Infestation Norms for Dacus cucurbitae in Momordica balsamina, and Seasonal Differences in Activity of the Parasite, Opius fletcheri[1]

IRWIN M. NEWELL, WALLACE C. MITCHELL, and FRANCIS L. RATHBURN[2]

UNIVERSITY OF HAWAII, COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION

In February, 1950, the first releases of a newly introduced opiine parasite of *Dacus cucurbitae* Coquillett were made on the island of Oahu, Territory of Hawaii. This parasite, now known as *Opius watersi* Fullaway, 1951, had been found in Bareilly, United Provinces, India, in the course of explorations for parasites of *Dacus dorsalis* Hendel. In breeding tests conducted by the Bureau of Entomology and Plant Quarantine in Honolulu, and also in pilot and mass breeding by the Territorial Board of Agriculture and Forestry, it showed considerable promise, and more than 115,000 parasites were bred and released throughout the Territory during 1950 (data from records of the Territorial Board of Agriculture and Forestry).

In order to check on the effectiveness of this parasite in the event it should become established, it was felt desirable to measure the relative abundance of *Dacus cucurbitae* before and after establishment. There are several ways that this can be done, but the method finally decided upon was to measure the larval infestation in *Momordica balsamina* Linnaeus, a wild cucurbit that grows abundantly in many parts of the Hawaiian Islands. It was thought that any significant reduction in the level of *Dacus cucurbitae* would be reflected in a lowered infestation level in the various hosts. Commercial crops such as cucumbers and tomatoes were excluded from consideration since cultural practices vary so greatly, producing correspondingly great variations in infestation.

Unfortunately, *Opius watersi* has not yet become established in the Territory, but the data obtained are published here in order to present an up to date picture of infestation by *Dacus cucurbitae*. With the continuing interest in biological control of fruit flies, there is still the possibility that a parasite may be found which will supplement the work of *Opius fletcheri* Silvestri to such an extent that a further reduction in abundance of the melon fly may be brought about. In such an event, these data would provide a valuable standard for comparison of infestation before and after introduction. Furthermore, this study revealed a pronounced seasonal difference in activity of *O. fletcheri*, a fact of considerable intrinsic interest which apparently has not been realized previously, and the results of the studies on parasitism are also presented here. *O. fletcheri* was introduced into Hawaii in 1916, and is a well established parasite (Willard, 1920).

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[2] The last-named author is now with the Territorial Board of Agriculture and Forestry, Honolulu, T. H.

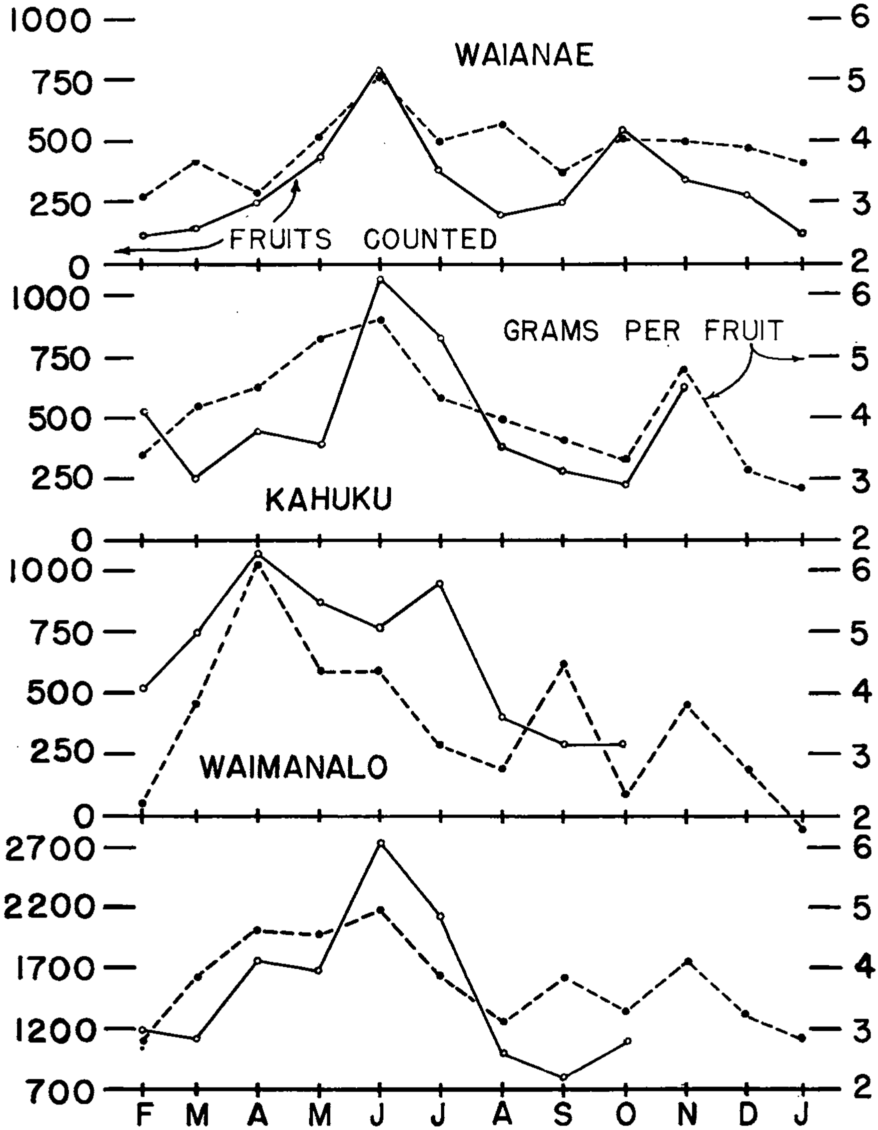

Fig. 1. Host fruit production factors. Number of *Momordica* fruits and average weight per fruit for each locality and for the three localities combined. The bottom graph is based on either the total (number) or average (weights) of the three values in the upper graphs.

METHODS

Fruit collections were made at fixed points near Waianae (Makaha Valley), Kahuku (near the air strip), and Waimanalo, all three localities on the island of Oahu. At each locality, from four to six stations were sampled. The five stations near Kahuku were laid out along a road and in direct continuity with one another. The four stations near Waianae were in two groups of two each, the groups being about a mile apart. The six at Waimanalo were scattered over an area approximately one mile long and one-third of a mile wide. The same stations were sampled throughout the year as much as possible, although several changes were required as a result of clearing or burning by growers, especially in the Waimanalo area. Most of the stations were roadside patches ranging in length from 100 to 350 feet, although three of those in Makaha Valley were of the order of 1000 feet long. Fruits were collected once a month. Mature orange or yellow fruits were gathered when possible, but almost always there were a few green-yellow or even green-white fruits included in the sample. Broken fruits were avoided as much as possible. All fruits seen at the time of sampling were counted, even those which had just recently dropped the petals. The sample usually comprised one-third to one-half of the fruits counted. In the laboratory, weight and number of stings were recorded for each sample, and the larvae were removed from the fruits. The larvae were reared on diced pumpkin in a manner described elsewhere (Newell *et al.,* 1951). The dissected fruits were then kept in a jar or pan, depending on the size of the sample, and were examined each day until no further recoveries of larvae were made.

When emergence of flies and parasites was complete, the puparia were checked, and any unemerged individuals were added to the totals. Occasionally the chalcid *Tetrastichus giffardianus* Silvestri was encountered, and this necessitated a close examination of the puparia for the characteristic exit hole of this species, for three to ten adults may emerge from a single puparium. For the purposes of this study, each puparium from which *Tetrastichus* emerged was counted as a single *O. fletcheri,* since the development of *T. giffardianus* in *D. cucurbitae* requires the presence of *O. fletcheri* (Pemberton and Willard, 1918). The data are presented in tables 1 to 4.

ABUNDANCE OF HOST FRUIT

Momordica balsamina bears fruit throughout the year, although more abundantly during the months of April to July. In 1951, maximum production came in June in the Waianae and Kahuku areas, but at Waimanalo more fruits were found in April than in any other month. At all three localities, the time of maximum fruiting coincided with the time of greatest fruit size (fig. 1). The curve for abundance of *Momordica* generally parallels the total production of the principal commercial hosts of *Dacus cucurbitae* (table 5). There was no positive indication that any seasonal trends in fly or parasite activity which were measured here were significantly influenced by the quantity of host material available, although it is quite possible that certain of the differences between locali-

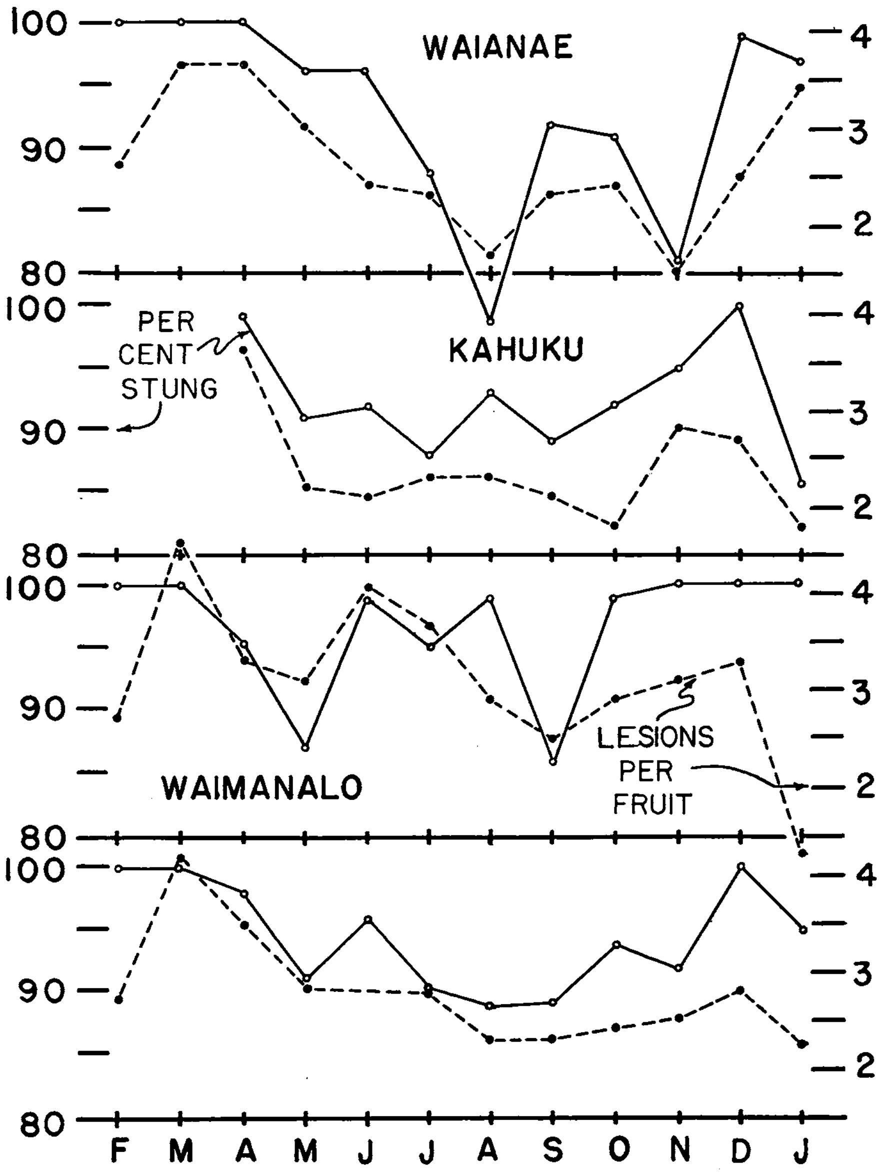

Fig. 2. Egg lesions per fruit and per cent of fruits stung at each locality. The bottom graph is based on the average of the three (or two) values in the upper graphs.

ties were associated with the factor of host abundance. For example, the infestation averaged 3.1 and 3.4 larvae per fruit for the 12 monthly collection periods at Waianae and Kahuku respectively, but 4.0 per fruit at Waimanalo, one of the chief truck crop centers on the island. Yet, the average infestation per *Momordica* fruit at these three localities during the peak period of production of commercial hosts (April through August) was 3.1, 3.4, and 4.1 respectively, compared with 3.1, 3.2 and 3.9 larvae per fruit for the seven remaining months. Thus, while the higher infestation at Waimanalo may possibly have been a consequence of the greater abundance of host material there, no seasonal differences in infestation could be associated with this factor.

Truck cropping at Waianae was at a very low ebb throughout most of the time this study was in progress, owing to financial reverses of the growers. The previous season's crop (1949) had been fairly heavy, and plantings were increasing during the last two or three months of 1950. There were no commercial plantings of cucurbitaceous or solanaceous crops within several miles of the Kahuku locality. Here the cultivated land is planted exclusively to sugar cane, except for a few home gardens.

OVIPOSITIONAL ACTIVITY AND LARVAL INFESTATION

The per cent of stung fruits dropped noticeably during the summer months, and the number of lesions per fruit also dropped slightly, although the latter was not significant statistically. Nevertheless, in conjunction with the seasonal variations in the other factors, it seems likely that the trends in both curves are real. But because of the differences in fruit abundance from month to month, it is impossible to conclude that these trends alone indicate lowered ovipositional activity on the part of the flies. However, an index of the total number of lesions in each area can be derived by multiplying the number of fruits counted by the number of stings per fruit, and when this is done (fig. 2), a curve is obtained which has a June maximum 3.9 times as great as the September minimum. The rest of the curve conforms to what one would expect if there were a drop in ovipositional activity of the fly population beginning in July.

The curve for larval population parallels the one for egg lesions, but is somewhat higher except in October. The June maximum is 4.8 times as high as the October minimum.

The mean value for the twelve monthly collections at Waianae was 3.1 larvae per fruit, while at Kahuku and Waimanalo it was 3.4 and 4.0 larvae per fruit, respectively. Infestation maxima occurred in March and December when all three localities combined averaged over 4.5 larvae per fruit, compared with the minimum of 2.2 larvae per fruit in October. From the foregoing account, it will be evident that larvae per fruit is not in itself a good indicator of ovipositional activity because of seasonal differences in fruit abundance, although it probably provides a good index of relative fly abundance when collections are made over a period of a year.

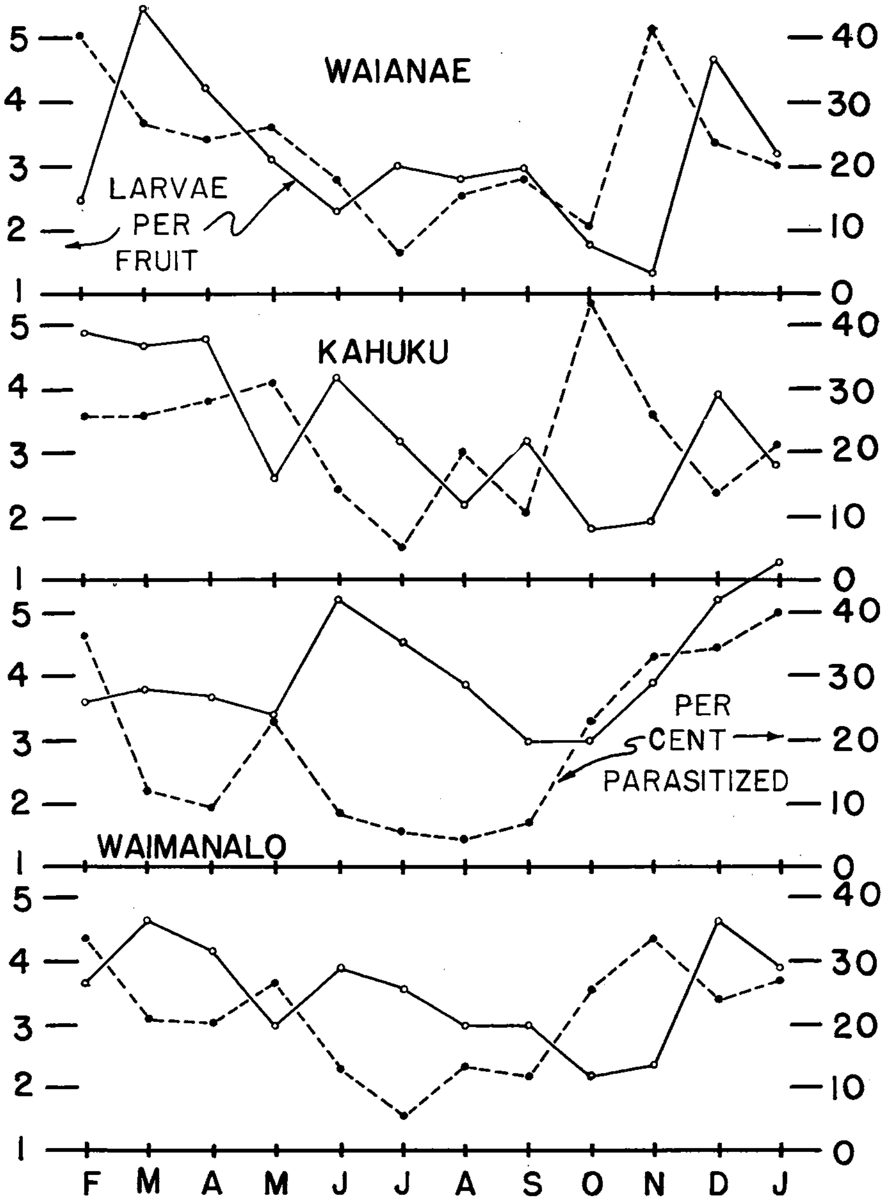

Fig. 3. Larval infestation per fruit and per cent of larvae parasitized at each locality. The bottom graph is based on the three values in the upper graphs.

INCIDENCE OF PARASITISM

In considering the data on incidence of parasitism by *Opius fletcheri*, it is important to keep in mind the method of larval recovery used in this study. The larvae removed from these fruits were in all stages of development at the time the fruits were picked. Since *O. fletcheri* oviposits chiefly in the second or third instar larvae, and probably not at all in the eggs, many of the individuals present in the fruits had never been subjected to parasitism. Therefore, the results obtained by this method are not comparable with the results obtained when only the more mature larvae are used. Nevertheless, there is no reason to believe that the proportion of the population exposed to parasitism should show any marked seasonal variations resulting from the methods used.

A study of figure 3 will show that there was a pronounced depression in the degree of parasitism at all stations during the months of June, July, August, and September. An analysis of variance of the per cent parasitism for the twelve months of the year gave an l.s.d. value (least significant difference) of 16.3 which is significant at the 19:1 level, and 23.0 at the 99:1 level. There was no statistically significant difference between any of the three localities. The question now arises, was this depression due to a real decline in numbers or activity of parasites, or was it a reflection of some change in the number of host larvae? A very large and sudden increase in the larval population, with no corresponding change in the parasite population could, conceivably, result in just such a drop in parasitism as we see here. Using the figures for fruits counted, larvae per fruit, and per cent of larvae parasitized, it was possible to obtain estimates of the relative numbers of fly and parasite larvae in the populations sampled. While these are only approximations, the seasonal differences were considerable and probably real. Figure 4 shows the number of larvae available for oviposition, and the number of larvae attacked by *Opius fletcheri*. From the latter curve, it can be seen that there was a marked drop in the activity of the parasite population during the months of July, August, and September, at which time the incidence of parasitism was also at its lowest point. Parasite activity increased in October and this trend continued unchecked into November at both Kahuku and Waianae, and into December at the latter locality. Difficulties in sampling due to disturbance of several of the areas made it impossible to continue the comparison into these months, however. From figure 4 it is evident that the drop in per cent of larvae parasitized (fig. 3) was in no way the result of an increase in number of available larvae; in fact, it actually coincided with a drop in the number of host larvae. Therefore, it seems evident that there was a real decline in the activity of the parasite population during the summer months.

Turning now to the matter of the decline in larval abundance, it can be seen that this began in June or July and continued unchecked until October (and probably November). It would seem reasonable to suppose that maximum emergence of larvae from the fruits occurred in June and July, with peak emergence of the adults in late June, July, and early August. Yet there is no change in the trends in larval population until

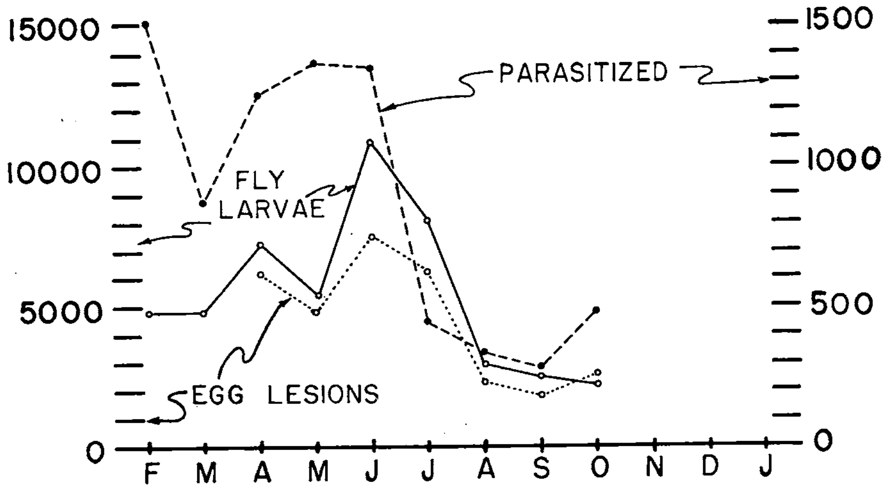

Fig. 4. Relative number of fly larvae available, larvae parasitized by *Opius fletcheri*, and number of lesions for the three areas combined. Calculated from data on fruit abundance, larval infestation, per cent of larvae parasitized, and egg lesions per fruit.

November or December. This suggests very strongly that the great majority of flies emerging during the summer months do not contribute materially to fruit infestation that season, but carry over until the following winter or even summer. Returning to the decline in parasite activity during the summer months, it is possible that this is another manifestation of the same phenomenon, arising from a depletion of the ovipositing stock which was largely developed during the preceding season. The upward inflection of the curve in October probably represents the beginning of ovipositional activity by the parasite population developed from the summer crop of fly larvae. Clearly there are many things we need to know about the mechanisms involved in the populations of both flies and parasites. At the risk of being overly axiomatic, it should be emphasized that wild populations of flies and parasites probably do not behave the same as individuals or populations reared in the laboratory where there is no marked seasonal variation in tendency to mate and lay eggs.

DISCUSSION

The analyses presented here, especially those dealing with total larval populations are subject to errors from a number of sources. One source is in the factor of number of fruits counted. The estimates of populations of larvae and parasitized larvae were necessarily based on the assumption that the immature fruits counted would have developed to maturity and sustained the same infestation as the fruits collected. Furthermore, there is the implied assumption that a decrease in fruit number with no change in population of ovipositing flies or parasites will be accompanied by a compensating increase in the degree of attack on the remaining fruit, etc.

Of these two assumptions, the latter is probably the more tenuous, and at present there is no way of assessing its validity.

However, if we accept the estimates at face value, then there is a drop in the activities of *Opius fletcheri* during the summer months. It would appear that while the number of larvae available for oviposition fell, the number of ovipositing female parasites declined even more rapidly. It is unfortunate that *Opius watersi* has not become established in Hawaii, for this is a species which undergoes a winter diapause. Possibly its different seasonal cycle would result in a more prolonged period of parasite activity during the summer months, augmenting the work of *Opius fletcheri* at its weakest point.

The data presented here are not comparable with any of the published data obtained during the early years of the invasion of Hawaii by *Dacus cucurbitae*. Back and Pemberton (1917, pp. 17-18) cited one instance of a single collection of *Momordica* from the Kona district of the island of Hawaii in November, 1914, which averaged 6.5 larvae per fruit. Willard (1920, p. 437) published additional data on collections from this same district made by Pemberton in May of 1916 and April of 1918. These averaged 4.0 and 0.3 larvae per fruit respectively (a ratio of 13:1). This very significant decline was presumed due to the activities of *Opius fletcheri* which was first liberated there during the summer of 1916. While there is no doubt that the parasite was in part responsible for lowered abundance of the fly, it is important to note that marked seasonal variations in infestation do occur. Moreover, it cannot be safely assumed that the cycle is the same from year to year. In the present study the minimum infestation found in any one month was 2.3 larvae per fruit, while the maximum was 5.8 (a ratio of only 2.5:1). These were in different localities on Oahu so the data are therefore not directly comparable, and neither figure can be compared with the single collection records from Hawaii in 1914, 1916 and 1918. The only way to obtain a reliable measure of infestation is to make collections of fruit at regular intervals over a period of at least a year. These need not be at monthly intervals, but should not be at intervals greater than two months. When the data presented here were analyzed on the basis of bimonthly collections, the average deviation from the mean infestation of 3.5 was only 8.0 per cent. But when analyzed on the basis of trimonthly collections, the average deviation from the mean was 29.7 per cent. Had only three collections per year been made, an average deviation of 35.1 per cent could have been expected.

SUMMARY

1. The results of one year's study of the infestation of *Momordica balsamina* by *Dacus cucurbitae* and of the seasonal incidence of *Opius fletcheri* are presented.

2. Fruiting of *Momordica* was heaviest from April through July, with the maximum occurring in June. This followed the curve for commercial production of host plants.

3. The mean infestation, based on twelve monthly readings, was 3.1, 3.4, and 4.1 larvae per fruit in the Waianae, Kahuku, and Waimanalo areas respectively.

4. The incidence of parasitism by *Opius fletcheri* was significantly lower during the months of June, July, August and September than during the rest of the year.

5. It is suggested that this decline in incidence of parasitism may have been due to depletion of the population of ovipositing female parasites at a rate more rapid than that of the fly stock. It was not due to swamping of the parasite population by a large increase in the number of fly larvae available for attack.

6. The interval between maximum larval populations of both fly and parasite in June, and the beginning of the upward trend in October was considerably greater than the minimum pupal and preoviposition period for either species. It is thought that this may reflect a natural lag in the ovipositional activities of field populations of flies and parasites.

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Table 1. Data on fruits collected in Makaha Valley, near Waianae, Oahu. 1950-1951.

Date	Fruit Seen	Fruit Coll.	% Fruit Stung	Stings per Fruit	Larvae per Fruit	Av. wt. Fruit	Flies + Paras.	% Paras.
Feb. 3	125	63	100	2.6	2.5	3.1	94	40.4
Mar. 6	150	75	100	3.6	5.5	3.7	383	26.8
Apr. 5	254	116	100	3.6	4.2	3.2	421	24.2
May 3	442	155	96	3.0	3.1	4.1	429	25.8
June 5	780	287	96	2.4	2.3	5.1	524	17.9
July 3	381	147	88	2.3	3.0	4.0	403	6.4
Aug. 7	210	91	76	1.7	2.8	4.3	249	15.6
Sept. 11	250	120	92	2.3	2.9	3.5	314	18.2
Oct. 9	540	237	91	2.4	1.8	4.1	399	10.5
Nov. 6	349	186	81	1.5	1.3	4.0	211	41.7
Dec. 4	284	145	99	2.5	4.7	3.9	616	24.0
Jan. 15	131	64	97	3.4	3.2	3.7	151	21.2
Total	3,771	1,686	..	..	..	..	4,194	..
Mean	...	...	93	2.6	3.1	3.9	...	22.7

Table 2. Data on fruits collected near Kahuku, Oahu. 1950-1951.

Date	Fruit Seen	Fruit Coll.	% Fruit Stung	Stings per Fruit	Larvae per Fruit	Av. wt. Fruit	Flies + Paras.	% Paras.
Feb. 8	544	173	..	..	4.9	3.4	610	25.4
Mar. 8	260	112	..	..	4.7	4.2	493	25.9
Apr. 10	438	191	99	3.6	4.8	4.5	880	28.2
May 10	388	127	91	2.2	2.6	5.3	263	30.7
June 14	1,204	308	92	2.1	4.2	5.6	1,093	13.9
July 10	836	312	88	2.3	3.2	4.3	879	5.0
Aug. 21	385	150	93	2.3	2.2	4.0	263	20.2
Sept. 18	283	97	89	2.1	3.2	3.7	270	10.4
Oct. 16	226	108	92	1.8	1.8	3.4	170	44.1
Nov. 27	627	136	95	2.8	1.9	4.8	192	26.6
Dec. 18	...	50	100	2.7	3.9	3.2	176	13.6
Jan. 22	...	39	87	1.8	2.8	2.9	94	21.3
Total	5,191	1,803	..	..	..	..	5,383	...
Mean	...	...	93	2.4	3.4	4.1	...	22.1

Table 3. Data on fruits collected near Waimanalo, Oahu. 1950-1951.

Date	Fruit Seen	Fruit Coll.	% Fruit Stung	Stings per Fruit	Larvae per Fruit	Av. wt. Fruit	Flies + Paras.	% Paras.
Feb. 16	533	218	100	2.7	3.6	2.1	695	36.4
Mar. 22	759	313	100	4.5	3.8	3.8	1,050	12.1
Apr. 19	1,104	328	95	3.3	3.7	6.3	1,125	9.6
May 15	880	274	87	3.1	3.4	4.4	781	23.3
June 19	772	235	99	4.0	5.2	4.4	1,038	8.2
July 17	935	381	95	3.7	4.5	3.3	1,523	5.6
Aug. 28	388	167	99	2.9	3.9	2.8	609	4.7
Sept. 25	299	123	86	2.5	3.0	4.5	324	6.5
Oct. 30	295	185	99	2.9	3.0	2.3	467	22.9
Nov. 29	...	173	100	3.1	3.9	3.9	574	33.1
Jan. 3	...	76	100	3.3	5.2	2.9	354	34.7
Jan. 29	...	44	100	1.3	5.8	1.8	225	40.0
Total	5,149	2,517	..	..	..	..	8,765	...
Mean	...	...	97	3.1	4.1	3.5	...	19.8

Table 4. Total and mean values for all three areas combined. 1950-1951.

Date	Fruit Seen	Fruit Coll.	% Fruit Stung	Stings per Fruit	Larvae per Fruit	Av. wt. Fruit	Flies + Paras.	% Paras.
Feb.	1,202	454	100	..	3.7	2.9	1,399	34.1
Mar.	1,166	500	100	..	4.7	3.9	1,926	21.6
Apr.	1,796	635	98	3.5	4.2	4.7	2,426	20.3
May	1,710	556	91	2.9	3.0	4.6	1,473	26.6
June	2,756	830	96	2.7	3.9	5.0	2,655	13.3
July	2,152	840	90	2.9	3.6	3.9	2,805	5.7
Aug.	983	408	89	2.6	3.0	3.2	1,121	13.5
Sept.	832	340	89	2.3	3.0	3.9	908	11.7
Oct.	1,061	530	94	2.5	2.2	3.3	1,036	25.8
Nov.	...	467	92	2.6	2.4	4.2	977	33.8
Dec.	...	271	100	2.8	4.6	3.3	1,146	24.1
Jan.	...	147	95	2.6	3.9	2.8	470	27.5
Total	12,456	5,978	..	..	..	..	18,342	...
Mean	...	...	94	2.7	3.5	3.8	...	21.5

Least difference for significance: (19:1)............ 16.3
(11:1)............ 23.0

Table 5. Commercial production of principal crops serving as hosts of *Dacus cucurbitae,* in short tons per month, Island of Oahu, 1950. Slightly modified from "1950 Statistics of Diversified Agriculture in Hawaii," University of Hawaii, College of Agriculture, May 1951. The total number of *Momordica* seen at the three localities used in this study are given at the bottom for comparison.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Tomatoes	60	40	40	65	75	110	100	75	63	100	100	63
Cucumbers	35	40	40	35	63	75	25	25	40	45	25	15
Peppers, Eggplant	25	23	23	75	63	63	53	23	25	35	35	15
Squash, Pumpkin	6	6	6	6	7	7	17	9	9	8	9	9
Watermelon	0	0	0	100	200	500	350	250	125	50	25	5
Total	126	109	109	281	413	755	545	382	262	238	194	107
Momordica	....	1202	1166	1796	1710	2756	2152	983	832	1061	....	....