

Recent Research on Insect Pollination of Cocoa*

John A. Winder

CSIRO, Division of Entomology, C.P. 322, Curitiba, 80.000 Parana, Brazil

The cocoa crop is ultimately limited by the amount of pollination and fruit setting which occurs. Generally, less than 5% of the total number of flowers produced are pollinated, but observations suggest that, in some areas, the final fruit yield may be greatly increased under certain conditions (14, 15, 19, 31). However, in spite of the importance of pollination and the activity of the pollinating agencies in crop production, research efforts in this area have been very restricted.

The recent reviews by Free (4) and Entwistle (3) summarised most of the pollination investigations carried out prior to 1968, but since then, research on cocoa pollination has gained a new impetus especially in Costa Rica, Brazil and West Africa. This paper will concentrate on results of these more recent studies.

The Pollinating Agents

The idea held by earlier workers, that wind pollination was the only, or at least the principal means of pollination, was shown to be incorrect by the experiments of Harland (5), Billes (1) and Soetardi (18), but it was only in 1941 that Billes was able to show that cocoa pollination was carried out chiefly by small, biting, female flies of the genus *Forcipomyia*, family Ceratopogonidae. Even today, their small size (0.5 to 2.0 mm long) and quick movements make observations on these insects a difficult undertaking. These difficulties are compounded by a lack of easily recognisable adult characters which makes identification difficult and laborious, even for specialist taxonomists. The best morphological characters for separating the different species are, in fact, found in the larvae and pupae.

Much of the recent research on cocoa pollination has concentrated on the actual identity of the pollinators (29). Although more than 75 species of ceratopogonids in 10 genera have been found frequenting cocoa flowers, only about 50% have actually been observed pollinating (29). Other Microdiptera frequenting cocoa flowers include the Cecidomyiidae, Chironomidae, Drosophilidae, Psychodidae and Sphaeroceridae. Cecidomyiids are the most important numerically but the contribution by these insects to total pollination seems to be minimal. However, preliminary observations (8, 15) suggest that cecidomyiids and drosophilids may sometimes be important pollinators in Ghana and the Cameroons respectively.

The genus *Forcipomyia* contains the greatest number of known pollinators and is now divided into 16 subgenera (Wirth, pers. comm.), a great increase over the original six subgenera proposed by Saunders (17). The most important subgenera are *Euprojoannisia* (formerly known as *Proforcipomyia* and *Euforcipomyia*), *Thyridomyia* and *Forcipomyia*. Their relative importance in different cocoa-growing areas of the world is shown in Table 1.

*This paper was presented during the XV International Congress of Entomology held in Washington, D.C., U.S.A. from August 19 to 27, 1976.

TABLE 1

Diptera observed pollinating cocoa throughout the world and their known breeding sites.

Taxon	No. of Pollinating Species observed				Known Breeding Sites
	Africa	East Indies	Central America and West Indies	South America	
CERATOPOGONIDAE					
<i>Forcipomyia</i> (<i>Forcipomyia</i>) spp.	12	—	2	—	Rotten cocoa pods; rot holes in trees; cocoa leaf litter; rotten banana trunk.
<i>F. (Euprojoannisia)</i> spp.	3	1	6	4	Cocoa leaf litter; rotten banana stem and bracts; rot holes in trees.
<i>F. (Thyridomyia)</i> spp.	—	—	2	—	?
<i>F. (Microhelea)</i> sp.	1?	—	—	—	Rotten cocoa pods. Rotten banana leaves.
<i>F. (Warmkea)</i> sp.	—	—	2	—	Probably waterholding plants of some sort.
<i>F. (Lasiohelea)</i> sp.	—	1	—	—	?
<i>Dasyhelea</i> sp.	—	—	1	—	?
<i>Culicoides</i> sp.	1	—	—	—	?
<i>Stilobezzia</i> spp.	2	—	—	—	Rotting wood.
<i>Atrichopogon</i> sp.	1	—	—	—	?
CECIDOMYIIDAE	1	—	—	—	Organic debris in soil.
DROSOPHILIDAE					
<i>Drosophila</i> sp.	1	—	—	—	?
Total	22	2	13	4	

The species of Diptera observed frequenting cocoa flowers, their pollinating activity and breeding places have been recently reviewed (29). There has been little success in locating the breeding sites of the cocoa flower Diptera, especially of pollinators, until fairly recently. The immature stages of the Ceratopogonidae generally breed in moist, rotting organic substrates, and in cocoa plantations the most important sites seem to be cocoa leaf-litter, rotten cocoa pod husks, rotten banana stems and epiphytic bromeliads (28, 29, 30, 31) (Fig. 1). Although no known pollinator has yet been found in epiphytic bromeliads, this substrate may probably be one of their most prolific breeding sites (29).

Kaufmann (9, 10, 11, 12) has attempted to demonstrate the pollinating ability of some ceratopogonid species and also of a cecidomyiid (8) by cage experiments in which the species to be tested was enclosed in a mesh cage containing cocoa flowers. Winder (29) has suggested that such experiments may be misleading as to actual pollinating potential in the field, since such factors as the number of flowers available per midge, cage size, and the physiological state, fed or unfed, of the flies, were not taken into account. The only satisfactory way to discover whether a particular species is a pollinator or not, is by careful field observations and collection, as was done by Soria (19) in Costa Rica.



B



D



A



C

Fig. 1. *Forcipomyia* spp. breeding sites in cocoa plantations, Brazil: (A) Cocoa leaf litter; (B) Empty cocoa pods; (C) Rotting banana trunk; (D) Epiphytic bromeliads on shade tree.

Many other insects frequent cocoa flowers, chiefly ants, aphids, thrips and coccids, but the cross-pollinating activity of these groups seems very doubtful, although some setting may occur on self-compatible trees. Kaufmann (7) showed that the psyllid, *Tyora tessmanni* Aulmann pollinated flowers under laboratory conditions, but the large number present during the February to April flowering period in West Africa, when virtually no setting occurs, indicates that this species is probably not important under field conditions. Microscopic examination of various species of ants, coccids, cicadellids and the aphid, *Toxoptera aurantii* B. de Fonsc., found in flowers during May and June in Bahia State, when most setting occurs, showed that no specimens carried pollen grains (Winder, unpublished observations). In Costa Rica, the thrips *Frankliniella parvula* Hood probably complements *Forcipomyia* pollination during the dry season (6, 19).

Vello and Magalhaes (26) showed that the presence of the "cacarema" ant, *Azteca chartifex spiriti* Forel, may increase total effective pollination on cocoa trees in Bahia, not through its own activity but perhaps by attracting ceratopogonid pollinators. However, further experiments are needed to substantiate these results owing to the small number of trees observed per treatment and the absence of any treatment replication. Soria (20) has reviewed the evidence on the pollinating activity of the stingless Meliponine bees in cocoa and came to the conclusion that this was usually accidental. Recently, Kaufmann (13) has stressed the importance of the halictid bee, *Lasioglossum* sp. in pollinating canopy level flowers in Ghana. However, the low viability of pollen grains carried by the meliponine bee *Trigona jaty* Smith in Costa Rica (6), suggests that the pollinating efficiency of *Lasioglossum* may not be as high as expected.

Ecology of Ceratopogonid Pollinators

The complete life-cycle of *Forcipomyia*, from egg to adult, lasts approximately 28 days at 24°C (Fig. 2). Adults live 1-12 days under laboratory conditions (6, 21, 24, 25). One of the most important objectives in rearing through different species of *Forcipomyia* is the value of the immature stages in identifying different species.

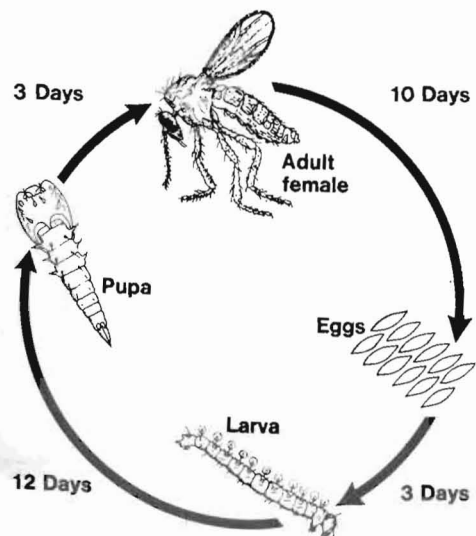


Fig. 2. Life cycle of *Forcipomyia* spp.

Pollinating activity by the female ceratopogonid midges seems to occur mainly in the early morning, before 9 a.m., with a further activity peak in the mid-afternoon (3, 28); any collecting should be done at this time. Pollinators are affected by climate: rainy, overcast conditions inhibit pollinating activity whereas sunny weather enhances it (3, 6, 19, 28). They seem to have distinct preferences for certain trees in a plantation, which produce more fruit than their neighbours but over a period of time relative attraction changes so that unattractive trees become attractive and vice versa (6, 19). The reason for this behaviour is not known. Why more female than male ceratopogonids visit cocoa flowers is uncertain, although several hypotheses have been put forward. In fact, both males and females pollinate flowers (6, 9, 10, 11, 12), although male pollination seems to account for only a very small part of the total. Since midges are attracted equally to "comun" flowers with red guide lines and "catongo" flowers, with no red guide lines, flower colour would not appear to be the main attraction stimulant (19). Downes (2) found that females of a species in the ceratopogonid genus, *Atrichopogon*, fed on pollen grains inside the honey-suckle flower, where they apparently obtained their protein for egg maturation; female ceratopogonids may visit cocoa flowers for the same reason. Certainly, flower visiting is a common activity for female ceratopogonids throughout the world (2, 29) but the ratio of pollinating Diptera to cocoa flowers varies from 1:7122 in Brazil to 1:316 in Costa Rica (29). Cocoa flowers pollinated by *Forcipomyia* characteristically carry a large and compact mass of pollen on the tip of the stigma (Fig. 3).

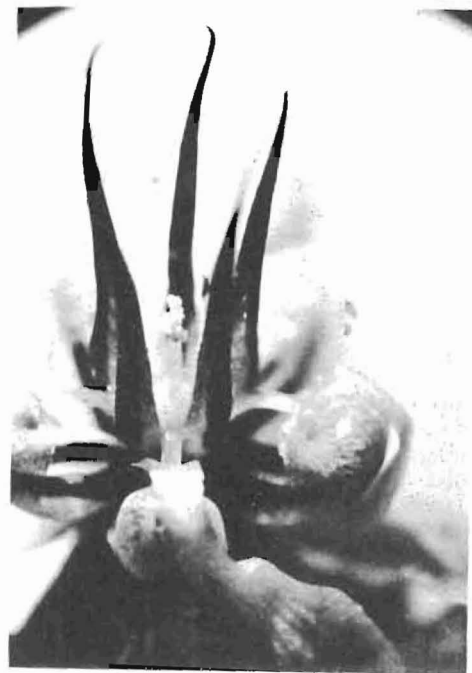


Fig. 3. Cocoa flower pollinated by *Forcipomyia* sp. Note the large and compact mass of pollen on the tip of the stigma.

Knowledge of the flight behaviour of pollinators is important when setting up a cocoa seed garden. Observations indicate that the flies traverse quite long distances (16). Suction trap studies in Bahia with traps set above and below the crown of shaded cocoa showed that five to seven times as many *F. (Euprojoannisia)* spp. and *F. (Forcipomyia)* spp. adults were present above as below the crown. This suggests that wind currents are probably very important in determining the distribution of adult ceratopogonid populations.

Seasonal Abundance of Ceratopogonids

Very little research has been done on the seasonal abundance of ceratopogonids and pollinators in cocoa plantations. Preliminary results from a two-year (1969–1971) emergence trap study in Bahia, of cocoa leaf-litter diptera in areas treated and untreated with BHC 1%, suggested a positive relationship between soil moisture and ceratopogonid populations. High populations were correlated with excess soil moisture and low populations with a deficit (31). The ceratopogonids in this study comprised more than 30 species in 9 subgenera of *Forcipomyia* and 5 other genera of ceratopogonids, including pollinating species from the subgenus *Euprojoannisia* (Winder and Wirth, unpublished observations).

A one-year study (1973) in Bahia, of the aerial populations of *F. (Euprojoannisia)* spp. and *F. (Forcipomyia)* spp. in shaded cocoa, using insect suction traps 2 m above ground, showed that the largest numbers of both subgenera occurred from May to July (23). The soil moisture excess in this period was characterised by "advectional" rainfall, i.e., a little rainfall in short periods, whereas the soil water excess from November to January was characterised by "convectional" rainfall, where abundant rain fell in a very short time (23). This latter rainfall pattern may not provide the continuous wet conditions necessary for ceratopogonid egg and larval development. The probable importance of rainfall in ceratopogonid abundance in cocoa in Java was pointed out by Soetardi (18) and by Entwistle (3) for Ghana, where the dry, hot northerly wind or "harmattan" dries out breeding places, resulting in no pollination despite heavy flowering.

Effect of Insecticides

Although experiments showed that the use of wide-spectrum insecticides such as BHC, DDT and Dieldrin did not have a noticeable effect on pollination rates (3), the experimental planning was often deficient. The main problem in interpreting results has been the small size of the treatment areas, allowing immigration and emigration, and the absence of treatment replications (Table 2).

An experiment to measure the effects of three different treatments, mineral oil, lime and copper oxide solution, compared with a control, on the dipterous populations of cocoa pod heaps in Bahia was undertaken in 1971 (31). Preliminary results indicate that both lime and copper oxide treated pod heaps do not differ significantly in the number of ceratopogonids produced per unit weight (30 per kilo) from the control. However, the mineral oil treatment produced a mean of only 20 ceratopogonids per kilo of empty cocoa pod husk (Winder and Wirth, unpublished observations). When identification of all the insects collected is completed it will be apparent whether the treatments affected species diversity.

TABLE 2

Investigations on the effects of insecticides on cocoa pollinators.

Country/Authority	Insecticides Tested	Area Treated	Comments
Ecuador (14)	Carbaryl Malathion	approx. 300 m ² (0.03 ha)	No measurable effect on fruit set. No Replications (D. F. Edwards pers. comm.)
Java (27)	Endrin	3300 m ² (0.3 ha)	Mo measurable effect on fruit set. No replications.
Brazil (22)	BHC Carbaryl Methyl Parathion	(a) 625 m ² (0.06 ha) (b) 2500 m ² (0.25 ha)	Only % mortality on <i>Forcipomyia</i> spp. measured. Populations had recovered to original levels after 1 week. No replications.

Our present knowledge of the pollinator breeding sites indicates that they are generally well-protected from the immediate action of insecticides although the long term effect of residues may have serious consequences (3, 24, 28, 30). There is, therefore still a need for properly designed experiments on the effects of insecticides on pollinators and pollination rates. The possible side-effects of insecticides may, of course, be diminished by applying low concentrations and dosages of narrow spectrum insecticides during times when pollination rates are normally low.

Increasing Natural Pollination

Assuming that natural pollination of cocoa is a limiting factor in cocoa production in a particular area, fruit set might theoretically be increased through the manipulation of pollinator populations. Although only Microdiptera and especially certain *Forcipomyia* species are morphologically adapted to pollinate cocoa, this fly-flower association is not symbiotic as stated by Soria (19) since the tree depends on the fly but the fly does not seem to depend on the tree. This hypothesis is supported by the preliminary field data from emergence traps which suggests that there are many more potential pollinators present than pollinations effected.

A hectare of Bahian cocoa produces an average of 450 kilos, approximately 15,000 fruits, assuming that each fruit has 30 grams of beans. Also, assuming that each female fly only carries out one effective pollination, then only 15,000 pollinators would be needed during the year, a very small percentage of the total number available (28, 31). As already stated, ceratopogonids visit the flowers of many plants, and many species are also haematophagous, i.e., sucking the blood of other insects and small mammals. Therefore, visiting cocoa flowers seems to account for only a small portion of the activities of a pollinator species. Even if the number of pollinators could be increased for a particular area then, there would not necessarily be an associated increase in pollination rates. However, it may be advantageous to increase populations at specific times of the year when natural pollinator populations and pollination rates are low (28).

Pollinators are difficult to rear in the laboratory and the most economical approach would be to increase the number of natural breeding sites or perhaps, even provide artificial ones. Cultivation practices such as the non-removal of epiphytic bromeliads (28) and the amassing of empty cocoa pods into heaps may prove beneficial. However, a more detailed knowledge of the breeding sites is necessary for any scheme of this nature to be successful.

ACKNOWLEDGEMENTS

I wish to thank Dr. S. Soria, CEPEC, CEPLAC, for providing figures 2 and 3.

REFERENCES

1. Billes, D. J. (1941). Pollination of *Theobroma cacao* L. in Trinidad, B.W.I. *Trop. Agric. (Trinidad)* 18(8): 151-156.
2. Downes, J. A. (1958). The feeding habits of biting flies and their significance in classification. *Ann. Rev. Ent.* 3: 249-266.
3. Entwistle, P. F. (1972). Pests of cocoa. (Longmans, London).
4. Free, J. B. (1970). Insect Pollination of crops. (Academic Press).
5. Harland, S. C. (1925). Studies on cocoa. Part I. The method of pollination. *Annals of Applied Biology.* 12: 403-409.
6. Hernandez, J. (1965). Insect pollination of cocoa (*Theobroma cacao* L.) in Costa Rica. Ph.D. Thesis, University of Wisconsin. 167pp.
7. Kaufmann, T. (1973a). Biology and ecology of *Tyora tessmani* (Homoptera: Psyllidae) with special reference to its role as cocoa pollinator in Ghana, W. Africa. *J. Kansas Ent. Soc.* 46(3): 285-293.
8. Kaufmann, T. (1973b). Preliminary observations on a cecidomyiid midge and its role as a cocoa pollinator in Ghana. *Ghana J. Agric. Sci.* 6: 193-198.
9. Kaufmann, T. (1974). Behavioural biology of a cocoa pollinator, *Forcipomyia inornatipennis* (Diptera: Ceratopogonidae) in Ghana. *J. Kansas Ent. Soc.* 47(4): 541-548.
10. Kaufmann, T. (1975a). Cocoa pollination by males of *Forcipomyia squamipennis* (Diptera: Ceratopogonidae) in Ghana. *Trop. Agric. (Trinidad)*. 52(1) 71-74.
11. Kaufmann, T. (1975b). Ecology and behaviour of cocoa pollinating ceratopogonidae in Ghana, W. Africa. *Environmental Entomology.* 4(2): 347-351.
12. Kaufmann, T. (1975c). Studies on the ecology and biology of cocoa pollinator, *Forcipomyia squamipennis* I. & M. (Diptera, Ceratopogonidae), in Ghana. *Bull. ent. Res.* 65(2): 263-268.
13. Kaufmann, T. (1975d). An efficient, new cocoa pollinator, *Lasioglossum* sp. (Hymenoptera: Halictidae) in Ghana, West Africa. *Turrialba (Costa Rica)*. 25(1): 90-91.
14. Medina, M. F. (1973). Efecto de las polinizaciones artificiales y entomófila en el rendimiento del cacao. Tesis de Ingeniero Agronomo, Facultad de Agronomía y Veterinaria, Universidad de Guayaquil, Ecuador. 44pp.
15. Mire De, B. and Mbondji, P. M. (1975). Insectes pollinisateurs du cacaoyer en fecondation croisée au Cameroun. *Proceedings 4th Int. Cocoa Res. Conf.*, Trinidad and Tobago, January 1972, 566-569.
16. O'Donohue, J. B. (1966). Cocoa research and experiment programmes in Papua and New Guinea. South Pacific Commission Technical Meeting Cocoa Production, British Solomon Islands, Paper 41.
17. Saunders, L. G. (1956). Revision of the genus *Forcipomyia* based on characters of all stages (Diptera, Ceratopogonidae). *Canadian Journal of Zoology.* 34: 657-705.
18. Soetardi, R. G. (1950). De Betekenis van Insecten by de Bestuiving van *Theobroma cacao* L. *Arch. Koffiecult.* 17(1): 1-31.
19. Soria, S. (1970). Studies on *Forcipomyia* spp. midges (Diptera, Ceratopogonidae) related to the pollination of *Theobroma cacao* L. Ph.D. Thesis, University of Wisconsin, 129pp.
20. Soria, S. (1975). O papel das abelhas sem ferrão (Meliponinae) na polinização do cacaueiro na América Tropical (Monografia). *Revista Theobroma (Brazil)*. 5(1): 12-20.
21. Soria, S. (1976). Tabelas etárias dos polinizadores do cacaueiro, *Forcipomyia* spp. (Diptera, Ceratopogonidae) em condições de laboratório. *Revista Theobroma (Brazil)*. 6: 5-13.
22. Soria, S. and Abreu, J. M. de. (1974). Mortalidade dos polinizadores *Forcipomyia* spp. (Diptera, Ceratopogonidae) causada pela aplicação de inseticidas nos cacauais baianos. *Revista Theobroma (Brazil)*. 11(1): 15-20.
23. Soria, S. and Abreu, J. M. de. (1976). Dinâmica populacional de *Forcipomyia* spp. (Diptera, Ceratopogonidae) na Bahia, Brasil I - Flutuação estacional dos polinizadores do cacaueiro relacionada com chuva e balanço de água (Thorntwaite) *Revista Theobroma (Brazil)*. 6: 47-54.
24. Soria, S. and Silva, P. (1974). A polinização do cacaueiro na Bahia e algumas do uso de inseticidas e outras práticas culturais. *Cacau Atualidades (Brazil)*. 11(1): 15-20.
25. Soria, S. and Wirth, W. W. (1975). Ciclos de vida dos polinizadores do cacaueiro *Forcipomyia* spp. (Diptera, Ceratopogonidae) e algumas anotações sobre o comportamento das larvas no laboratório. *Revista Theobroma (Brazil)*. 5(4): 3-22.
26. Vello, F. and Magalhães, W. S. (1971). Estudos sobre a participação da formiga caçarema (*Azteca chartifex spiriti* Forel) na polinização do cacaueiro na Bahia. *Revista Theobroma (Brazil)*. 1(4): 29-42.
27. Widjanarko, S. (1967). Pollination of cocoa by *Forcipomyia* spp. in relation to endrin spraying. *Menara Perkebunan (Bogor)*. 36(11-12): 22-23.
28. Winder, J. A. (1977). Field observations of Ceratopogonidae and other Diptera: Nematocera associated with cocoa flowers in Brazil. *Bull. ent. Res.* 67: 57-63.
29. Winder, J. A. (In Press). Cocoa flower diptera: their identity, pollinating activity and breeding sites. *PANS*.
30. Winder, J. A. and Silva, P. (1972). Cocoa pollination: Microdiptera of cocoa plantations and some of their breeding places. *Bull. ent. Res.* 61: 651-655.
31. Winder, J. A. and Silva, P. (1975). Current research on insect pollination of cacao in Bahia. *Proceedings 4th Int. Cocoa Res. Conf.* Trinidad and Tobago, January 1972. 553-565.