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Zoogeographical and Ecological Studies of *Dacus cucurbitae* (Diptera-Tephritidae) in India

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Toshiyuki Nishida

INTRODUCTION

In 1899, Coquillett described a new species of tephritid fly, *Dacus cucurbitae,* from specimens reared from cucurbits in Hawaii (Coquillett, 1899). Shortly thereafter, the occurrence of this tephritid fly, commonly known as the melon fly, was reported from India and from other countries. During 1959–60, the writer had the opportunity of studying this fly at the Government Agricultural College, Kanpur, Uttar Pradesh, India. This paper presents some of the zoogeographical and ecological studies conducted in India.

The study area included most of India, an extensive country lying between 7° and 37° North latitude. The distance between its south and north extremities is approximately 2,200 miles, and between its east and west extremities, about 1,200 miles. Geographers divide the Indian subcontinent into three regions, the Himalayas, the Indo-Gangetic Plains, and the Deccan Plateau. The mountainous Himalayan region lies at the northern extremity. Here are the sources of the Ganges, Indus, and Brahmaputra rivers. To the south of the Himalayas lie the fertile Indo-Gangetic Plains through which flow these three largest rivers of India. The triangular, peninsular portion of south India is referred to as the Deccan Plateau, which is bordered on the west by mountain ranges called the Western Ghats and on the east, by the Eastern Ghats.

The climate of India is diverse in many respects. There is, however, a certain climatic pattern common to many parts of the country because of the widespread influence of the monsoon. January to June is the season of the northeast monsoon and during this time the prevailing northeast winds blow from the inland regions of central Asia. During this period, the temperature is low and the rainfall is scant. From March to June, the temperature rises rapidly, but the rainfall continues to be scant. From June to December is the season of the southwest monsoon and, during this period, the winds shift to the southwest. The period of high rainfall and high temperature comes between June and September. From September to December, the temperature drops and the rainfall decreases.

Although India is, in many respects, because of its diverse terrain and climate, an ideal locality for the study of the ecology of *D. cucurbitae*, there is relatively little published literature on the melon fly in that country. This situation exists because of the greater economic importance of this insect in countries other than India. Among the important Indian publications are those of Srivastava (1948), Shah, Batra, and Renjhen (1948), Renjhen (1949), and Batra (1953). In addition to these, there are short notes in such publications as Proceedings of the Entomological Meetings, Pusa; Proceedings of the Indian Academy of Science; Indian Museum Notes; Indian Journal of Agricultural Science; Indian Museum Notes; and reports of the departments of agriculture of various Indian states.

The life history of *D. cucurbitae* has been studied in Hawaii (Back and Pemberton, 1914, 1917, 1918), in Formosa (Koreishi, 1937), in the Philippines (Ponce, 1937), and in India (Srivastava, 1948). Except for a generalized life cycle, no attempt will be made to give an extensive review of this subject, because it has been adequately covered by Christenson and Foote (1960). The flies lay their eggs in the tissues of the host plants. After the eggs hatch, the larvae feed and bore into the plant tissues. When fully grown, the larvae pupate in the soil. The adults, which emerge from puparia in the soil, bore their way up out of the soil. These newly emerged adults fly onto favorable nonhost plants and here feeding and mating occur. When gravid, the females move into areas where host plants are present and here they lay their eggs (Nishida and Bess, 1957).

METHODS

The results of these studies are based on field and laboratory observations. Field observations were made using the Department of Entomology and Zoology, Government Agricultural College, Kanpur, as headquarters. Laboratory studies were also conducted at the same institution, using its facilities. Although not always feasible, efforts were made to utilize materials available in India.

Upon my arrival in India, it was hoped that most of the investigations could be carried out in the vicinity of Kanpur. Preliminary observations, however, showed that it was desirable to include all of India as the study area, since it was found that *D. cucurbitae* was widely distributed throughout that country.

Field Methods

Situated in the heart of the Indo-Gangetic Plains of North India, much of the vast land surrounding my headquarters was agricultural land with villages of various sizes scattered throughout. Field trips were taken at least once a week to collect infested fruits and to make observations on the activity and behavior of *D. cucurbitae*. In addition to these frequent short trips, others of longer duration were taken to as many places as possible in order to obtain distributional data and to correlate activity with various features of the environment.

To obtain information on parasites and host plants of *D. cucurbitae*, field collections of fruits showing evidence of infestation were made. These fruits were brought to the laboratory in polyethylene bags containing sawdust, which absorbed the excess liquid from the decaying fruit. Furthermore, the sawdust was useful because, on long excursions, the maggots pupated in it, and the pupae were sifted out after reaching the laboratory. In the laboratory the infested fruits were placed in gallon-size jars with sand from the Ganges River at the bottom. Upon pupation, the pupae were separated from the sand and placed in 8-dram shell vials. Upon emergence, the number of adult fruit flies and the number of parasites were recorded.

The climatological records were obtained from Sawyer and Reichelderfer (1951), Strauss and Reichelderfer (1959), Kendrew (1953), and the Government Agricultural College, Kanpur, India.

Laboratory Methods

The adults in captivity were kept in gallon-size glass jars that are available in Indian markets at a very reasonable price. Although not very uniform in size, these handmade jars were suitable as small cages. The jars were placed in a horizontal position on a table, and the jar openings were covered with thin organdy held in place with rubber bands that had been made by cutting strips from the inner tubes of bicycle tires. Water was supplied by means of small earthen cups into which was placed a piece of absorbent cotton, which was kept always moist by adding water daily. The food, which was placed on a sheet of wax paper, consisted of cane sugar and yeast hydrolysate, a food supplement necessary for egg production (Hagen and Finney, 1950).

The method for obtaining eggs from the flies kept in captivity was similar to the one used by Keck (1951). Small, circular or oval sections approximately 2 inches in diameter were cut out of fruits. The inner soft tissues were scraped off with a kitchen teaspoon, the peripheral edges of which had been ground into a cutting edge. The rind was then placed on a 2½-inch-square glass plate with the convex inner portion of the rind down against the glass plate. To hold the rind in place, melted paraffin was placed along the edge. Punctures were made in the rind using a No. 3 insect pin. Preliminary tests showed that the rind of various cucurbit fruits, such as lauki, *Lagenaria vulgaris* Ser.; kundru, *Coccinia indica* W. and A.; ghia torai, *Luffa aegyptiaca* Mill.; arro torai, *L. acutangula* Roxb.; and parwal, *Trichosanthes diocia* Roxb., were found satisfactory. The rind of lauki was used most frequently because of its availability even during the winter months.

After exposing the prepared rind to the adults, eggs were laid, and these were then brushed off from the inner surface of the rind. The eggs were placed on black moist paper in petri dishes, and upon hatching, the young larvae were transferred into the rearing medium.

The rearing of larvae presented a difficulty because of the lack of refrigeration facilities for storing the media. A series of tests was conducted in an effort to rear the larvae in media that did not require fresh fruits. Because of the availability of a large variety of dried legumes and other seeds in India, tests were made to determine whether these materials could be utilized as rearing media. Ground dried seeds, of *Cucumis* sp.; grams, *Phaseolus* spp.; and pulses, *Vicia* spp., *Pisum* sp., and *Cajanus indicus* Spreng, were tried. Although it was possible to rear larvae in these media, the mortality rate was very high, apparently due to rapid fermentation of the paste made with the dried seeds. Thus, all larva rearing was carried out using coarsely grated fresh lauki fruit, even though it was not always convenient to purchase fresh fruits whenever they were needed. Pant, Ghai, and Chawla (1959) have reported on an unfortified rice medium for the rearing of *D. cucurbitae*. However, this medium was not tried, because the publication did not appear until about the time of my departure from India.

The containers used in rearing the larvae were small, earthen, handmade cups approximately 2½ inches in diameter and 2 inches deep. They were placed in wide-mouthed glass jars which contained a layer of Ganges River sand on the bottom. When larval development was completed, the pupae were collected and placed in 8-dram shell vials containing sand. Upon emergence, the adults were transferred into the gallon-size glass jars.

ZOOGEOGRAPHICAL CONSIDERATIONS

It is more than 60 years since *D. cucurbitae*, the melon fly, was first described by Coquillett (1899). During this period, a considerable amount of information has appeared in various periodicals. This information has been extremely valuable in determining distributional patterns and in elucidating some of our ideas on this fly's origin.

Distribution

The presently known world distribution of *D. cucurbitae*, as shown in figure 1, reveals that its distribution is not extensive. This world distribution includes India, Burma, Malaya, the Philippines, southern China, Formosa, Okinawa and nearby islands, Kenya, Mauritius, Saipan, Guam, and Hawaii. This pattern clearly indicates that *D. cucurbitae* is a component of the fauna of the Oriental Region.

Figure 1 also indicates that the distribution of *D. cucurbitae* is restricted to the area lying between 35° North latitude and 22° South latitude. Such a distribution pattern shows also that this insect is adapted to tropical, subtropical, and, to a certain extent, temperate conditions.

The roughly elliptical shape of the distribution pattern shown in figure 1 is of interest from an ecological viewpoint. If dispersal occurs at random in a uniform environment, the pattern of distribution will be circular. However, this tendency is usually altered due to climatic differences along

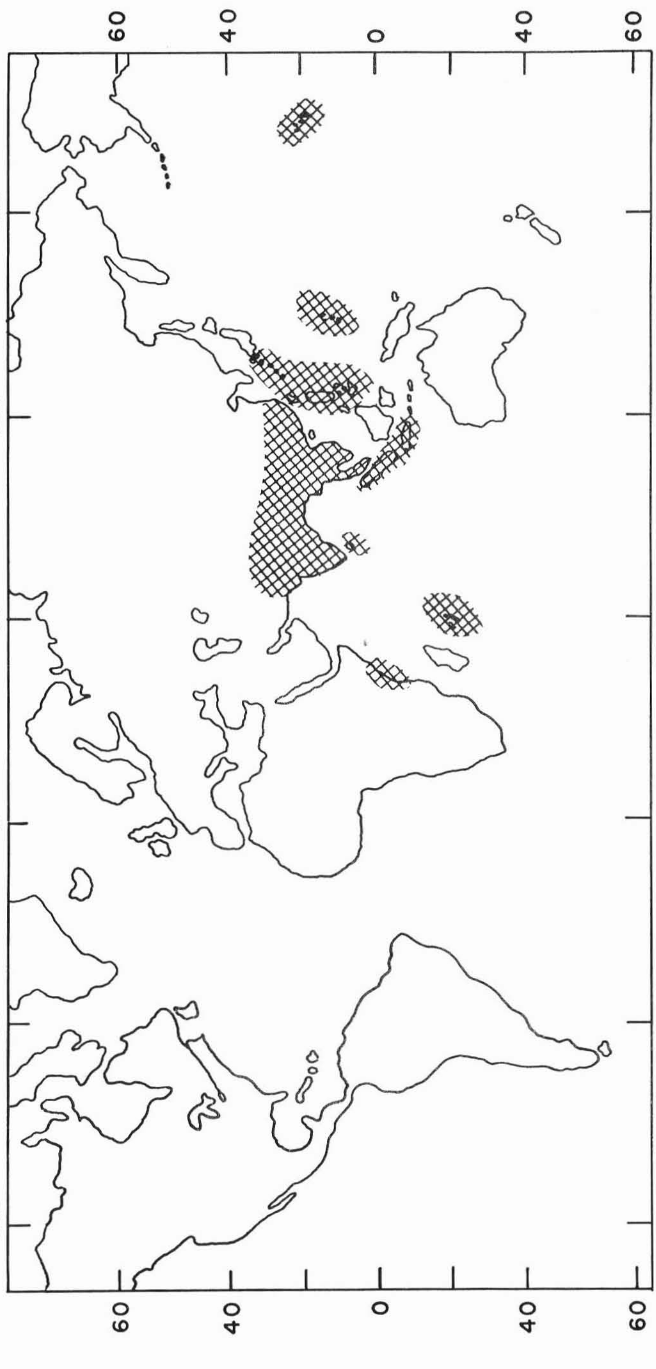

FIGURE 1. The world distribution of *D. cucurbitae*.

the peripheral area. Because climatic changes are of greater magnitude latitudinally than longitudinally, the pattern of distribution tends to assume an oval or elliptical shape. This tendency is clearly indicated in the distribution of *D. cucurbitae.*

The northern and southern dispersal of *D. cucurbitae* has been hindered by certain ecological barriers. From the elliptical distribution pattern, it is evident that the barrier to northward or southward dispersal is associated with climatic factors. Studies on the effects of temperature on the various life stages of this insect indicate that low temperature is one of the important barriers to northward and southward dispersal (Koidsumi, 1931, 1933; Messenger and Flitters, 1954, 1958).

There are, without doubt, temporary establishments of *D. cucurbitae* occurring along the northern and southern peripheral areas. Hill (1915) reported that the melon fly was collected in northern Australia, but it has not been found in Australia since that report. According to Back and Pemberton (1917), this fly was reared by Compere from fruits collected in Nagasaki, Japan; but it appears that the fly has not become established in Japan, for Shiraki (1933) does not list it in his work on the Trypetidae of the Japanese Empire. Temporary establishment has also occurred at least once in California (Maehler, 1957).

Original Home

The original home of *D. cucurbitae* has long been a subject of speculation, for it was recognized early that even though this insect was first described from specimens collected in Hawaii, Hawaii was not its native home. In 1902, Perkins speculated that the original home of this insect was either Japan or China. According to Froggatt (1909), Bezzi (1913), and Illingworth (1913), its native home was India. Severin *et al.* (1914) stated that Compere was of the opinion that *D. cucurbitae* was native to the Philippines. The Indo-Malayan region was also mentioned as a possible locality by Back and Pemberton (1918). On the assumption that the distribution patterns have not changed in the past, the original home must lie somewhere within the limits of the present distribution. The problem is to pinpoint the most likely areas on the basis of available evidence. An attempt will be made to present evidence which indicates that south India is the native home of this insect. This evidence is based on host plant specificity and parasite complex.

The close affinity of *D. cucurbitae* to its host plants in the family Cucurbitaceae is well known throughout its distribution. Such close affinity indicates that this insect is native to areas where the Cucurbitaceae have originated. According to Vavilov (1950), the Cucurbitaceae had multiple centers of origin. As shown in figure 2, the distribution of the approximate centers of origin of this family, indicate that the distribution of the centers of origin of the Cucurbitaceae is much wider than that of *D. cucurbitae.* However, on the basis of this information it is possible to eliminate areas where *D. cucurbitae* does not occur, for, obviously, such areas cannot be

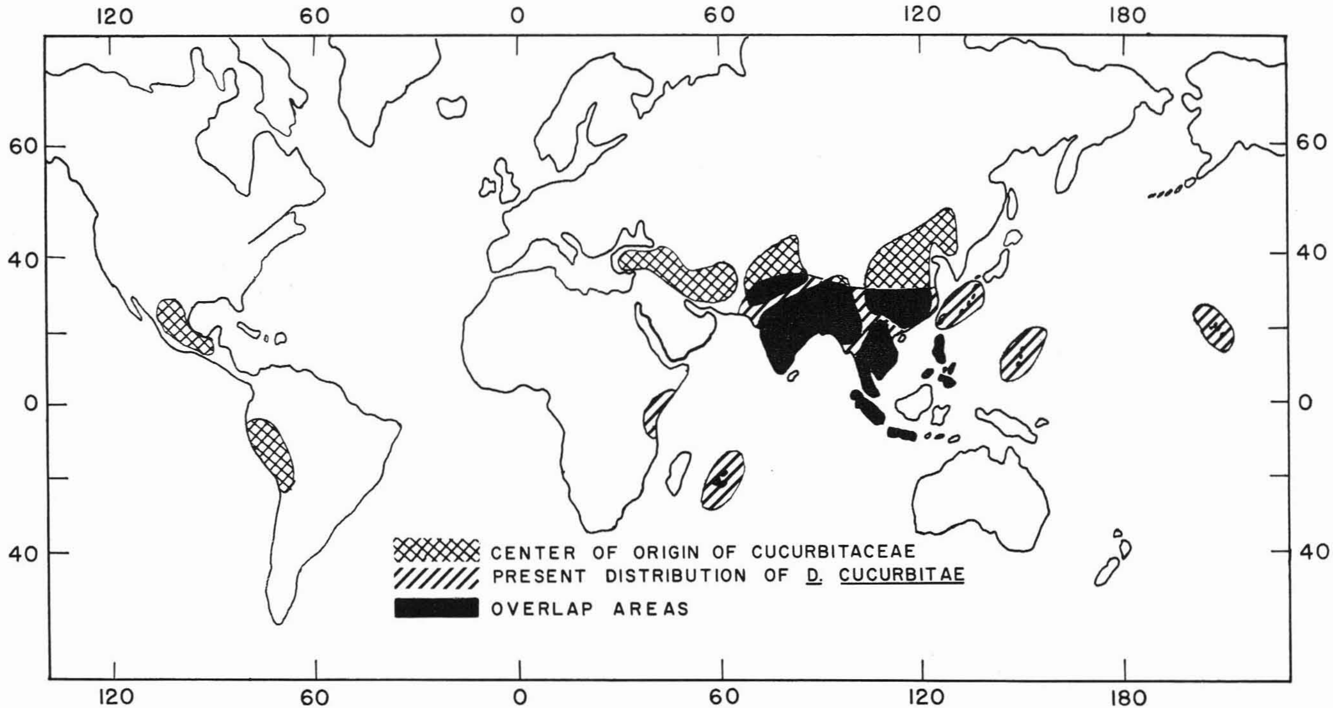

FIGURE 2. The distribution of the origins of the botanical family Cucurbitaceae in relation to that of *D. cucurbitae*. (Distribution data of Cucurbitaceae after Vavilov, 1950.)

the original home. It seems that the most likely areas must lie in the tropical regions of India, Burma, Thailand, Malaya, and, possibly, south China.

In order to narrow down further the most likely areas where the native home might be located, data on the parasite complex of this species were compiled. This procedure was taken on the assumption that the fauna of natural enemies of a given species is richest at the center of origin. The data presented in table 1 indicate that the number of species of natural enemies of the various species of *Dacus* is highest in the area extending from India to Malaya. The data also show that the number of parasite species of *D. cucurbitae* is highest in India. These facts show that *D. cucurbitae* as well as other species in the genus *Dacus* had their origin in India.

TABLE 1. Distribution of number of parasites of *Dacus* spp. compared with that of parasites of *Dacus cucurbitae* Coq.

	NUMBER OF PARASITES OF VARIOUS *Dacus* SPP.	NUMBER OF PARASITES OF *D. cucurbitae*
India	16	5
Thailand	6	0
Malaya	15	1
China	2	0
Formosa	6	0
Java	1	0
Borneo	2	1
Philippines	4	0
Total	52	7

From our current knowledge of *D. cucurbitae*, it seems most probable that tropical south India is its home, for a number of reasons. The biological characteristics of this species are not like those of temperate zone species. For example, there is no diapause stage (which some tephritids of the temperate areas possess). Experimentally, it has been shown that, under temperate conditions, *D. cucurbitae* cannot complete its biological development (Messenger and Flitters, 1954). Furthermore, with the exception of the parasite *Opius watersi* Fullaway, which undergoes diapause (Marucci, 1952), all other parasites do not undergo diapause and therefore their distribution is restricted to tropical areas. The known world distribution of *D. cucurbitae*, as shown in figure 1, also indicates that it is a tropical species.

According to geologists, the tropical peninsular portion of south India, known today as the Deccan Plateau, was once a large island and was separated from the Himalayas by a shallow sea during the Tertiary period. On the basis of the evidence presented, it seems that *D. cucurbitae* and its relatives originated on this ancient island.

ECOLOGICAL CONSIDERATIONS

The literature on the ecology of *D. cucurbitae* in India is very scant and fragmentary. The present contribution, which represents the results of my studies during 1959–60, should be regarded as an introduction to the study of the ecology of this tephritid fruit fly in India, where the ecosystem is, in many areas, still devoid of the drastic disturbing influences of modern agricultural practices.

Field observations conducted during my sojourn indicated that the general level of abundance of *D. cucurbitae* in India was lower than the level in Hawaii. After my experiences with this fly in Hawaii, it was indeed a surprise to find that various cucurbits such as watermelons, cantaloupes, and gourds were being grown in India without any control measures. Extensive surveys showed that the damage caused by this insect was slight, most of it occurring in localized areas, particularly near villages and cities. Lawrence (1950) also reported that the abundance of this insect was so low that it was not as serious a pest in India as it was in other countries. Even though *D. cucurbitae* was not abundant, there still appeared to be a general increase in abundance throughout the year in the Indo-Gangetic Plains. The population was lowest from December to March; then it began building up in April and reached a peak during July to September. During this latter period, infested wild and cultivated fruits were commonly found in the field and also in the vegetable markets where produce susceptible to attack was sold. Furthermore, the adults were seen perched on the lower surface of the leaves of such plants as castor bean, *Ricinus communis* L.; guava, *Psidium guajava* L.; and citrus varieties. The population began to decline in October, and, by January, the adults had disappeared from their perching sites. Coinciding with the disappearance of the adults, infested fruits became very scarce.

Physical Environment and Activity

Field surveys and information obtained from the literature indicated that *D. cucurbitae* is widely distributed throughout India under extremely diverse conditions. Although not the only important factors, temperature and rainfall are considered in this discussion because they determine to a large degree, either directly or indirectly, the gross features of the environment.

Temperature and rainfall data taken along a transect extending from south to north India vary considerably (fig. 3). In south India, monthly temperatures vary little throughout the year, because of the maritime influence. As one proceeds northward, the monthly variation in temperature throughout the year becomes progressively greater, with higher summer

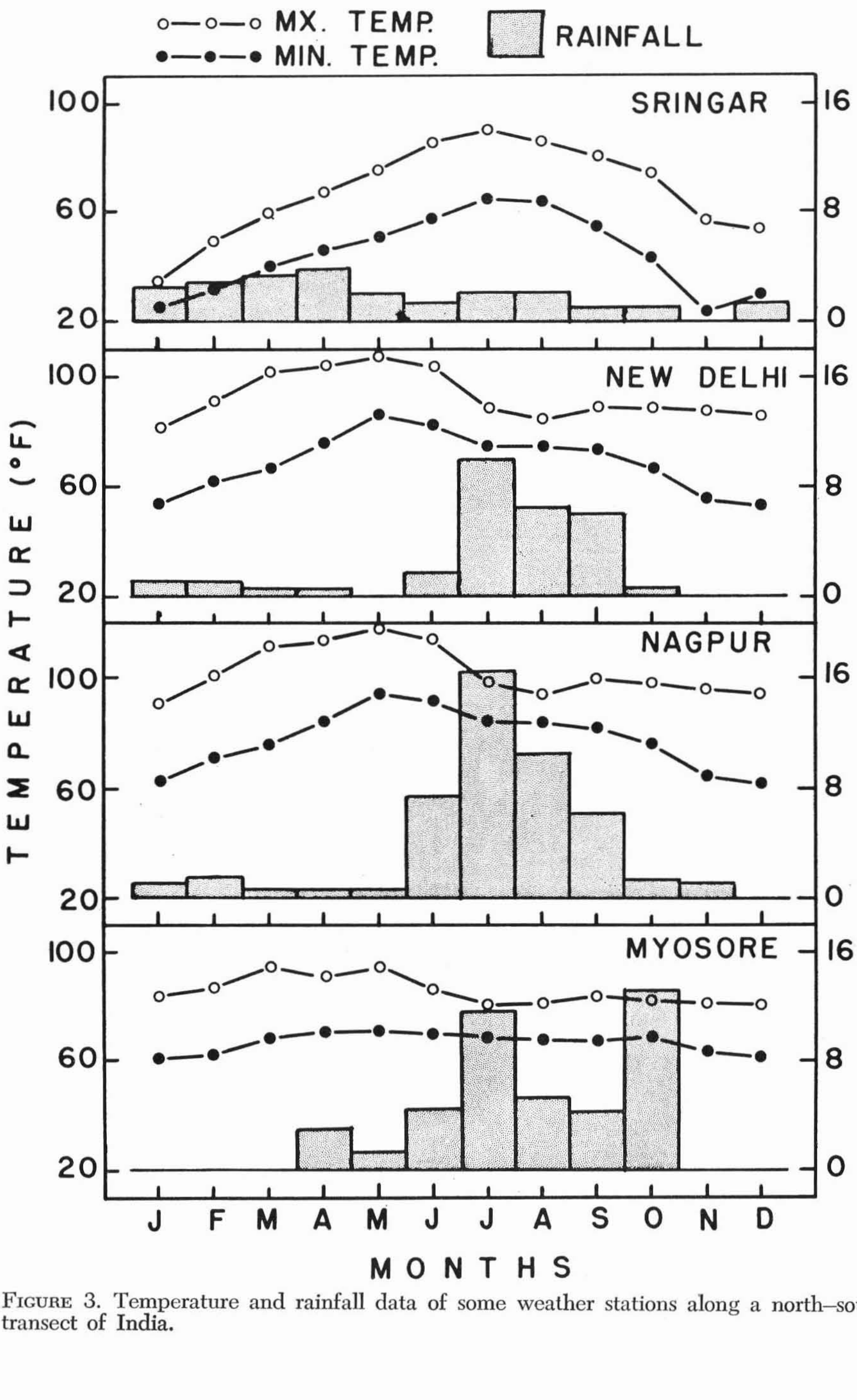

FIGURE 3. Temperature and rainfall data of some weather stations along a north–south transect of India.

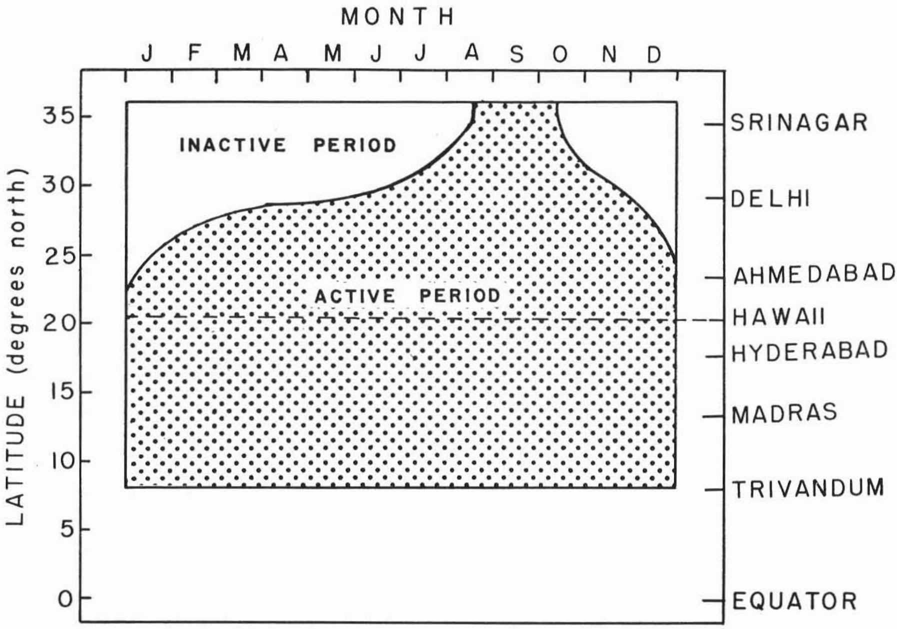

FIGURE 4. Seasonal reproductive activity of *D. cucurbitae* at various latitudes in India.

temperatures and lower winter temperatures than in the southern regions. In other words, the annual temperature extremes become increasingly greater in the northern areas.

The rainfall distribution data shown in figure 3 indicate that, with the exception of Srinagar (a city), the general rainfall distribution patterns were similar, evidently because of the seasonal activity of the Indian monsoon. Throughout most of India, the rainfall is generally high during July to October. Srinagar, situated in the northernmost area where the climate is not influenced by the monsoon, was an exception, for here the highest rainfall occurred during January to March.

The seasonal changes in the reproductive activity of *D. cucurbitae* appeared to be correlated with differences in climatic factors at various latitudes (fig. 4). In the southern latitudes, under conditions of favorable temperatures, *D. cucurbitae* is active throughout the year. But, in the northern latitudes, its period of activity becomes shorter due to the decrease in the period of favorable environmental conditions.

For purposes of comparing the diversity of conditions between India and Hawaii, a composite climatograph was constructed (fig. 5). This climatograph was constructed using the temperature and rainfall data of 25 stations from India, and 25 from Hawaii. The data for each country were plotted and then lines demarking the extremes were drawn.

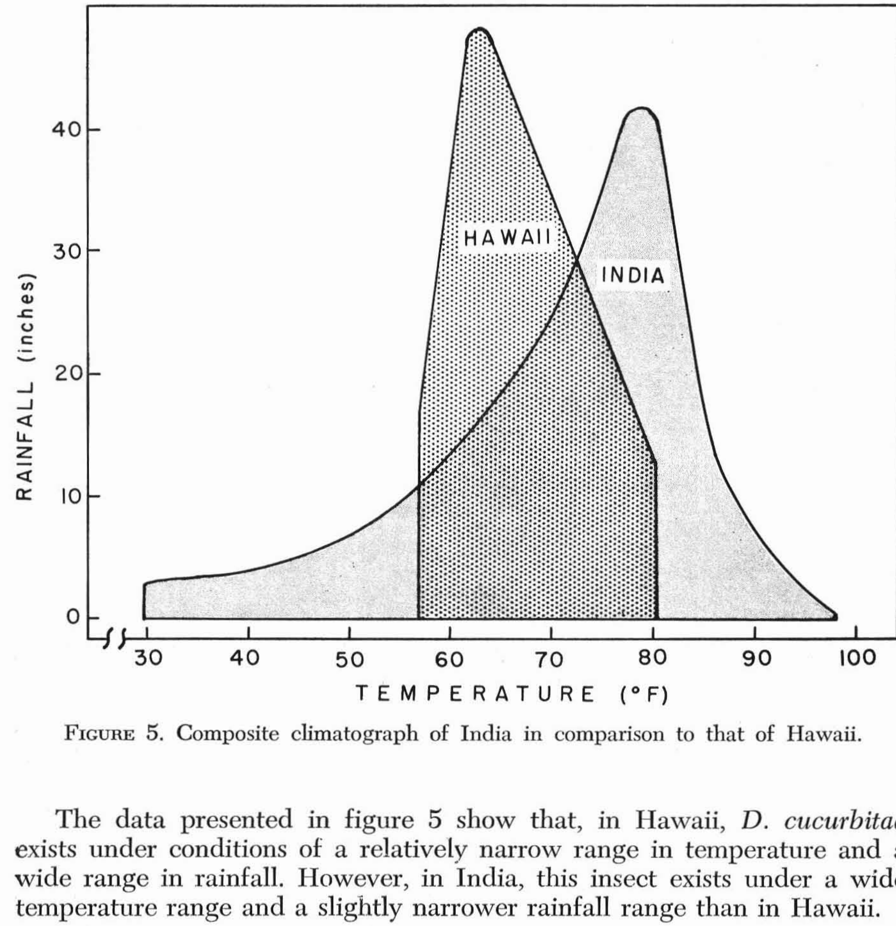

FIGURE 5. Composite climatograph of India in comparison to that of Hawaii.

The data presented in figure 5 show that, in Hawaii, *D. cucurbitae* exists under conditions of a relatively narrow range in temperature and a wide range in rainfall. However, in India, this insect exists under a wide temperature range and a slightly narrower rainfall range than in Hawaii.

Overwintering Behavior

The tolerance of *D. cucurbitae* to various temperatures has been investigated by workers in Hawaii (Keck, 1951; Messenger and Flitters, 1954, 1958) and in Formosa (Koidsumi, 1931, 1933; Shibata, 1936). The results of the work of these workers are not always in agreement because of the inherent difficulty in determining when development ceased and also probably because of the genetically different individuals that were used. It is possible, however, on the basis of these results, to obtain a general picture as to the approximate temperature range in which development is possible. The lowest and highest temperature range at which the development of any of the life stages is possible is between 50° and 100° F. Temperature ranges beyond these extremes are of common occurrence in many parts of India where *D. cucurbitae* occurs.

The adults of *D. cucurbitae* were reproductively inactive during the winter in north India. In the Indo-Gangetic Plains of north India, the adults were active from about March to November. However, from December to March of the following year, no individuals were observed in the field even though host fruits such as lauki (*Lagenaria vulgaris*) and tomatoes (*Lycopersicon esculentum*) were present.

These observations led to a study of the overwintering habits. There appears to be a lack of agreement among Indian entomologists as to the stage in which this insect overwinters. Some have speculated that the fly overwinters as pupae in debris, while others believe that the fly overwinters as adults.

In an effort to answer this question, field observations were conducted throughout the winter. These observations showed that the adult stage was the most resistant to winter conditions. Immature stages were not found during the winter, but the adults were noted under the leaves of favorable plants. When the temperature dropped below 58° F., the adults became inactive and unable to fly. Parenthetically, these observations corroborated my previous work in Hawaii which indicated that, on the slopes of Haleakala at an elevation of 3,500 feet, the adults clustered under plant leaves when the temperature dropped below 60° F. In the city of Peshawar in Pakistan, Shah, Batra, and Renjhen (1948) also reported that, at temperatures as low as 29° F., the adults overwinter under the folds of various leaves.

Ecologists classify insect development on the basis of annual developmental cycles. The continuous development is called homodynamic and the discontinuous, heterodynamic (Uvarov, 1931). My laboratory and field studies showed that in south India the development of *D. cucurbitae* is homodynamic, but that it is heterodynamic in the north. Heterodynamic development occurs in the north because development is arrested during winter. However, this arrested development cannot be considered true hibernation since the adults do not undergo complete inactivity. Thus, the term "partial" or "quasi-hibernation" appears appropriate for this type of overwinter behavior.

The zones, with the respective types of development, are presented diagrammatically in figure 6. This figure represents a transect along the 77° longitude extending from the southern tip of India to Kashmir—the south to north limits of the distribution of *D. cucurbitae*. From the figure presented, it may be noted that south of 25° North latitude, the development is homodynamic. However, between 25° to 34° North latitude, the development is heterodynamic, for in this zone *D. cucurbitae* undergoes a state of quasi-hibernation. In the areas north of this zone, *D. cucurbitae* does not occur at all. Individuals which sometimes are present there during the favorable season are most likely migrants from the southern areas. The last two zones are the peripheral or the marginal areas; these are the transition areas between favorable and unfavorable environments.

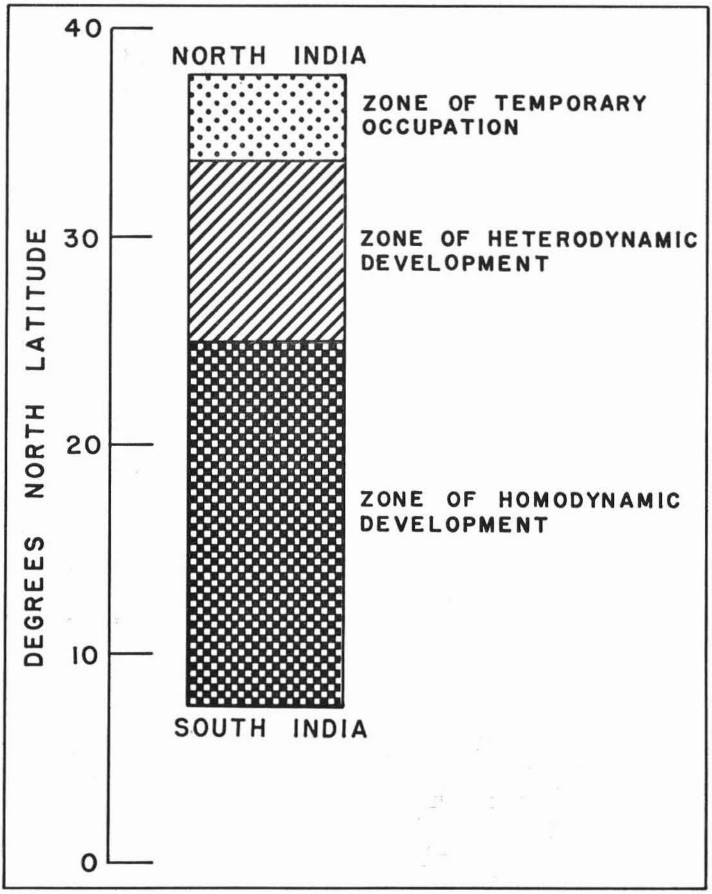

FIGURE 6. Homodynamic and heterodynamic zones of India.

Fecundity in Summer and Winter

Because of the wide range between summer and winter temperatures, particularly in north India, studies on the fecundity of *D. cucurbitae* were conducted, at Kanpur, India, during these two seasons. The general procedure consisted of exposing adult flies to the prevailing out-of-door temperatures and recording the number of eggs laid. The food for the flies consisted of sugar, water, and yeast hydrolysate, the latter a product of Marvin R. Thompson Company, Stamford, Connecticut. The beneficial effect of yeast hydrolysate on the fecundity of fruit flies in Hawaii has been reported by Hagen and Finney (1950). The principal constituents of this product are amino acids, polypeptides, and vitamin B complex.

The summer experiments were conducted during August and September, 1959, when the temperature ranged from 24.1° to 31.4° C. Four groups of flies, each composed of five females and five males, were placed near an open window where they were exposed to the prevailing temperatures. Two of the groups of flies were fed sugar and water, and the remaining two, yeast hydrolysate, in addition to the water and sugar. The number of eggs laid by the flies in each of the groups was determined by exposing fruit sections of lauki (*Lagenaria vulgaris*) for 4 hours and counting the number of eggs laid.

The data obtained are presented in figure 7. They show that the flies which had been fed yeast hydrolysate began laying eggs about 8 days after emergence. In contrast, no eggs were laid by the flies that were fed only sugar and water. These results are in agreement with the findings in Hawaii by Hagen and Finney (1950).

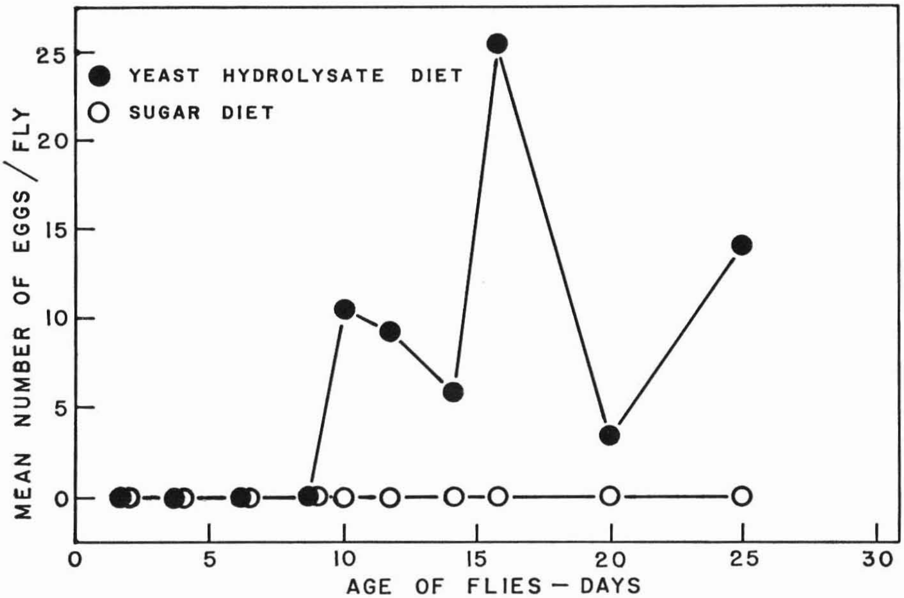

FIGURE 7. The fecundity of *D. cucurbitae* under summer conditions of the Indo-Gangetic Plains.

A comparison of the data obtained in India with those obtained in Hawaii shows the number of eggs laid by *D. cucurbitae* in India was lower than the number usually laid by this species in Hawaii. The cause of this low fecundity was not apparent from this study. Perhaps, *D. cucurbitae* of north India represents strains that are inherently of low fecundity. It is also possible that the high temperatures that prevailed during this period had an adverse effect on fecundity. That temperature did have an adverse effect was evidenced by the shortened life expectancy of many of the flies in captivity.

A similar study was conducted under winter conditions during November to March at a time when the temperature ranged from 7° to 25° C. Four lots of flies, each with an initial number of 20 nongravid females and 20 males, were exposed to the prevailing out-of-door temperatures. Two lots were fed sugar and water, and the remaining two, yeast hydrolysate in addition to sugar and water. At various intervals, samples consisting of two females were taken from each lot of flies. The individuals were killed and ovaries and oviducts were dissected out. The ovaries were stained with eosin, mounted in balsam, and measured with an ocular micrometer. In expressing the size of the ovary, either volumetric or weight units are, no doubt, most accurate, but in this study the width and length measurements were used as an index of size. It was felt that this index would serve the purpose, as this study was concerned with relative changes in the ovaries rather than with absolute size.

The data obtained indicated that the rate of growth of the ovaries was exceedingly low under winter conditions, and that the ovaries failed to develop completely even among flies fed on yeast hydrolysate (fig. 8). Furthermore, the data showed no significant differences in the size of the ovaries between flies fed yeast hydrolysate and those that were not fed this proteinaceous diet. The mean length and the mean width of ovaries

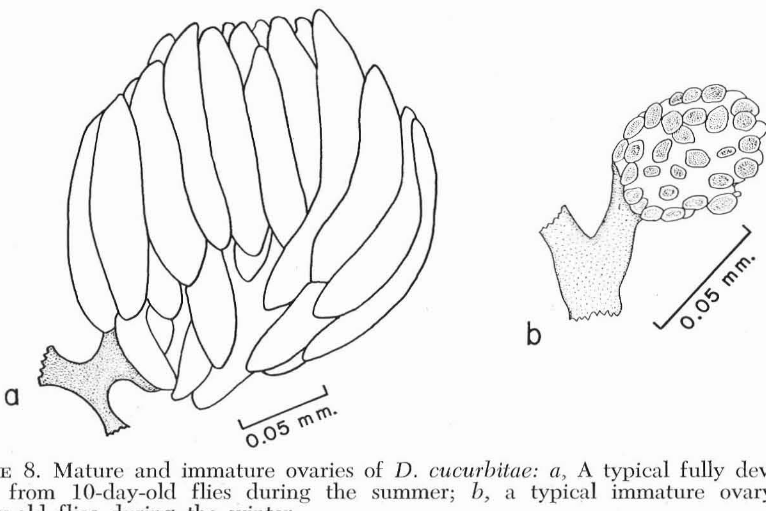

FIGURE 8. Mature and immature ovaries of *D. cucurbitae*: *a*, A typical fully developed ovary from 10-day-old flies during the summer; *b*, a typical immature ovary from 30-day-old flies during the winter.

of flies fed yeast hydrolysate were 0.04 ± 0.001 mm. and 0.03 ± 0.006 mm., while those of flies fed on sugar were 0.04 ± 0.001 mm. and 0.03 ± 0.001 mm., respectively. This lack of difference in the size of ovaries between yeast hydrolysate-fed flies and sugar-fed flies indicates that the flies did not feed under winter conditions.

These studies were conducted using initially nongravid flies. Other studies simultaneously conducted showed that gravid individuals did lay a few eggs in the middle of winter when the day temperature was favorable for short periods. However, the eggs failed to hatch, due either to low temperature or to the lack of fertilization because of low evening temperatures that were not conducive to mating.

These observations indicate that winter conditions of the Indo-Gangetic Plains of India are not lethal to the adults. The main effect of winter is the suppression of ovarian development.

Habitat and Host Relations

The habitat of *D. cucurbitae* in India is similar to that in Hawaii. In general, this insect frequently occurs in cultivated areas where host plants and other succulent nonhost plants, which are suitable perching sites for the adults, are found. It also occurs in the wilds where noncultivated hosts and other suitable nonhost plants are present. Host plants and nonhost plants on which the adults can perch were the important components of its habitat wherever *D. cucurbitae* was found.

Changes in area of the habitat, which are correlated with changes in climatic factors, were observed. During July to September under conditions of adequate rainfall, there were extensive areas suitable for *D. cucurbitae.* However, during the dry hot periods of April to June, a general contraction of the habitat occurred. This was brought about by the drying out of the shallow-rooted herbaceous plants. Furthermore, the destruction of the vegetation, during this period of food shortage, by the feeding and trampling of cattle and other grazing animals, was an important factor in the contraction of the habitat.

The contraction of the habitat has an adverse effect on the reproduction of *D. cucurbitae.* Host plants and the plants on which the adults perch become separated; thus, the females must travel considerable distances to get to the host plants. However, during the wet season, host plants and perching plants are close together, and the situation is conducive to reproduction.

In general, the habitat of *D. cucurbitae* in India, although similar in regard to its basic components to that of other countries, is not as favorable as it is in Hawaii. India is an overpopulated country and, therefore, because of the resultant population pressure, every parcel of land has been exploited either by man, cattle, buffalo, sheep, horses, or goats. This situation, has no doubt had a marked effect on the vegetation of that country. Because of these factors as well as the climatic factors, a large portion

TABLE 2. Host plants of *D. cucurbitae* and their fruiting cycle in the Indo-Gangetic Plains

HOST PLANTS	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Cucurbitaceae												
Arro torai (*Luffa acutangula* Roxb.)					X	X	X	X	X			
Cantaloupe (*Cucumis melo* L.)				X	X	X	X					
Chachenda (*Trichosanthes anguina* L.)						X	X	X	X			
Cheechera (*T. cucumerina* L.)					X	X	X	X	X	X	X	
Cucumber (*Cucumis sativa* L.)						X	X	X	X	X		
Chia torai (*Luffa aegyptiaca* Mill.)					X	X	X	X	X			
Kakri (*Cucumis utilissimus* Roxb.)				X	X	X	X	X				
Karela (*Momordica charantia* L.)			X	X	X	X	X	X	X			
Kundru (*Coccinia indica* W. & A.)					X	X	X	X	X	X		
Lauki (*Lagenaria vulgaris* Ser.)			X	X	X	X	X	X	X	X	X	X
Parwal (*Trichosanthes diocia* Roxb.)					X	X	X	X	X	X	X	
Petha (*Benincasa cerifera* Sari.)								X	X	X	X	X
Phut (*Cucurbita maxima* Duch.)								X	X	X	X	
Pumpkin (*Cucumis pepo* L.)				X	X	X	X	X				
Tinda (*Citrullus fistulosus* Stock.)					X	X	X	X	X	X		
Torai (*Luffa cylindrica* L.)					X	X	X	X	X			
Watermelon (*Citrullus vulgaris* Schrad.)				X	X	X	X					
Solanaceae												
Tomato (*Lycopersicon esculentum* Mill.)	X	X	X	X					X	X	X	X

of India now has a savannah-type of vegetation—a vegetation that is not suitable to *D. cucurbitae.*

The common host plants of *D. cucurbitae* in the Indo-Gangetic Plains and the approximate fruiting season for each are given in table 2. This table shows that, with the exception of tomatoes, all of the hosts are in the family Cucurbitaceae, an observation that has also been made in Hawaii as well as in other countries. The host list given in table 2 represents some of the common host plants in India. Without doubt, further studies would reveal a considerably larger host list than the one presented in view of the botanical work of Chakravarty, which shows that India has one of the richest cucurbit flora in the world (Chakravarty, 1946). According to Chakravarty (1959), there are 108 species of cucurbits occurring in India and of these 38, or 35 percent, are endemic.

The availability of various hosts to *D. cucurbitae* throughout the year is shown in table 2 and figure 9. It is clear that host fruits are available throughout the year in most parts of India. However, the number of species fruiting is highest during May to September, and lowest during December to March.

Although the association of *D. cucurbitae* and its host plants in the family Cucurbitaceae is close, there is a great difference between the insect and host plants in the tolerance to environmental conditions. This

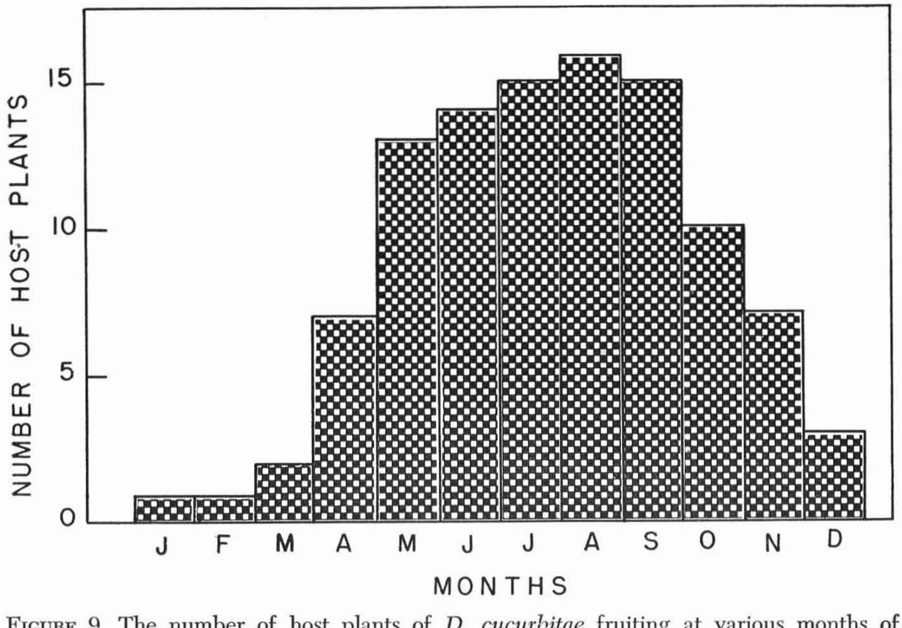

FIGURE 9. The number of host plants of *D. cucurbitae* fruiting at various months of the year in the Indo-Gangetic Plains.

difference is indicated by the occurrence of some cucurbits in north India in winter, when *D. cucurbitae* is not active. This difference also becomes evident when one considers the world distribution of the Cucurbitaceae in relation to *D. cucurbitae*. The Cucurbitaceae is a large plant family whose distribution ranges from tropical to temperate regions of the world (Chakravarty, 1959). The distribution of the insect, a tropical species, ceases, however, somewhere between the subtropical and temperate zones. The importance of establishing this imaginary boundary has long been recognized, and the work of Messenger and Flitters (1954) was concerned with this aspect of the problem.

Natural Enemies

Our knowledge of the natural enemies of *D. cucurbitae* in India is based on the work of many entomologists. British and Indian workers have made valuable observations for many years. The foreign exploration in India and other areas, made by the Hawaii Board of Agriculture and Forestry during 1915 to 1916 (Clausen, 1956), has also contributed to our knowledge on this subject. The most thorough search for natural enemies in India was one undertaken when the Oriental fruit fly, *Dacus dorsalis* Hendel, was discovered in Hawaii. This tremendous undertaking was carried out jointly by various agencies (Carter, 1950; Clancy, *et al.*, 1952).

One of the objectives of the present investigation was to study the activity of the various parasites of *D. cucurbitae*. Unfortunately, parasites were very scarce in north India. Over 5,000 larvae were sampled from field-collected fruits, as well as from those purchased in the vegetable markets. The only species reared was *Opius fletcheri* Silvestri, a braconid introduced into Hawaii in 1916 (Fullaway, 1916). In north India the parasitization by this species did not exceed 3 percent. This low incidence of parasitization in north India was also reported by Chaturvedi (1947), who found that the parasitization by *O. fletcheri* never exceeded 4.5 percent.

In addition to *O. fletcheri*, there are other parasites that are known to attack *D. cucurbitae* in India. These are *Opius watersi* Fullaway (Fullaway, 1951); *Syntomosphyrum indicum* Silvestri; *Spalangia* sp. (Fletcher, 1917); *Ipobracon* sp. (Ayyar, 1910); and *Dirhinus* sp. (Clancy *et al.*, 1952).

The reason for the low incidence of parasitization in north India is not clear. Field observations indicate that unfavorable climate is one of the important factors. North India is a marginal area for *D. cucurbitae* as well as for its parasites. The overwintering in the adult stage is not conducive to the survival of the parasites which attack the immature stages of their host. *Opius watersi* is, evidently, the only parasite adapted to north Indian conditions, for it undergoes diapause during the winter months (Marucci, 1952). But even though it appears to be adapted to northern conditions, this parasite was not abundant in north India.

DISCUSSION

The distribution of *D. cucurbitae* in India extends from the southern tip to the northernmost boundaries. The south to north distribution is, therefore, larger than that in any other single country in the world. Here, the natural population of *D. cucurbitae* is found in tropical, subtropical, and, to a certain extent, temperate latitudes. Thus, India is without doubt one of the most interesting areas to study the zoogeography and ecology of *D. cucurbitae* under natural conditions.

The occurrence of *D. cucurbitae* in Srinagar, 35° North latitude, represents the northernmost distribution of this insect. It is not known, however, whether or not it overwinters at this latitude. The northernmost area where *D. cucurbitae* is known to overwinter is in Peshawar, West Pakistan, about 200 miles southwest of Srinagar. In Peshawar this insect has been observed to overwinter as adults at temperatures as low as 29° F. (Shah, Batra, and Renjhen, 1948). It is possible that migration into Kashmir Valley occurs annually from Peshawar; however, further investigations are necessary before final conclusions can be drawn.

The dispersal of *D. cucurbitae* from south India, its original home, to the northern areas must have been a gradual process. In some respects, this northward dispersal does not seem difficult because of the contiguous land mass and the wide distribution of the fly's host plants. Man, no doubt, played an important role in hastening this process by transporting infested materials from one place to another. In other respects, there must have been climatic barriers because of the changes that occur with latitude. This penetration of these ecologic barriers must have been a gradual process, one which involved the development of strains adapted to northern conditions—in a manner similar to that of *Dacus tryoni* in Australia (Andrewartha and Birch, 1960).

The general level of abundance of *D. cucurbitae* was found to be much lower in India than in Hawaii. Even though quantitative evidence is lacking, it might be desirable to discuss some of the possible factors which influence the population in India. It must be realized that *D. cucurbitae* in India is only a small component of a complex ecosystem and that a multitude of interacting factors are involved.

Natural enemies, no doubt, play an important role in keeping the population down even though the percentage of parasitization is lower than that in Hawaii. The occurrence of a number of species of parasites in spite of the low host density is remarkable.

The changing characteristics of the habitat are also an important factor. The habitat can support a moderately high population only for a short duration during the wet season which occurs during July to September. During this time host fruits are abundant. Adult food in the form of honeydew from homopterous insects and glandular secretions from various plants is also abundant. These plants also serve as sheltering sites where the adults are protected against sun, wind, and rain. However, these favorable conditions do not last very long, for with the onset of the dry periods most of the favorable plants die from drought. Furthermore, due to food shortage, much of the habitat is destroyed by foraging animals including cattle, buffaloes, sheep, goats, and horses.

Another important consideration is the unhealthy structure of the ecosystem. India, being a land of scarcity, is a land where the number of primary producers is small in relation to the number of consumers. Approximately 80 percent of the people are engaged in agricultural production; yet, there is a shortage of food. Food is also scarce for animals such as cattle, buffaloes, goats, sheep, horses, monkeys, and birds. Under such conditions, almost every fruit produced is consumed either by man or by other animals. The ultimate effect of this population pressure is host scarcity of *D. cucurbitae.* Host scarcity leads to competition for food among other species of cucurbit-feeding Tephritidae, such as *Dacus ciliatus, D. hageni,* and *Myopardalis pardalina,* which have similar host requirements. The competition phenomenon among these cucurbit-infesting tephritids has not been studied *per se.* However, the results reported by Chaturvedi (1947) indicate that there is competition between *D. ciliatus* and *D. cucurbitae.*

Finally, the adverse effects of temperature extremes on the population will be briefly considered. Temperature extremes in India are large, particularly in the northern areas where the temperature may drop to freezing or lower in winter and may rise as high as 110°–115° F. in other seasons. These extremes, which are far beyond the thresholds of development (Koidsumi, 1931, 1933; Shibata, 1936; Keck, 1951; Messenger and Flitters, 1958), no doubt cause considerable mortality, particularly in the immature stages. Although adults can survive the winter conditions of the northern areas of India, their mating is adversely affected. For example, during November the day temperatures in Kanpur were favorable for adult activity; however, the twilight temperatures were too low for mating, which takes place soon after sundown. Because the evening temperature, which was below 60° F., was not conducive to mating, adults in captivity laid infertile eggs.

This study represents a preliminary study on the field ecology of *D. cucurbitae* in India, an exceedingly fertile country for the study of many tephritid fruit flies. A study of these fly species, many of which are of considerable economic importance, should be undertaken in India, for it is through such a study that a thorough understanding can be obtained of their ecology in their native habitats. If we expect to understand the ecology of tephritid fruit flies in their exotic habitats, we must first understand their ecology in their native habitats. This general idea has been elucidated in a thought-provoking article by Doutt (1961).

SUMMARY

This study was concerned with certain aspects of the zoogeography and the ecology of *D. cucurbitae*. It was conducted during 1959–60 with headquarters at the Government Agricultural College, Kanpur, India.

The present world distribution of *D. cucurbitae* is not extensive. It has been reported from India, Burma, Malaya, the Philippines, southern China, Ceylon, Pakistan, Formosa, Okinawa and the nearby islands, Kenya, Mauritius, Saipan, Guam, and Hawaii. These areas are within 35° North and 22° South latitudes, which include the tropical, subtropical, and fringes of the temperate zones. Evidence based on host preferences, natural enemy complex, and general biology indicated that the native home of *D. cucurbitae* is south India.

The duration of the period of reproductive activity of *D. cucurbitae* varied throughout India. In south India, reproduction continued throughout the year; however, as one proceeded northward the duration of the reproductive activity became shorter. These changes were correlated with climatic differences.

In north India, *D. cucurbitae* overwinters in the adult stage. The ovaries of the overwintering individuals remained undeveloped for periods as long as 4 months. Under field conditions, adults have been reported to overwinter at temperatures as low as 29° F.

Expansion and contraction of the habitat were observed. The expansion occurred from July to September under conditions of adequate rainfall brought by the monsoon. The contraction occurred during the dry period. The activity of foraging animals, including cattle, sheep, buffaloes, horses, and goats, hastened this process. The population of *D. cucurbitae* appeared to be correlated with changes in habitat.

Plants in the family Cucurbitaceae are the principal hosts of *D. cucurbitae*. Of the 19 common hosts listed, 18 belong to the Cucurbitaceae. Because of the rich cucurbit flora of India, the host list of this insect is believed to be considerably longer than that reported in this paper.

Six species of parasites are known to attack *D. cucurbitae* in India. These are *Opius fletcheri* Silvestri, *O. watersi* Fullaway, *Syntomosphyrum indicum* Silvestri, *Spalangia* sp., and *Ipobracon* sp. The most abundant species was *O. fletcheri*, the predominant parasite of *D. cucurbitae* in Hawaii.

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