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Seasonal Occurrence of *Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae), a Parasitoid of *Bactrocera correcta* (Bezzi) (Diptera: Tephritidae) in a Guava Orchard in Central Thailand

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ABSTRACT Relationships between the parasitoid, *Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae), its fly host, *Bactrocera correcta* (Bezzi) (Diptera: Tephritidae), and the host plant, *Psidium guajava* L., are described. The abundances of fruit and fruit flies per fruit were correlated with seasonal changes in the mean maximum monthly relative humidity. The analysis model was: $\sqrt{\text{fruit flies per fruit}}$ = 0.892(monthly mean max %RH) - 79.753. The mean maximum temperature over the month before fruit harvest was correlated with parasitoids per fruit ($r = 0.530$; $P < 0.05$). Both the fruit and fruit fly abundance were found to influence parasitoid number. The regression equation is described by Ln (parasitoid no.) = 1.673 + 0.029 (fruit no.) + 0.238 Ln (fruit flies per fruit). In nature, the ratio of female : male parasitoids was 4:3. Larger fruits may provide more nutrients, produce larger host flies and in turn, affect the parasitoid size. *D. longicaudata* females were produced from larger fly hosts whereas males were produced from smaller fly hosts. Larger female parasitoids produce more offspring than smaller females. The production of more parasitoids, as observed, may provide better biological control.

KEYWORDS: *Diachasmimorpha longicaudata*, *Bactrocera correcta,* parasitoid, biological control.

INTRODUCTION

The guava fruit fly, *Bactrocera correcta* (Bezzi) (Diptera: Tephritidae), is an important pest of commercial guava and is known to attack a wide range of other fruits in Thailand.[1] To date, *B. correcta* is a minor but potentially serious pest of fruits. It often occurs with the oriental fruit fly, *Bactrocera dorsalis* (Hendel) in the same fruits.[2] An attempt to eradicate fruit flies in Thailand has been made using the sterile insect technique (SIT) to suppress *B. dorsalis* populations.[3] If *B. dorsalis* eradication were successful, this may provide an opportunity for *B. correcta* to replace *B. dorsalis* and eventually become an economically serious pest. Because of this threat, an investigation on the parasitoids that might be useful in the future biological control of *B. correcta* populations becomes obvious.

No parasitoids of *B. correcta* have been previously reported. From the preliminary study, the braconid parasitoid, *Diachasmimorpha longicaudata*, associated with *B. correcta* was found at the study site in the district of Samphran in Nakhon Pathom province, a guava orchard in central Thailand. *Diachasmimorpha longicaudata* (Hymenoptera : Braconidae) is a larval endoparasitoid that has been utilized for biological control of fruit fly pests in the family Tephritidae in Hawaii.[4,5,6] Host plant (guava fruit) characteristics and, therefore, fruit fly (*B. correcta*) and parasitoid (*D. longicaudata*) may vary with the season. The seasonal environmental factors that contribute to the growth and development of this parasitoid are not well understood.

The body size of parasitoids may vary as a function of the size of the fly host on which they develop. Smaller hosts may represent a more limiting food resource which results in the production of smaller adult parasitoids. Male parasitoids are usually smaller than females because they develop faster within the host puparia.[7,8] Larger size in the female parasitoid is more important in terms of reproductive success[9] but also is important in male *D. longicaudata.*[10] *D. longicaudata* is a solitary endoparasitoid and large females produce more offspring than small females (Kitthawee, unpublished data). Variation in the size of females, therefore, provides variable opportunities for their offspring.

This investigation aimed to determine (1) the population dynamics of *D. longicaudata* on guava fruit, (2) the effects of fruit position and fruit size on fruit fly and parasitoid populations, and (3) the effects of fruit fly size on laboratory-reared parasitoids.

Materials and Methods

Study site

The study was conducted in a 3,200 m^2 guava orchard in Samphran district, Nakhon Pathom province, Central Thailand. No insecticides had been used in this orchard for one year prior to the investigation. The 150 guava trees, *Psidium guajava* (Myrtaceae), were planted in four rows and were subdivided into several block units. Each unit consisted of three guava trees. Weather data was recorded in the orchard and included max-min temperature and max-min relative humidity using a thermohygro-graph, and rainfall using a rain gauge.

Fruit collections

Fruit samples were made in each unit at high and low fruit positions (>150cm and<75cm respectively above the ground) with large and small fruit sizes (large>50gm and small <50gm). Fruit collections were made bimonthly from May 1995 through March 1997. Three fruits were randomly collected per fruit size per position in each block unit. Fruit samples were brought back to the laboratory, weighed and placed in plastic boxes (18x25x8 cm) containing sterilized sawdust as a pupation medium. Fruits were held for two weeks and then dissected to remove fruit fly larvae and pupae from the fruit. Pupae were transferred to another smaller plastic container (11x11x6 cm) with sterilized sawdust. For sample with up to 100 adult fruit flies or parasitoids, all were identified,[1,11] whereas 100 individuals per sample were identified for larger samples. Intact puparia were dissected to determine the presence or absence of parasitoids.

Parasitoid wing and ovipositor measurements

Adult parasitoid size was determined by measuring the lengths of wing and female ovipositor. The forewings of each parasitoid were removed with forceps, placed on a glass slide and covered with a cover slip. The ovipositor of each female was removed and prepared on the same slide with their wings. The length of the right forewing was measured from the base of the costa to the apical margin. The ovipositor was measured from the distal end to its base. Measurements were made using under a dissecting microscope equipped with an ocular micrometer.

Host pupa size measurement

Measurements of pupa sizes were made by placing each specimen on a glass microscope slide and measuring the length and width of each pupa using a dissecting microscope equipped with an ocular micrometer.

Host size effects on parasitoid size

A colony of *D. longicaudata* (local Thai strain) collected from a field site in Nakhon Pathom was maintained in the laboratory by rearing on *B. correcta* larvae. The larvae of *B. correcta* were allowed to develop for 4-5 days post hatch on banana; the third instar larvae were exposed to *D. longicaudata*. Host pupae were then transferred to vials (one per vial) for parasitoid emergence. Host pupa size was determined by pupa case measurement (as described above). Parasitoid size was measured (as described above) for comparison with the host size. The parasitoids and their host flies were held at 27±2°C, 70±10% RH and 12 : 12 (Light : Dark).

Statistical analysis

Descriptive statistics [mean and standard error (SE)] were used to compare the parasitoid size. A series of one-way analyses of variances was performed on wing length, ovipositor length, fruit size, fruit position, fruit number, fruit fly numbers and parasitoid numbers. Simple linear regression procedures were used to determine the linear relationship between fruit flies per fruit and humidity. The square root transformation was used on fruit flies per fruit data to linearize the relationship. A multiple regression was used to analyze the relationships between the dependent variable (parasitoid number) and the independent variables (fruit number and fruit flies per fruit). The natural log (Ln) transformation was used on parasitoid number and fruit flies per fruit data. Correlations were calculated for comparisons between ovipositor length and wing length, and among fruit number, fruit flies per fruit, parasitoids per fruit and environmental factors (e.g. temperature and humidity). These tests are fully explained by Sokal and Rohlf[12] and Steel and Torrie.[13] All analyses were performed with "Statistix".[14]

Results

D. longicaudata was the only parasitoid found in large numbers at the guava study orchard in Samphran district, Nakhon Pathom province.

A total of 5,075 *D. longicaudata* was collected from 47,124 *B. correcta* found in 3,546 guava fruits. The sex ratio of females : males was ca 4:3 (3013:2062). The wing lengths of 645 males and 694 females were measured. The mean wing length of *D. longicaudata* was 3.40±0.01 mm (Table 1). When

Table 1. Fruit (guava) number, fruit fly (*B. correcta*) number, parasitoid (*D. longicaudata*) number and mean parasitoid size (mean ± SE) from different fruit sizes and positions.

	No fruits collected	No Hosts collected	No parasitoids collected	Wing – size (mm) (no obs)		
				Male	Female	Total
Fruit size						
Large	1840	27174	2803	3.256 ± 0.013 (354)	3.595 ± 0.012 (372)	3.430 ± 0.011 (726)
Small	1706	19950	2272	3.172 ± 0.015 (291)	3.532 ± 0.014 (322)	3.361 ± 0.013 (613)
Total	3546	47124	5075	3.218 ± 0.010 (645)	3.566 ± 0.009 (694)	3.398 ± 0.008 (1339)
F	0.690	3.510	0.400	17.420	11.770	17.050
df	1,190	1,190	1,174	1, 643	1,692	1,1337
P	0.413	0.059	0.536	<0.001*	<0.001*	<0.001*
Fruit position						
High	1794	25075	2879	3.203 ± 0.013 (359)	3.568 ± 0.012 (388)	3.393 ± 0.011 (747)
Low	1752	22049	2196	3.238 ± 0.015 (286)	3.563 ± 0.014 (306)	3.406 ± 0.012 (592)
Total	3546	47124	5075	3.218 ± 0.010 (645)	3.566 ± 0.009 (694)	3.398 ± 0.008 (1339)
F	0.070	0.610	0.660	2.970	0.090	0.710
df	1,190	1,190	1,174	1,643	1, 692	1, 1337
P	0.785	0.443	0.423	0.081	0.758	0.441

* = significant difference (P < 0.001)

the wing lengths of males and females were compared, those of the females were significantly larger (F = 646.28; df = 1,1337; P < 0.001) (Table 2). The mean wing lengths of males and females were 3.22±0.01 mm and 3.57±0.01 mm respectively.

Females have a long ovipositor for laying eggs. The correlation between the ovipositor length and wing length was highly significant (r = 0.925; P < 0.001)(Table 2).

In the laboratory, the mean fruit fly pupa width and pupa length were 1.84±0.02 mm and 3.86±0.03 mm respectively (Table 3). Adult parasitoid size was highly correlated with host pupa width (r = 0.786; P < 0.001) and pupa length (r = 0.750; P < 0.001) (Fig 1). Both the parasitoid sexes were affected by host size; the female parasitoids more often emerged from larger host flies and males from smaller flies. Females tended to emerge from larger pupae than males, based on the pupa width and length (one-way ANOVA, P < 0.001) (Table 3).

The numbers of *D. longicaudata* were correlated with the abundance of *B. correcta* and guava fruit (Fig 2). Observation and analyses indicated that the number of fruit flies reared from fruit was not associated with fruit position (Table 1). The data analysis suggested that the number of fruit flies tends to be associated with fruit size, but this association could not be demonstrated with confidence (F = 3.510; df = 1, 190; P = 0.059). The parasitoid number was significantly correlated with the fruit abundance and fly abundance per fruit (Fig 2). These relationships were significant (F = 3.665; df. = 2, 98; P = 0.015; R^2=0.070). The regression equation is described by Ln (parasitoid no.) = 1.673 + 0.029 (fruit no.) + 0.238 Ln (fruit flies per fruit).

Although the parasitoid abundance was not associated with the fruit position nor the fruit size, the parasitoid size was related to fruit size. The mean wing length from large fruit and small fruit were 3.43±0.01 mm and 3.36±0.01 mm, respectively (Table 1). The differences in parasitoid wing length between large fruit and small fruit were significant using one-way ANOVA (F = 17.050; df = 1, 1337; P < 0.001). There was no significant difference in

Table 2. Mean (± SE) wing lengths and ovipositor lengths of *D. longicaudata* from guava orchard.

Month	Wing-size (mm) (no obs)		Ovipositor (mm) (no obs)
	Male	Female	
May-95	3.245 ± 0.228	3.613 ± 0.019	5.421 ± 0.038
	(124)	(118)	(118)
Jul-95	3.260 ± 0.025	3.513 ± 0.022	5.167 ± 0.045
	(104)	(124)	(122)
Sep-95	3.372 ± 0.056	3.811 ± 0.042	5.800 ± 0.105
	(10)	(21)	(20)
Nov-95	3.181 ± 0.029	3.612 ± 0.022	5.336 ± 0.043
	(97)	(126)	(126)
Jan-96	3.153 ± 0.099	3.280 ± 0.105	4.693 ± 0.172
	(9)	(9)	(9)
Mar-96	-	-	-
May-96	3.117 ± 0.020	3.429 ± 0.022	5.067 ± 0.045
	(126)	(119)	(119)
Jul-96	3.264 ± 0.019	3.612 ± 0.015	5.431 ± 0.034
	(161)	(160)	(160)
Sep-96	3.240 ± 0.072	3.673 ± 0.037	5.540 ± 0.104
	(8)	(9)	(9)
Nov-96	3.264 ± 0.118	3.609 ± 0.082	5.520 ± 0.059
	(5)	(7)	(7)
Jan-97	3.300 ± 0.000	3.600 ± 0.000	5.580 ± 0.000
	(1)	(1)	(1)
Mar-97	-	-	-
Total[a,b]	**3.218 ± 0.010**	**3.566 ± 0.009**	**5.306 ± 0.019**
	(645)	**(694)**	**(691)**

[a] = significant difference between male and female wing size ($F = 646.28$; df = 1,1337; $P<0.001$).

[b] = correlation between wing size and ovipositor length ($r = 0.925$; $P<0.001$).

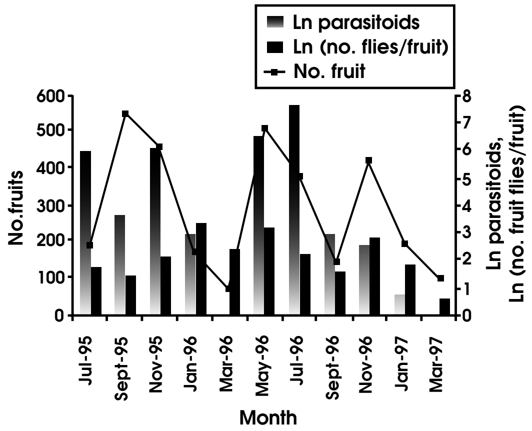

Fig 2. Variation in fruit number, fruit flies per fruit (Ln) and parasitoid number (Ln).

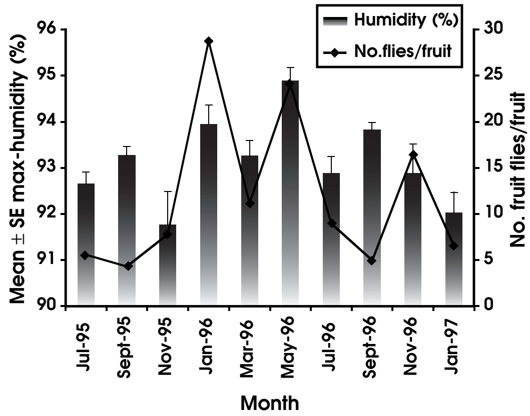

Fig 3. Variation in number of fruit flies per fruit and mean maximum humidity (%).

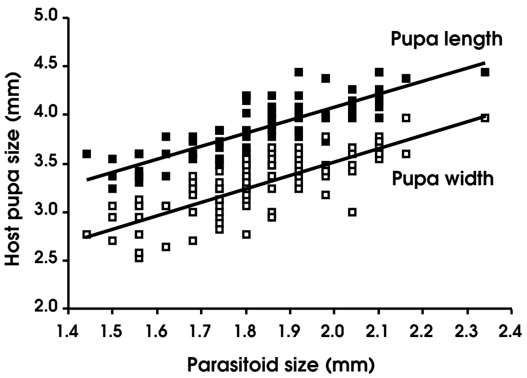

Fig 1. Relationship between adult parasitoid (*D. longicaudata*) size (mm), based on wing length, and fruit fly (*B. correcta*) size (mm), based on pupa width and pupa length.

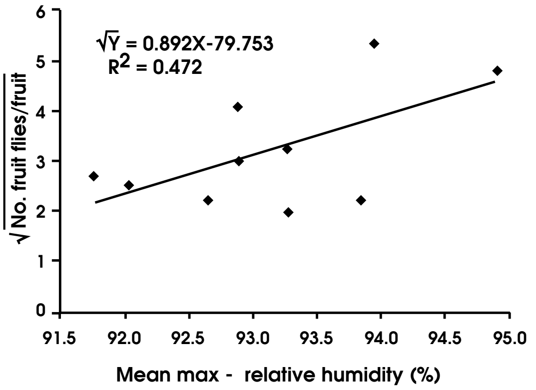

Fig 4. Relationship between number of fruit flies per fruit and mean maximum humidity (%).

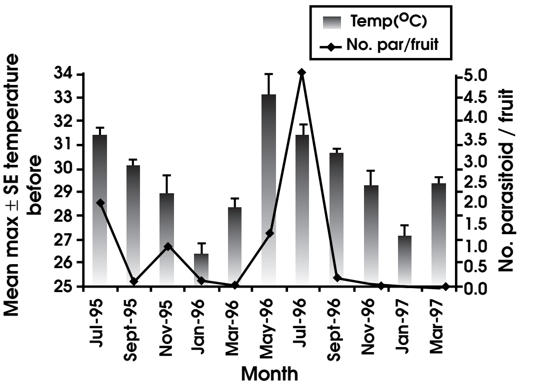

Fig 5. Variation in number of parasitoids per fruit and mean maximum temperature (°C) during the month before fruit collection.

the mean wing length of *D. longicaudata* collected from the fruit at different positions; high (>150cm) and low (<75cm) were 3.39±0.01 mm and 3.41±0.01 mm respectively (F=0.710; df = 1,1337; P = 0.441) (Table 1).

Tests on the relationship between the abundance of fruit flies and environmental factors indicated that monthly mean maximum relative humidity was important. The analysis model ($F = 8.920$; df = 1, 10; $P < 0.006$; $R^2 = 0.472$) is given by $\sqrt{\text{fruit flies per fruit}}$ = 0.892 (monthly mean max %RH) - 79.753 (Figs 3 and 4). There was a significant correlation between fruit flies per fruit and fruit abundance ($r = 0.640$; $P < 0.010$) (Fig 2). The number of parasitoids per fruit were also correlated with the mean maximum temperature during the month before fruit collection ($r = 0.530$; $P < 0.050$) (Fig 5).

Discussion

The high parasitization during periods of high host density suggests that *D. longicaudata* behaves in a density dependent manner. Very few papers have been written that document density dependent relationships between parasitoids and their hosts. The winter moth, *Operophtera brumata* (L.) in Nova Scotia has been shown to be regulated by a parasitoid.[15] Similarly, Ives[16] identified the parasitoid, *Olesicampe benefactor* Hinz, as the only density dependent factor affecting the larch sawfly, *Pristiphora erichsonii* (Hartig). It is not certain that only density dependent parasitism can be expected in host-parasitoid interactions. Density independent and even inverse density dependent host/parasitoid relations have been found.[17] Although the numbers of *D. longicaudata* correlate positively with those of its host, a perfect density dependent relationship is not apparent. The population of *D. longicaudata* was low in March (1996 and 1997) despite the high population of *B. correcta* (Fig 2). The reason for this is unknown. However, these may be caused by predators such as ants. In the dry season from November to March, the population of *D. longi-caudata* was low. This may have been caused by the habitat drying up and the host plant (guava) becoming less suitable. When the rains returned in May, *D. longicaudata* was recovered from most of the sampling units.

In general, higher humidity caused higher survival of fruit flies. The humidity was related to rainfall and was apparently responsible for the seasonal variation in parasitoid number.

Fruit number and fruit flies per fruit proved to be important factors affecting the parasitoid number. The parasitoid populations were relatively low in the dry season. Although the parasitoid number was not significantly related to the fruit position or fruit size, the parasitoid size was correlated with the fruit size. Larger fruit produced larger flies (Table 1), presumably because larger fruit provided a more suitable food source.

Parasitoid development was synchronized with that of the host. There was a strong correlation between adult parasitoid size and host pupal size (Fig 1). Heinz[18] suggested that the adult female pteromalid, *Catolaccus grandis*, developed from large sized hosts and males from small hosts. In this study, *D. longicaudata* females were produced from large hosts and males were produced from small hosts in the laboratory (Table 3). The data from field populations showed that there was a significant difference in wing length between males and females. Females are larger

Table 3. Difference in size of parasitoid females and males emerging from different pupa sizes (fruit fly size) in laboratory rearings.

Measurements	Mean size ± SE (mm) (no obs)		
	Female	Male	Total
Pupa width[a]	1.914 ± 0.030 (39)	1.783 ± 0.022 (53)	1.838 ± 0.019 (92)
Pupa length[b]	4.080 ± 0.042 (39)	3.695 ± 0.032 (53)	3.858 ± 0.032 (92)
Wing length[c]	3.443 ± 0.045 (39)	3.181 ± 0.041 (53)	3.292 ± 0.033 (92)

a,b,c = significant difference between male and female parasitoids.
a = (F=13.350; df=1,90; P<0.001)
b = (F=55.220; df=1,90; P<0.001)
c = (F=18.370; df=1,90; P<0.001)

because they take longer time to develop in the host puparia. The wing length of female parasitoids was also correlated with ovipositor length. *D. longicaudata* obtained from large host puparia had greater wing length and ovipositor length. King and Hopkins[19] suggested that adult size is usually positively correlated with adult longivity in the pteromalid, *Nasonia vitripennis*, and on various other species of parasitic wasps.[8,20,21,22] Thus, the parasitoid size may be affecting both their ability to parasitize and to contact more hosts. The ratio of female: male parasitoids (4:3) in this study suggested that female parasitoids played a critical role in producing the offsprings.

A female wasp can attack several pest flies because they are solitary parasitoids and lay one egg per host. From the field observations, *D. longicaudata* can really move between fruits and trees in search of their food, oviposition sites and shelter. The data (Fig 2) also suggest that *D. longicaudata* can recolonize almost as rapidly as its host and indicate that this parasitoid is capable of suppressing its host.

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