996. Reproductive biology of teak and its implication in tree improvement. *In*: M.J. Dieters, A.C. Matheson, D.G. Nikles, C.E. Harwood and S.M. Walker (eds.) *Tree Improvement for Sustainable Tropical Forestry. Proc. QFRI-IUFRO Conf.*, Queensland, Australia, 27th Oct.-1st Nov.1996, pp.244- 248.

Neelay, V.R., Bhandari, R.S. and Negi, K. S. 1983. Effect of insecticidal and hormonal spray on the production of growth in teak seed orchard. *Ind.* For., 109 (2): 829-839.

Owens, J.N. 1993. Constraints to seed production: temperate and tropical forest trees. *In: Tree Physiology* 1995, 15: 7- 8; 477-484.

Palupi, E.R. and Owens, J.N. 1996. Reproductive biology of teak (*Tectona grandis* L.f.) in east Java, Indonesia. *In*: M.J. Dieters, A.C. Matheson, D.G. Nikles, C.E. Harwood and S.M. Walker (eds.), *Tree Improvement for Sustainable Tropical Forestry,* Proc. QFRI-IUFRO Conf., Queensland, Australia, 27th Oct.-1st Nov.1996, pp. 255- 260.

Pandey, D and Brown, C. 2000. Teak: a global overview. *Unasylva* 51: (2000/2): 3-11.

Rawat, M S. 1994. Fruit/ seed setting in teak (*Tectona grandis* L. f.) A point to ponder. *Ind. For.,* 120(12): 1076-1079.

Shivanna, K R and Rangaswamy, N S 1992. Pollen-pistil interaction: Aniline blue fluorescence method to study pollen germination and pollen tube growth in the pistil. *Pollen Biology. A Laboratory Manual*. Spriger Verlag, 199pp.

Sirikal, W. 1992. Constraints to seed ontogeny and seed production in Thailand- an overview. Technical publications ASEAN, Canada. Forest Tree Seed Centre, 14 (4), 12pp.

Styles, B F. 1972. The Floral Biology of Meliaceae and its bearing on tree breeding. *Silva Genet.,* 21(5): 175-182.

Subramanian, K. and Seethalakshmi, T.S.1984. A preliminary note on pollen in teak in relation to fruit set. *Ind. For.*, 110(10): 1023-1029.

Tangmitcharoen, S and Owens, J N. 1996. Floral biology and pollen tube growth in relation to low fruit production of teak (*Tectona grandis* L.f.) in Thailand. *In:* Dieters, M.J., Matheson, A.C., Nickels, D.G., Harwood, C.E. and Walker, S.M. (eds.). *Tree Improvement for sustainable Tropical forestry*. Proc. QFRI-IUFRO Conf., Caloudra, Queensland, Australia 27 Oct.-1 Nov. 1996, pp.265-270.

Udovic, D. and Aker, C. 1981. Fruit abortion and regulation of fruit number in *Yucca whipplei. Oecologia,* 49: 245- 248.

Wilson, M F and Bertain, R.I. 1979. Flower visitors, nectar production and inflorescence size in *Asclepias syriaca. Can. J. of Bot.*, 57: 1380-1388.

Young, A.M. 1981. The ineffectiveness of stingless bee *Trigona jaty* (Hymenoptera: Apidae: Meliponinae) as a pollinator of cocoa (*Theobroma cacoa* L.). *J. of App. Eco.*, 18:149-155.

Zapata, T. R. and Arroyo, M.T.K. 1978. Plant reproductive ecology of a secondary deciduous tropical forest in Venezuela. *Biotropica,* 10: 221- 230.

Appendix 1

Insects recorded from teak inflorescence

Order/family/species	Frequency of visit	Remarks
Hymenoptera		
Apidae		
.*Anthophora niveo-cincta* Smith	HF	P
Anthophora zonata L.	"	"
Apis indica Fabr.	LF	"
A. florea Fabr.	HF	"
Mefipona iridipennis Dall.	"	"
Halictus tectonae Narendran & Joberaj.	"	"
Megachile carbonaria Smith	"	"
Nomia elliotii Smith	"	"
Eumenidae		
Eumenes flavopicta Blanch	"	"
Rhynchium brunneum (Fabr.)	"	"
Sphecidae		
Chalybion bengalensis Dahlb.	LF	"
Unidentified sp. 1	"	"
" sp. 2	"	"
" sp. 3	"	"
" sp.4	"	"
" sp. 5	"	"
Lepidoptera		
Acraeidae		
Acraea violae Fb.	"	V
Danaidae		
Euploea core Cramer	"	"
Tirumala limniace leopardus (Butler)	"	"

Erycinidae		
Abisara echerius (Stoll)	LF	V
Tagiades litigiosa Moschler	"	"
Udaspes sp.	"	
Hyblaeidae		
Hyblaea puera Cramer	Seasonal	"
Lycaenidae		
Caleta caleta Hewitson	LF	"
Celaenorrhinus leucocera Kollar	"	"
Unidentified sp. 1		
" sp. 2	"	"
" sp. 3	"	"
" sp. 4	"	"
" sp. 5	"	"
" sp. 6	"	"
" sp. 7	"	"
" sp. 8	"	"
Hesperiidae		
Unidentified sp. 1	"	"
" sp. 2	"	"
Nymphalidae		
Neptis hylas Moore	"	"
Hypolimnas bolina L.	"	"
Junonia iphila Fruh slovfer	"	"
Papilionidae		
Graphium doson Felder	"	"
Papilio polytes L.	"	"
Pieridae		
Delias eucharis Drury	"	"
Pyralidae		
Syngamia floridalis Zell.	"	"

Satyridae		
Mycalesis subdita Moore	"	"
Syntomidae		
Euchromia polymena L.	LF	V
Diptera	Seasonal	"
Unidentified sp. 1	"	"
" sp. 2	"	"
" sp. 3	"	"
" sp. 4	"	"
" sp. 5	"	"
" sp. 6	"	"
" sp. 7	"	"
Coleoptera		
Unidentified sp. 1	"	"
" sp. 2	"	"
" sp. 3	"	"
" sp. 4	"	"
Thysanoptera		
Unidentified sp. 1	"	"
" sp. 2	"	"

HF: Highly frequent; LF: Less frequent; P: Pollinator; V: Visitor

Appendix 2

Insects affecting inflorescence and fruits of teak

Order / Family / Species

Lepidoptera

Pyralidae

Aphomia sp.

Dichocrocis punctiferalis Guenee

Geometridae

Cleora sp.

Hesperiidae

Potanthus sp.

Lymantriidae

Euproctis scintillans Walker

Heteroptera

Pentatomidae

Tessaratoma sp.

Tingitidae

Tingis beesoni Drake

Flattidae

Pochazia fuscuta Fab.

Flata sp.