STUDIES ON THE BIOLOGY AND COMMODITY CONTROL OF THE BANANA FRUIT FLY, *DACUS MUSAE* (TRYON), IN PAPUA NEW GUINEA

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ABSTRACT

Work on the distribution, oviposition behaviour, life stage durations and seasonal population fluctuations of Dacus musae *(Tryon), a serious pest of cultivated bananas in Papua New Guinea, is reported and discussed. Female flies oviposited into full-sized green bananas, and the incubation period ranged from 3 to 11 days. If, after 11 days, the pulp had not softened, eggs failed to hatch. The larval and pupal durations were 7 to 11 and 7 to 10 days respectively. In a 2 ha banana block, male flies were trapped throughout the year, but peak populations occurred during the dry season (July to September) and in December during the wet season.*

In other studies, it was shown that the banana variety Giant Cavendish was less infested by larvae than the shorter varieties Tui and Dwarf Cavendish, and that this may have been due to a preferred flight height, or to the differing hardness of the fruit skins. D. musae *was also found to infest chillies, tomatoes and guavas. An earwig,* Chelisoches morio *F., which may exert a small predatory influence on larvae and pupae in the field, was the only natural enemy detected.*

Based on the biological data reported, and on results of insecticide dipping trials, recommendations for commodity treatment of export bananas are given.

INTRODUCTION

Fruit flies (Diptera: Tephritidae) are distributed virtually world-wide, and the genus *Dacus* contains a very large number of species which inhabit the warmer areas of the world. Drew (1972 a, b) has recently reviewed the classification of the Dacini from the South Pacific area.

The banana fruit fly *D. musae* (Tryon) appears to be confined to areas in North Queensland, Papua New Guinea and the Solomon Islands (Drew 1975) but it is very probable that its range extends into Irian Jaya, Indonesia, the western half of the main island of New Guinea. In Papua New Guinea, the species is widely distributed throughout the mainland, where it has been recorded at elevations up to 1,600 m, and is found on some of the off-shore islands. Although found on New Britain, the fly has not been detected on either New Ireland or Bougainville, despite trapping programmes on these islands (Drew 1972 b, 1975).

D. musae has long been considered an economic pest of bananas (*Musa* spp.) in Papua New Guinea (Szent-Ivany and Barrett 1956), but detailed studies were not conducted until 1972, when the species was found to cause substantial damage to trial plots of commercial banana varieties in the Northern Province.

In this paper, work on the life history, ecology and commodity control of *D. musae* infesting bananas is reported.

MATERIALS AND METHODS

Initially, attempts were made to breed banana fruit fly in the laboratory. No successful method of maintaining *D. musae* cultures was found, although adults were offered honey and water solutions, sugar and water solutions, freshly cut bananas or guavas and a high protein (casein) powder as food sources. Since laboratory oviposition could not be induced, all life history studies were conducted on fruit "stung" in the field.

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Unstung fruits at different stages of ripeness were exposed to field populations of *D. musae*. As each individual fruit was stung, it was then removed to the laboratory, checked twice daily to record the time of hatching and the larvae reared to the adult stage. During the period of investigation, laboratory temperatures ranged from 25°C to 31°C.

To record field population changes, cylindrical, plastic fruit fly traps (Steiner 1957), containing methyl eugenol attractant (Drew 1974) were placed for a 24 hour duration each week at four separate stations in a 2 ha banana block at Lejo DPI Experimental Station, North Sangara, Northern Province, and the number of trapped flies was counted and recorded over a 3-year period from October, 1972 to September, 1975.

In laboratory and field investigations, other factors which may have affected oviposition and fruit infestation rates were examined. These included the variety of banana, height of the bunch above the ground, hardness of fruit skin, presence of alternate host fruit and the effect of an earwig predator. Heenan (1973 a, b) has described the growth characteristics of the three banana varieties tested for fruit fly infestation rate, height of bunch above ground and hardness of skin.

In order to determine the preferred flight height of *D. musae* males, a long pole was erected in an area of the banana block which contained all three varieties, and lure traps were hung at heights of 0, 150, 300 and 450 cm above the ground. These heights corresponded to those of the developing bunches in Dwarf Cavendish, Tui and Giant Cavendish bunches respectively. Trapping was carried out over a 24-hour period each week, for a total of nine samplings, between April and June 1973, and the results analysed statistically.

Differences in skin hardness between varieties were determined by using a "tensiometer" (Heenan 1973 b), which measured the pressure needed to penetrate the skin of each variety.

Finally, commodity treatments which could be used to guarantee banana fruit free from *D. musae* larval infestation were tested. In a preliminary experiment, five separate trials were conducted, using freshly prepared emulsions of commercially available insecticides at the following concentrations, into which individual fingers of bananas were dipped:

Dimethoate - 30% w/v a.i. - 0.01, 0.03, 0.05 and 0.10%
Fenthion - 55% w/v a.i. - 0.01, 0.03, 0.05, 0.075 and 0.10%

Trials I and II used fingers from bunches of Tui or Dwarf Cavendish bananas (Heenan 1973 a) which had been harvested from the 2 ha block previously mentioned and held in a fly-proof, well ventilated room for 5 to 7 days before selecting for "stung" fruit.

The three later trials used fingers selected for fullness, hard green skin and fruit fly stinging, within one day of harvest. Each trial comprised at least three replicates of 10 fingers each for the insecticide concentrations previously mentioned, and a similar number to act as controls. These latter fruit were dipped in rain water. Fingers were divided at random into replicates, and fingers of each replicate were dipped individually, using tongs, into the appropriate treatment emulsion for 5 seconds. Detergent, at the rate of 0.25 ml per litre of emulsion, was added to each of the treatments to act as a wetting agent.

After dipping, the fingers in each replicate were placed on sawdust in flat aluminium or plastic trays, and held in the fly-proof room until ripe, when each fruit was dissected and the number of live or dead *D. musae* larvae counted. The few larvae which escaped from the fruit into the sawdust were also counted.

Several 10-second dipping experiments showed no difference in infestation rate when compared to a 5-second treatment.

After the results of the preliminary trial had been analysed, it was apparent that dipping fruit into a 0.05% fenthion emulsion for a 5-second period should prevent *D. musae* larvae from developing, and the main experiment of seven trials was conducted.

This main experiment differed from the previous trials in that hands of bananas, rather than individual fingers, were dipped for a 5-second period. In trials I and II, Giant Cavendish and Tui bunches were used since no Dwarf Cavendish bunches were available, but in the remaining five trials, Tui and Dwarf Cavendish fruit were treated. For each trial, 5 to 10 bunches of each variety were harvested at the normal, hard-green stage and held for up to three days before treatment. Just prior to treatment, all hands from the bunches of one variety were detached and piled into one heap from where they were picked at random for each treatment. A similar procedure was followed for the other variety.

Three treatments were applied: dimethoate 0.05%, fenthion 0.05% and rain water (as control). From the concentrated insecticides mentioned previously, 8 litres of each emulsion was freshly prepared in clean buckets and 5 ml of detergent added to each bucket as a wetting agent. Each hand of fruit was totally immersed in the appropriate treatment emulsion for 5 seconds before being placed on a sawdust tray and held in the fly-proof room until ripe. Heavy duty gloves were worn by the operator during the dipping. Individual fruits were dissected when ripe, and live and dead *D. musae* larvae counted.

RESULTS

Life history of D. musae

Gravid females preferred to oviposit into green bananas at the "full" stage (Heenan 1973 a), when fruits were hard and totally green but would begin to colour in about 3 days. Some fruit was stung at the hard green stage before complete "filling out", but very few fingers were stung after the fruit had actually begun to colour or the pulp had begun to soften.

Ovipositing females made several exploratory stings of several seconds duration before depositing eggs in batches of 7 to 12 (mean 9.0) just below the skin and into the hard pulp. Incubation time ranged from 3 to 11 days, provided the pulp had softened within this period. If after 11 days, the pulp had not softened, eggs failed to hatch.

Larvae developed over a 7 to 11 day period (mean 8.6 days) before the mature larvae left the rotting fruit and sought suitable pupation sites. In the laboratory, larvae readily pupated in moist soil, and the pupation period lasted 7 to 10 days. The sex ratio of several hundred *D. musae* reared was very close to unity.

Under normal tropical lowland conditions, the total generation time was 3 to 4 weeks.

Field Population Fluctuations

During the 3 year study period, it was found that *D. musae* males were trapped throughout the year, and that peak catches tended to occur in August - September and December. A summary of banana fruit fly catches over the entire period is presented in *Figure 1*.

Factors affecting Fruit Infestation Rates

(1) Variety of banana

Field collected bunches of the three varieties of bananas grown in the block were inspected for fruit fly infestation. A summary of these data is shown in *Table 1*.

The information collected was statistically analysed, using the angular transformation, and showed that ripe fingers from Giant Cavendish bunches were much less infested ($p < .01$) than those of the two shorter varieties. However, a similar analysis comparing infestation rates of the total number of fingers was less sensitive, and the only significant difference to emerge showed Giant Cavendish bunches to be less infested with *D. musae* larvae than Dwarf Cavendish ($p < .01$).

For these reasons, either Tui or Dwarf Cavendish bunches were used whenever possible in the subsequent dipping trials.

(2) Height of bunch above ground

In the traps hung at different heights in the banana block, *D. musae* males were collected much more frequently ($p. < .01$) at heights around 300 cm than at the other heights, and this level corresponds to the normal height of Tui bunches above ground level. It is not known if the females of this species show similar height preferences. A summary of the number of male flies trapped at each of the heights is presented in *Table 2*.

(3) Hardness of the fruit skin

Skin hardness varied with the variety of banana and the stage of ripeness. Some results have been published by Heenan (1973 b), who concluded that the fruit skin of Giant Cavendish was significantly harder ($p. < .01$) to penetrate than that of the variety Dwarf Cavendish. Data was also collected on the changes in skin hardness as the fruit ripened, and these are shown below:

Tui variety - Days to ripen	Skin hardness (arbitrary measurements in g)
1 - 3	*225 - 350*
4 - 7	*350 - 450*
> 7	— *450*

(4) Alternate hosts

During 1972, larvae of *D. musae* were found infesting 5% to 10% of the maturing pods of birds-eye chillies (*Capsicum annuum*) in a 0.5 ha block in the Northern Province. No subsequent infestation in the area has been reported.

D. musae has also been reared from the fruits of tomato (*Lycopersicum esculentum*) and guava (*Psidium guajava*). In the latter fruit, larvae and emerging pupae developed over very similar time periods to those recorded in bananas.

(5) Natural enemies

The only natural enemy of *D. musae* detected was the earwig *Chelisoches morio* F. (Dermaptera : Chelisochidae), which is widely found infesting banana bunches in the field. In the laboratory, adult *C. morio* readily attacked and consumed two or three half grown *D. musae* larvae per day.

Figure 1 — Mean monthly numbers of male Dacus musae flies captured in methyl-eugenol lure traps over a 3 year period.

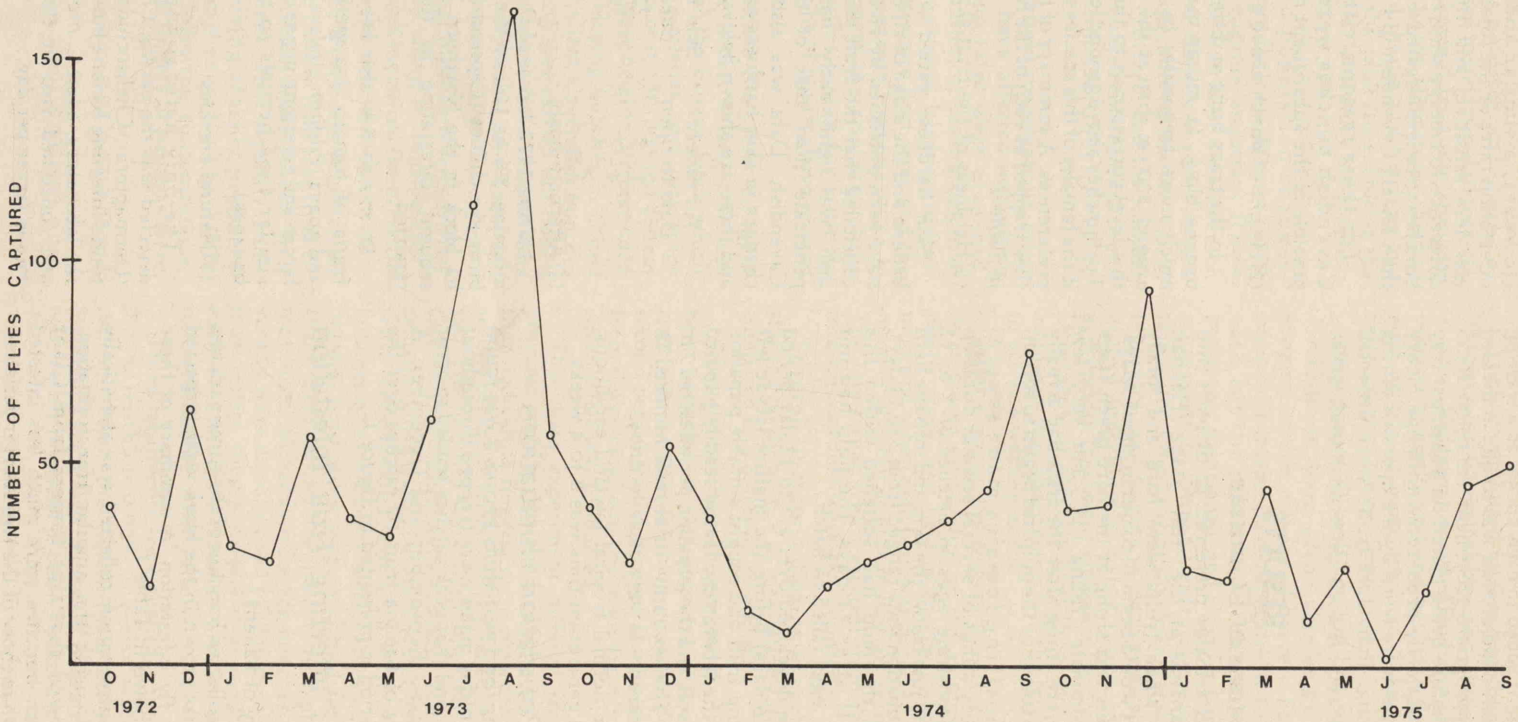

TABLE 1. — **(a)** ***D. MUSAE*** **INFESTATION RATES IN THREE VARIETIES OF BANANAS**

Variety of banana	TOTAL FINGERS				RIPE FINGERS ONLY			
	Dwarf	Tui	Giant	Total	Dwarf	Tui	Giant	Total
Number of bunches examined	18	26	19	63	18	26	19	63
Total fingers examined	3,018	4,433	2,840	10,291	1,627	1,028	1,575	4,230
No. of fingers infested by *D. musae*	642	407	155	1,204	642	407	155	1,204
No. Unripe fingers	1,391	3,405	1,265	6,061	—	—	—	—
% fingers infested	21.27	9.18	5.46	11.70	39.46	39.59	9.84	28.46

(b) LEAST SIGNIFICANT DIFFERENCES - TRANSFORMED DATA

Between Types	Difference between Means and Significance levels			
	Total fingers infested		Ripe fingers infested	
Dwarf - Tui	5.64	N.S.	7.66	N.S.
Dwarf - Giant	11.55	**	19.61	**
Tui - Giant	5.91	N.S.	27.27	***

* = p<.05 ** = p<.01 *** = p<.001

N.S. = Not significant

TABLE 2. — **NUMBERS OF *D. MUSAE* MALES COLLECTED AT METHYL EUGENOL BAITED TRAPS PLACED AT VARIOUS HEIGHTS IN A 2 ha BANANA BLOCK .**

(Total numbers collected after 9 exposures for a 24 hour period each week)

Trap Height	No. males	Mean No.
Ground level	85	9.4
150 cm	56	6.2
300 cm	252	28.0
450 cm	109	12.1
Combined catch	502	—

LEAST SIGNIFICANT DIFFERENCES

Between treatments	Difference between means and significance levels	
Ground level — 150 cm	3.2	N.S.
Ground level — 300 cm	18.6	**
Ground level — 450 cm	2.7	N.S.
150 — 300 cm	21.8	***
150 — 450 cm	5.9	N.S.
300 — 450 cm	15.9	**

* $p < .05$ ** $p < .01$ *** $p < .001$

N.S. = not significant

Commodity Treatment Trials

In the preliminary trials, several concentrations of both dimethoate and fenthion were tested against *D. musae* larvae. The results indicated that a 0.05% fenthion dipping emulsion should prevent fruit fly larvae from developing, although some larvae survived this and higher concentrations of fenthion, possibly due to the insecticide being from old stock held at the laboratory for 3 to 4 years before use. The results of these dipping trials are tabulated in *Table 3*.

Although no bunch dipping was carried out, a 5-second dipping period was selected with large scale bunch dipping in mind. Several experiments comparing 5-second and 10-second dipping periods showed that no difference in infestation rate could be expected by using the longer dipping time.

The main trials, which used hands of bananas, compared the sterilisation of fruit fly infested bananas dipped in 0.05% dimethoate, 0.05% fenthion or a control rain water treatment for a period of 5 seconds. These trials confirmed that 0.05% fenthion emulsion was a suitable concentration at which dipped banana fruit could be assured to be free of fruit fly infestation. A summary of the seven trials is presented in *Table 4*.

In addition, the very low infestation rates in the control treatments during these trials, indicated that by harvesting bunches at the hard green stage, one or two days before ovipositing normally occurred, the numbers of larvae subsequently hatching was greatly reduced.

DISCUSSION

In 1966, Saunders and Elder attempted to breed *D. musae* in the laboratory but, as in this study, no successful method was found. In the field *D. musae* preferred to oviposit into immature fruit, as also occurs in North Queensland (May 1963), but if after 11 days, the pulp had not softened, the eggs failed to hatch. A similar finding was reported by Umeya and Yamamoto (1971) who studied banana infestation by the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann).

Oviposition into fruit at the preferred stage had a distinct advantage since larvae emerged as the fruit softened and completed development before the fruit pulp had completely rotted. Gravid females selected those fruits which would provide softened pulp within three to four days, although it is possible that the enzymes which soften the pulp may have influenced the development of the eggs.

TABLE 3. — **PRELIMINARY STERILISATION DIPPING TRIALS AGAINST *D. MUSAE* BANANA INFESTATION USING VARIOUS CONCENTRATIONS OF DIMETHOATE AND FENTHION INSECTICIDES**

Mortality as a percentage of Water control treatment *

Trial No.	No. Reps. +	Water Control	DIMETHOATE .01	.03	.05	.10	FENTHION .01	.03	.05	.075	.10
I	3	2.4	76.5	96.1	—	—	95.6	97.5	—	—	—
II	3	10.4	—	87.3	96.0	95.4	—	97.9	99.8	—	100.0
III	5	2.5	—	—	99.2	98.6	—	—	100.0	98.9	99.4
IV	6	21.3	97.8	99.4	—	—	99.0	100.0	—	—	—
V	6	19.4	—	—	99.1	—	—	100.0	100.0	—	—
Mean		11.2	87.2	94.3	98.1	97.0	97.3	98.9	99.9	98.9	99.7

* Calculated from the number of fruit fly larvae found alive in each treatment, divided by the total number of larvae found in control treatment.

+ Each replicate consisted of 10 fingers dipped for 5 to 10 seconds in insecticide solution.

TABLE 4. — **STERILISATION DIPPING TRIALS AGAINST *D. MUSAE* BANANA INFESTATION USING 0.5% CONCENTRATIONS OF DIMETHOATE AND FENTHION INSECTICIDES**

Numbers of banana fingers infested

Trial No.	Banana Variety	CONTROL (WATER)			DIMETHOATE .05%			FENTHION .05%		
		Uninfested	Infested	Total	Uninfested	Infested	Total	Uninfested	Infested	Total
I	Tui	303	4	307	283	1	284	294	0	294
II	Tui	214	0	214	270	1	271	273	0	273
III	Tui	234	10	244	207	1	208	194	0	194
IV	Tui	302	0	302	282	0	282	297	0	297
V	Tui	239	2	241	280	1	281	268	0	268
VI	Tui	578	13	591	542	2	544	549	0	549
VII	Tui	530	1	531	529	0	529	579	0	579
TOTAL		2,400	30	2,430	2,393	6	2,399	2,454	0	2,454
%		98.77	1.23	—	99.75	0.25	—	100.0	0	—
I	Giant	194	0	194	179	0	179	178	0	178
II	Giant	209	0	209	205	1	206	229	0	229
III	Dwarf	260	0	260	324	2	326	215	0	215
IV	Dwarf	270	3	273	269	1	270	297	0	297
V	Dwarf	275	11	286	269	2	271	305	0	305
VI	Dwarf	688	52	737	665	8	673	610	0	610
VII	Dwarf	536	2	538	492	0	492	544	0	544
TOTAL		2,432	68	2,500	2,403	14	2,417	2,378	0	2,378
%		97.28	2.72	—	99.42	0.58	—	100.0	0	—
GRAND TOTAL		4,832	98	4,930	4,796	20	4,816	4,832	0	4,832
%		98.01	1.99	—	99.58	0.42	—	100.0	0	—

It was found that the variety Giant Cavendish was less liable to *D. musae* infestation than either Tui or Dwarf Cavendish bananas, and that only when ripe, were Tui fruit as heavily infested as Dwarf Cavendish (*Table 1*). These differences in infestation rates may possibly be explained by the variations in hardness of the fruit skins, and by the finding that male flies showed a strong tendency to fly at about 300 cm above ground level (*Table 2*), the height at which most Tui bunches were produced but below the height of the developing Giant Cavendish bunches. The skin of Giant Cavendish fingers was harder than that of the other two varieties (Heenan 1973 b; Anon. 1974), and it appears that the stimuli to oviposit mav be triggered by a "skin hardness" measure of 300 to 400 g, a figure generally exceeded in Giant Cavendish fingers, but not by the other varieties. Since the skin of Tui fruit softens during the ripening process (Wardlaw 1961) to a hardness measure less than 400 g within seven days of ripening (Anon. 1974), these fruit would become increasingly acceptable as oviposition sites by *D. musae* females, and if the female flight preference followed that of the males, the fruit would readily become infested.

During the studies, the fly was bred from four economic plant species, but in Queensland, it has also been reared from native bananas (*Musa banksii*), pawpaw (*Carica papaya*) and a bush shrub (*Capparis lucida*) (May 1953). It is likely that the species infests similar hosts in Papua New Guinea.

Marucci (1955) reported that two species of Hawaiian earwigs were predatory on fruit fly larvae from guavas and other rotten fruit and in the soil. It is thought that in this country the earwig *C. morio* may exert a small predatory influence on numbers of *D. musae* larvae and perhaps pupae which are exposed in the field.

If banana fruit is to be exported from Papua New Guinea, assurances must be made to the importing countries that the fruit is free from fruit fly infestation. In Queensland, "sound plantation hygiene practices and early harvesting" have been recommended for control of *D. musae* in bananas (Saunders 1961).

Braithwaite (1963) and Saunders and Elder (1966) showed that larvae of *D. tryoni* (Froggatt) (Queensland fruit fly) and *D. musae* respectively, were killed by dipping infested bananas into emulsions of dimethoate or fenthion insecticides. Braithwaite also presented data showing that the dipping of banana fruit into emulsions of fenthion 0.05% for as long as three minutes did not impart an undesirable flavour to the fruit, nor was any toxicity hazard to humans likely to have been encountered from the insecticide residues.

In the present study, the preliminary sterilisation dipping trials had been conducted with the view to determining an insecticide treatment which would prevent development of fruit fly larvae infesting bananas, and the results indicated that fenthion at 0.05% concentration would achieve this aim. The intention in the main trials was the development of a relatively simple commodity treatment, which would be applied during normal harvesting and shipping practices to bunches of fruit destined for export markets. In these trials, control by insecticides was considered inadequate if any flies could be reared out of dipped fruit.

On the basis of the *D. musae* life history studies and the dipping trials reported in this paper, a guarantee for banana fruit free from banana fruit fly infestation can be made as follows:

> Banana fruit, harvested at the hard green stage, held in a cool room for 11 to 12 days to prevent ripening, and then dipped in a freshly prepared 0.05% fenthion emulsion for a five-second period, before being shipped to the customer country in a refrigerated ship, can be guaranteed to be free from *D. musae* infestation.

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