



Flowering and pollination biology in coconut

*Regi J. Thomas and A. Josephraj Kumar

Central Plantation Crops Research Institute
Regional Station, Kayamkulam,
Krishnapuram P.O., Kerala - 690 533, India

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Abstract

Coconut is a seed propagated crop and knowledge on its flowering and pollination biology will be of significance for optimizing the pollination techniques and also to design efficient conservation strategies in gene banks. Coconut palm is monoecious, with inflorescence bearing both staminate and pistillate flowers. The male flowers are the first to open, beginning at the top of each spikelet and proceeding towards the base. The male phase is followed by female phase and in tall varieties there is a gap between these two phases within the same inflorescence. Although both wind and insects bring about pollination, insect pollination is more predominant. Strategies for employing honey bee colonies in coconut plantations and seed gardens for enhancing pollination and fruit set are discussed. Future lines of work with regard to pollination biology aiming increasing fruit set in coconut seed gardens are also pointed out.

Keywords: Breeding system, *Cocos nucifera*, floral visitors, monoecy, reproductive biology

Introduction

Coconut (*Cocos nucifera* L.), being a seed propagated crop, the sequence of events leading to fruit development is crucial in determining the genetic structure of any coconut population. The events leading to fruit development are flowering, pollination and fertilization culminating in fruit set. Hence, a detailed account of flowering and pollination biology will be of paramount significance to design efficient conservation strategies for coconut. Information in this direction would be helpful in the layout of seed gardens for hybrid seed production, for optimizing the pollination technique in coconut breeding programmes and also for knowledge on dispersal of coconut.

Floral biology

The coconut inflorescence called 'spadix', is 1-2 m long, and consists of a central axis or rachis, with 30 or more lateral branches called rachillae, each about 30-55 cm long and bearing 200-300 male

flowers from the top down and some rachillae have one or more female flowers at their base. The total number of female flowers in an inflorescence is dependent on genetic and environmental factors and varies from zero (especially at the very first flowering) to a few hundred. The normal inflorescence has several thousand male flowers but, in contrast, the spicata inflorescence has very few.

The coconut inflorescence is monoecious with male and female flowers in each spadix. Each inflorescence is borne singly, emerging from the axil of successive leaves of a bearing palm (Purseglove, 1972). Flowering commences at 4-6 years of age, depending on the variety (dwarf flowers earlier than tall) and may be delayed for years at times due to the management practices adopted such as under-planting or inter-cropping. In regular bearers, the number of leaves and the number of spadices remains the same, (*i.e.*, about 12 per year) but some of the developing spadices may abort due to drought or physiological disorders. Developing inflorescences are protected by two sheaths which form a protective

*Corresponding Author: regijacob@yahoo.com

spathe, consisting of a small outer sheath which stops growing early and is punctured by the inner sheath, growing slightly outwards and becoming fusiform (wide in the middle and tapered at the ends) and coriaceous (leathery, tough and stiff). When fully grown, the spathe is about 1-1.5 m long and about 15 cm in diameter at its widest part. The pressure of the growing inflorescence from within causes the spathe to rupture near the tip on the ventral side. The split extends downwards, allowing the inflorescence to unfurl.

Reproductive biology

Male flowers: The staminate flowers are borne singly or in two's or three's on each rachilla. They are sessile, 0.7-1.3 x 0.5-0.7 cm, usually pale yellow (shade of green and orange in some varieties), with six perianth segments in two whorls (three small outer tepals, three larger inner tepals, ovate, acute, coriaceous). There are six stamens arranged in two whorls of three each; anthers dehisce longitudinally. The pistil is rudimentary with three teeth at the apex bearing nectaries. Male flowers start to mature as soon as the inflorescence opens when their bracts open and pollen is released from the anthers. Opening of the bracts usually occurs early in the morning with the flowers shedding pollen throughout the morning before dropping off after mid-day. Flowers at the top of the inflorescence as well as on the terminal region of each rachilla tend to mature earlier.

Each anther contains between 111,000 and 221,000 pollen grains (Varkey and Davis, 1960) producing approximately 272 million pollen grains in an inflorescence (Aldaba, 1921). Coconut pollen grains are spherical (50 μm) when fresh but shrink rapidly after shedding and become ellipsoidal (65-69 μm in length and 28-30 μm in diameter) with a longitudinal suture. When placed in water, the pollen grain immediately gets hydrated regaining its spherical shape and the suture disappears. The pollen has been reported to remain viable for 2-8 days (Whitehead, 1962; Whitehead, 1965b) in laboratory conditions but in nature 75 per cent of shed pollen loses its viability after 12 hours (Furtado, 1924).

Female flowers: The globose pistillate flowers ("buttons") are 2-3 cm in diameter and have

a calyx consisting of six thick, imbricate (overlapping) perianth lobes in two whorls which are tightly folded over the pistil when young. Below the lobes are two bractioles (small bracts) at the juncture of the short stalk (peduncle). The perianth lobes are suborbicular (almost circular), concave and coriaceous; they enlarge and persist as the ovary develops into a fruit. There are abortive remains of six stamens between the ring of perianth lobes and the large, fleshy, globose ovary. As the pistillate flower develops, the apex of the trilobular ovary emerges between the lobes, with three ridges extending downwards, making it three-sided (triquetrous). Pistillate flowers become receptive early in the morning as indicated by a reflexed and moist stigmatic surface. In addition to the stigmatic appearance, nectar containing 9-12 per cent sucrose is produced from the receptive flowers (Jay, 1974) throughout the day. When receptive, the stigma is expanded as three erect teeth. The number of female flowers per inflorescence varies, but is usually 20-40. Young palms have fewer female flowers per spadix. The stigma remains receptive to pollen for 1-4 days (Sholdt and Mitchell, 1967; Henderson, 1988; Ashburner, 1995) before they dry up.

Breeding system

Male and female phases

The male flowers are the first to open in an inflorescence, beginning at the top of each spikelet and proceeding towards the base. The pollen is released after the male flower opens and the flower later abscise, the whole process taking one day. In tall palms, the male phase extends for 16-22 days and the female phase usually begins 22 days after the spathe has opened and lasts for 5-7 days. A single female flower remains receptive for 1-4 days (Sholdt and Mitchell, 1967; Henderson, 1988; Ashburner, 1995). Detailed studies in this direction may be helpful in optimizing the frequency of pollination during artificial pollination in coconut. The length of each phase is affected by the season and locality. Usually in tall ecotypes, the two phases do not overlap and hence the chance of intra-spadix pollination is negligible. However, an overlap of male and female phases between subsequent inflorescence is common. If the inflorescence in the leaf axil above is shedding pollen while female

flowers on the spadix below are still receptive, inter-spadix pollination can take place. Whitehead (1965a) reported that in Jamaican conditions the possibilities of selfing due to overlapping of consecutive inflorescences were substantial in Jamaica Tall and San Blas varieties. In dwarf varieties there is considerable overlapping of phases in the same inflorescence. Coconut varieties have been classified into four types based on flowering pattern (Rognon, 1976). In Type I flowering pattern (allogamy), there exists no overlap of male and female phases (within the same inflorescence and also between the inflorescences). In Type II flowering pattern (mixed allogamy and indirect autogamy), there is no phase overlap in the same inflorescence but phase overlap occurs between subsequent inflorescence. In Type III flowering pattern (direct autogamy), there is complete overlap of the phases within an inflorescence. In Type IV flowering pattern (mixed mating), flowering is characterized by partial overlap of the female phase within and between inflorescences.

Within flowering groups, the degree of phase overlap is highly dependent on environmental conditions. The coconut accessions characterized by Ratnambal *et al.* (1995; 2000) have been classified based on the grouping of Rognon (1976). It can be noted that in Type I & II category which includes mainly the tall accessions, with an exception of Nigerian Dwarf, have male phase extending from 18.66 to 19.04 days and there is a clear gap of 2.45 to 2.72 days between male and female phases (Tables 1 and 2). It is to be noted that in Type I flowering pattern, there is no overlapping of phases either due

Table 1. Coconut accession with Type I flowering pattern (Allogamy)

Sl. No.	Cultivar	Male phase (days)	*Gap (days)	Female phase (days)	Intra spadix overlapping (days)	Inter spadix overlapping (days)
1	Andaman Ranguchan	18.0	3.0	3.0	0	0
2	Car Nicobar	18.0	3.0	3.0	0	0
3	Gujarat Zanzibar	19.0	3.0	4.0	0	0
4	Kappadam Tall	19.3	1.6	3.2	0	0
5	Nadora Tall	19.0	3.0	4.0	0	0
	Mean	18.7	2.7	3.4	0	0

*Gap: Interval between male and female phase
(Source: Ratnambal *et al.*, 1995)

Table 2. Coconut accessions with Tpe II A flowering (Mixed allogamy/ indirect autogamy)

Sl. No.	Cultivar	Male phase (days)	*Gap (days)	Female phase (days)	Intra spadix overlapping (days)	Inter spadix overlapping (days)
1	Borneo Tall	21.0	4.0	4.0	0	2.0
2	Federated Malay States	18.0	2.9	3.2	0	5.1
3	Java Tall	19.2	2.7	3.3	0	2.4
4	Kongthienyong	17.3	2.7	5.3	0	3.6
5	Philippines Laguna	18.2	2.2	3.4	0	4.4
6	Philippines Lono	20.0	3.0	5.0	0	5.0
7	Philippines Ordinary	18.3	2.2	3.6	0	4.2
8	San Ramon	20.0	2.0	4.0	0	4.0
9	Strait Settlement Green	19.7	2.2	4.5	0	4.4
10	British Solomon Island	17.9	2.1	3.4	0	3.5
11	Fiji Tall	15.5	1.7	3.7	0	2.5
12	Guam Type-I	19.2	2.4	4.3	0	5.1
13	Guam Type-II	17.6	2.9	5.8	0	2.9
14	New Guinea Tall	18.5	2.7	3.9	0	5.5
15	Nufella	18.1	1.9	4.0	0	4.5
16	Nugili	17.9	2.0	3.5	0	4.8
17	Nuqawen	18.1	2.3	4.3	0	5.6
18	Nuwehung	18.5	2.8	4.1	0	4.8
19	Jamaica Sanblas	20.0	3.0	4.0	0	4.0
20	Jamaica Tall	17.8	2.9	5.3	0	2.8
21	Saint Vincent	20.0	3.0	5.0	0	4.0
22	Zanzibar Tall	18.5	2.5	3.4	0	3.3
23	Ceylon Tall	19.0	3.0	5.0	0	2.0
24	Gonthembili	19.3	2.8	3.9	0	2.0
25	Seychelles Tall	19.0	2.8	4.1	0	3.5
26	Andaman Giant	19.3	3.2	3.4	0	3.0
27	Andaman Ordinary	22.3	2.8	4.6	0	7.0
28	Benaulim	19.0	3.0	4.0	0	2.0
29	Calangute	18.2	3.3	6.1	0	2.2
30	Laccadive Micro	20.0	5.0	5.0	0	4.0
31	Laccadive Ordinary	19.0	3.0	4.0	0	3.0
32	Rangoon Kobbari	17.6	2.9	5.5	0	3.8
33	Sakhigopal	17.6	3.5	5.4	0	2.6
34	West Coast Tall	19.0	3.0	4.0	0	0.4
35	Ayiramkachi	19.8	1.8	3.8	0	1.5
36	Blanchisseuse	19.5	1.9	4.0	0	0.4
37	Cochin China	20.4	1.8	4.1	0	1.2
38	Fiji Rotuma	19.0	1.7	4.0	0	1.8
39	Gangapani	18.2	1.7	3.9	0	0.3
40	Karkar	19.5	1.8	3.8	0	0.5
41	Kenya Tall	18.2	2.4	3.9	0	2.7
42	Klapawangi	21.0	1.8	4.3	0	1.0
43	Lifou Tall	18.2	1.6	3.5	0	2.2
44	Malayan Tall	19.7	1.8	3.5	0	6.0
45	Markham Tall	18.1	2.5	3.9	0	3.9
46	Nigerian Dwarf	19.5	2.0	3.9	0	0.5
47	Nigerian Tall	18.2	2.2	3.8	0	3.3
48	Panama Tall	19.1	1.9	3.9	0	1.3
49	Philippines Dalig	19.5	1.7	3.7	0	0.1
50	Philippines Palawan	19.7	1.8	3.9	0	2.7
51	Surinam Tall	21.0	1.8	4.1	0	4.5
52	Tiptur Tall	20.6	1.4	3.4	0	2.8
53	Verikkobari	20.8	1.8	6.2	0	0.1
54	West African Tall	19.4	2.5	3.7	0	2.6
	Mean	19.0	2.5	4.17	0	3.0

*Gap: Interval between male and female phase
(Source: Ratnambal *et al.*, 1995; 2000)

to intra- or inter-spadix overlapping. Hence, out-crossing is the general breeding system in Type I category.

However, majority of the tall accessions belong to Type II flowering pattern where no phase overlap is noticed in the same inflorescence but phase overlap occur between subsequent inflorescence. This may be the reason for higher inbreeding co-efficient reported in tall ecotypes based on SSR analysis (Rajesh *et al.*, 2008; Thomas *et al.*, 2013). Spicata is a tall accession listed under Type II category but has exceptionally shorter male phase. The lesser number of male flowers present in this accession may be the reason for the shorter male phase. Hence, it is categorized as Type II-B (Table 3). Type III & IV category comprises mainly of dwarf accessions which has characteristic overlapping of male and female phases with no gap between the phases. This overlapping happens either due to intra-spadix overlapping (direct autogamy) as seen in Type III flowering pattern (Table 4) or due to intra and inter-spadix overlapping (mixed autogamy) as noticed in Type IV (Table 6). The Type II and IV types also have a shorter male phase in comparison with tall accessions and have a comparatively longer female phase. It is interesting to note two ecotypes (Fiji Longtongwan and Niu Leka) classified under Type III B (Table 5) with a characteristic gap between male and female phases have intra-spadix overlapping.

Pollination biology

The pollination mechanism in coconut is an intriguing phenomenon and a detailed account based on experimental evidence is elusive. Pollination in coconut has been attributed to wind, insects or both. The size of coconut pollen is larger than that of most anemophilous pollens (20–40 μm) (Moore, 2001).

Table 3. Coconut accession with Type II B flowering pattern (Mixed allogamy and indirect autogamy)

Sl. No.	Cultivar	Male phase (days)	*Gap (days)	Female phase (days)	Intra spadix overlapping (days)	Inter spadix overlapping (days)
1	Spicata	10.9	2.8	7.3	0	3.5

*Gap: Interval between male and female phase
(Source: Ratnambal *et al.*, 1995)

Table 4. Coconut accession with Type III A flowering pattern (Direct autogamy)

Sl. No.	Cultivar	Male phase (days)	*Gap (days)	Female phase (days)	Intra spadix overlapping (days)	Inter spadix overlapping (days)
1	Malayan Orange Dwarf	16.3	0	6.6	6.3	0
2	Malayan Yellow Dwarf	18.0	0	4.0	4.0	0
3	Chowghat Green Dwarf	16.0	0	5.0	4.0	0
4	Chowghat Orange Dwarf	18.0	0	5.0	4.0	0
5	King Coconut	15.2	0	7.2	6.5	0
	Mean	16.7	0	5.6	5.0	0

*Gap: Interval between male and female phase
(Source: Ratnambal *et al.*, 1995; 2000)

Table 5. Coconut accession with Type III B flowering pattern (Partial autogamy)

Sl. No.	Cultivar	Male phase (days)	*Gap (days)	Female phase (days)	Intra spadix overlapping (days)	Inter spadix overlapping (days)
1	Fiji Longtongwan	21.0	1.9	3.9	0.5	0
2	Niu Leka	19.9	1.2	5.6	2.1	0
	Mean	20.5	1.6	4.8	1.3	0

*Gap: Interval between male and female phase
(Source: Ratnambal *et al.*, 1995; 2000)

Table 6. Coconut accession with Type IV flowering pattern (Mixed autogamy)

Sl. No.	Cultivar	Male phase (days)	*Gap (days)	Female phase (days)	Intra spadix overlapping (days)	Inter spadix overlapping (days)
1	Malayan Green Dwarf	14.0	0	4.0	3.0	4.0
2	Gangabondam	17.9	0	6.1	5.9	2.5
3	Kenthali Dwarf	18.7	0	9.0	8.5	1.0
4	Strait Settlement Apricot	19.7	0	5.1	2.8	0.9
5	Cameroon Red Dwarf	16.9	0	6.3	2.1	0.6
6	Pattukottai Green Dwarf	18.9	0	8.8	10.9	0.5
7	Surinam Dwarf	17.8	0	4.8	4.9	7.0
	Mean	17.7	0	6.3	5.4	2.4

*Gap: Interval between male and female phase
(Source: Ratnambal *et al.*, 1995; 2000)

In addition, the presence of a prominent groove along the length of the pollen grain is considered an adaptation more suited for entomophily than anemophily (Child, 1974). Controlled pollination experiments that test the extend of autogamy, geitnogamy and xenogamy have rarely been conducted in palms (Barfod *et al.*, 2011). Even

though anemophily obviously occurs in coconut palm, entomophily is supposed to be the predominant pollination mechanism (Sholdt and Mitchell, 1967; Hedstrom, 1986; Henderson, 1986; 1988; Melendez-Ramirez *et al.*, 2004; da Conceicao *et al.*, 2004).

Being a predominantly insect pollinated crop, it would be of interest to describe the major floral visitors and also to understand whether all the floral visitors are pollinators. The floral visitors include different type of insects and nectarivorous bats (Start and Marshall, 1976). Bat pollination of coconut is unlikely since anthesis occurs during the morning (Aldaba, 1921). The coconut palm is one of the few plants which flowers throughout the year and for this reason may be the only source of nectar and pollen for the floral visitors at certain times (Sholdt and Mitchell, 1967).

Depending upon the geographic location there may be changes in the frequency and diversity of insect pollinators in any crop. Insects visiting coconut flowers have been recorded from various countries. In Brazil, da Conceicao *et al.* (2004) reported that ants and bees transported a meaningful amount of pollen and concluded that bees belonging to *Trigona*, *Plebeia* and *Apis* can be considered good pollinators of coconut palm. The ants carried a lower amount of pollen and contributed only casually to pollination due to its apterism. Sholdt (1966) enlisted 51 different insect species associated with coconut flowers in Hawaii. The most common insects are the honey bees (*Apis mellifera*), the black earwig (*Chelisoches morio*), the wasps (*Polistes exclamans*; *Polistes olivaceus*; *Polistes macaensis*) and the ants (*Paratrechina longicornis* and *Pheidole megacephala*). Kevan and Blades (1989) enumerated 52 species of visitors to coconut flowers in Maldives, but they also noted that only a few were confined to receptive pistillate flowers. In Trinidad, coconut pollen was heavily collected by honey bees and only occasionally collected by stingless bees (Sommeijer *et al.*, 1983). Melendez-Ramirez *et al.* (2004) reported that in Mexico, insects visiting coconut inflorescence belonged mainly to 83 morphospecies comprising of three orders: Hymenoptera, Coleoptera and Diptera. The most abundant order was Hymenoptera and insects

belonging to Heteroptera, Homoptera and Thysanoptera were less abundant. The majority of the individuals (83%) visiting pistillate flowers in search of nectar carried loads of coconut pollen from previously visited staminate flowers. Many of these (33%) then visited staminate flowers on the same inflorescence (Heard, 1999). This behaviour is conducive to efficient pollen grain transfer. Cock (1985) reported that one of the coconut specific insects was a derelomine weevil (*Derelomorphus eburneus*). This weevil live and breed in coconut flowers, feed on pollen and can be a pollinator. Another curculionid weevil (*Amorphoidea coimbatoensis*) was noticed in large numbers on male flowers of coconut inflorescence and was reported primarily as a minor pest (Subramaniam *et al.*, 1975). The preponderance of this weevil was also reported from Kayamkulam, Kerala on dwarf palms and it was usually found feeding on the male flowers (CPCRI, 2010).

In India, observations on West Coast Tall palms revealed that bees (*Apis cerena indica*, *Apis dorsata*, *Trigona iridipennis*) were the most predominant floral visitors whereas ants (*Anoplolepis gracilipes*, *Camponotus rufoglaucus*, *Camponotus parius*, *Camponotus binghamii* and *Camponotus compressus*) were the predominant visitors on Chowghat green dwarf palms (CPCRI, 2012). Devanesan *et al.* (2009) has enlisted the insects associated with coconut inflorescence which includes bees, ants, moths and beetles. A detailed knowledge of plant-pollinator relationship will be helpful to pinpoint the major insects involved in transfer of pollen (pollinators) in coconut.

Putative pollinators

Pollinators of coconut must visit both polleniferous staminate and nectar-studded pistillate flowers and carry pollen from the former to the latter. Entomophily in palms fall into three categories: bee (mellitophily), flies (myophily) and beetles (cantharophily). With the exception of *Cocos* and the closely related *Butia* all other genera grouped under the sub-tribe Butiinae are exclusively beetle-pollinated (Henderson, 1986). The open and laxly branching inflorescence of coconut has other features that are characteristic of bee-pollinated palms. The features include bright coloured (cream/

green/orange) inflorescence consisting of sweet scented protrandrous flowers which become attractive during the day. The inflorescences of *Cocos nucifera* are protandrous as in other mellitophilous palms and pollen is shed and liberated before the pistillate flowers become receptive. Bawa and Beach (1981) concluded that basipetal anthesis (*i.e.*, protandry), as seen in coconut palm, is better suited for bee foraging behaviour, since flowers at the time of anthesis are totally exposed. On the contrary, acropetal anthesis (*i.e.*, protogyny) is adapted for beetle foraging, since initially flowers at anthesis are in a concealed position. Although the inflorescences are visited by a wide array of insects, bees are the predominant pollinators. Other insects reported from *C. nucifera* are wasps, ants, flies, beetles, black earwigs, butterflies and these have been nullified greatly in pollination.

A short account of honey bee-coconut palm relationship is as follows. Honey bees are nectar/pollen collectors and grasp the male flowers with their middle and hind legs, and collect pollen with their proboscis and fore legs from the apical end of anther. They work their proboscis and flabellum around the base of the pistillode in order to gather nectar. Honey bees also hover quickly and efficiently over the female flowers, running their proboscis over the nectaries and stigmatic region collecting nectar. Large quantities of pollen grains were found on honey bees taken from both male and female flowers, as well as in the pollen sacs on the hind legs. Fewer bees were found on the female flowers than on the male flowers (Sholdt and Mitchell, 1967). This may be due to the fact that there are a lesser number of female flowers than male flowers and the nectar produced by the female flowers may not be as attractive as the ones produced by other sources. Bees depend on coconut for their pollen requirement than as a nectar source. In Hawaii, bee population in coconut plantation increase during winter (November-March) when the apiaries usually had large quantity of pollen but very little honey. During this period nectar was not available from other sources. Similarly, a decrease in bee population was noticed in rainy season when large amount of honey but very little pollen was stored. During certain periods, bees in apiaries store very little honey but store pollen in

increased amounts when nectar is not available from other sources.

Contribution of various modes of pollination in fruit set

In coconut, under natural pollination, a fruit set of up to 30-40 per cent can be expected. Results of controlled pollination experiments in coconut attribute 10 per cent fruit set to wind pollination, while wind pollination accompanied by self-pollination accounts for 20 per cent fruit set and wind and insect pollination accounts for 30 per cent fruit set (Melendez-Ramirez *et al.*, 2004).

Seasonal, sexual-phase and diurnal variation in floral visitors

Monthly changes in the abundance of visitors to coconut flowers in Mexico have been reported by Melendez-Ramirez *et al.* (2004). Under Mexican conditions, insect abundance peaked during the rainy season, was intermediate during the dry period, but was lowest during winter season. Daily temperature, light intensity and wind speed had no significant effect on insect abundance. Only relative humidity had positive correlation with insect abundance.

The diversity of insects visiting coconut inflorescences at the different sexual phases was similar. However, more insects were recorded from the staminate phase inflorescence than from receptive pistillate phase. Wasps, ants and flies were more abundant on pistillate phase than honey bees, but native bees were relatively less abundant than honey bees. The relative abundance of flower visitors seemed to depend to a less extent on flower type (male or female). The abundance of insect visitors and number of receptive pistillate flowers was positively correlated. There was a significant difference in the pollen load on the bodies of the most abundant insect visitors. *A. mellifera* carried the highest quantity of pollen when they visited staminate flowers (100s to 1000s of grains each), but moderate amounts (20-100 grains) when they visited pistillate flowers. More visits were made to tall rather than to dwarf ecotypes, although there was not much variation in the insect visit. However, when seasonality was considered, differences emerged and were more pronounced during the rainy

season, but lesser during winter and the dry season (Melendez-Ramirez *et al.*, 2004).

Coconut inflorescences in both sexual phases are most visited by insects during daylight from 9.00 hrs to 11.00 hrs. Honey bees continued to visit flowers up to 18.00 hrs, but showed an activity peak similar to other insects. The nocturnal insects that visited the coconut flowers were ants from 18.00 hrs to 23.00 hrs. Honey bees were the most abundant insect visitors and contributed maximum to fruit set and ants did not have any effect on fruit production (Melendez-Ramirez *et al.*, 2004).

Honey bee colonies in coconut seed gardens

At present, production of coconut hybrids involves bagging and there was a significant reduction in fruit set upon artificial pollination when climatic conditions are not favourable (Thomas *et al.*, 2012). This labourious process of bagging and pollen application can be dispensed with if honey bee colonies can be placed in coconut seed gardens (planted with a single female parent). The technique of placing honey bee colonies for enhancing fruit set has been attempted in coffee (Kodagu), oil seeds and vegetables (Punjab and Haryana) and apple (Himachal Pradesh) (Savoor, 1998). Honey bee colonies placed in the seed gardens can be 'loaded' (at the entrance of bee hives) with the pollen collected from the male parent. The bees emerging out of the hives in search of food (nectar and pollen) will carry the pollen 'load' on its legs and body parts and will naturally transfer them onto receptive stigma surface of female parental palms. This technique can be adopted for increasing fruit set in coconut seed gardens. In view of the lower quantity of nectar produced from coconut inflorescence, there were speculations regarding maintenance of honey bee colonies in coconut plantations. Devanesan *et al.* (2009) reported that Indian honey bee colonies can be maintained in coconut plantation by feeding them with sugar syrup (1:1) as artificial feed @ 200-250 ml hive⁻¹ week⁻¹.

Isolation distance in seed gardens

Honey bee is the principal pollinator in coconut gardens. Honey bees do not normally forage more than a few hundred meters to 3 km from the hive. In rare instances, honey bees may forage up to

15 km for unusually rewarding nectar sources. It has also been described that honey bee depend on coconut mostly as a pollen source and rarely as nectar source. Hence, an isolation distance of 3 km might greatly reduce contamination of a coconut seed garden. It has also been shown that during close contact in the hive, honey bees may inadvertently transfer pollen to each other. Thus, bees foraging 3 km in one direction may rub pollen on to a nest mate and the latter insect may then carry the pollen 3 km in the opposite direction. This also depends on the viability of pollen of different varieties. To rule out this factor an isolation distance of 6 km is indicated (Moore, 2001).

Conclusion

The coconut palm is one of the few plants which flowers throughout the year and for this reason may be the only source of nectar and pollen for the floral visitors at certain times of the year. A wider variation exists between ecotypes and geographic regions with regard to flowering phenology in coconut. Even though anemophily obviously occurs in coconut palm, entomophily is the major pollination source and it can be concluded that coconut is predominantly a bee-pollinated palm. Hence, coconut can be considered to be ambophilous with some amount of geitonogamy occurring. It can also be concluded that insect pollination is important for higher yield in coconut (Henderson, 1988). Nut yields are usually higher where honey bee hives are kept in coconut plantations (McGregor, 1976). More studies are needed on the following aspects like major pollinators and its contribution in increasing fruit set in coconut and also studies on stigma receptivity during different seasons for optimizing the pollination frequency. These studies would be useful to refine the artificial pollination technique and finally increasing the fruit set in coconut seed gardens.

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