Proc. Indian natn. Sci. Acad. B47 No. 2 pp. 185-193(1981)

Breeding Structure and Pollination Ecology of *Tribulus terrestris*

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(Received 20 July 1980)

The breeding structure and pollination ecology of thc populations of *Tribulus terrestris* L. growing at Visakhapatnam (17° 42'N and 82° 18'E) are studied. Quite a few varieties of insects utilise the flowers as pollen and/or nectar sources during 0600-1500 hr. Insects with relatively large body size such as honeybees and those such as ants with prolonged activity in the flowers bring about either auto, geitono-or xeno-gamous pollination by 'mess and soil'. In the absence of legitimate visitors, autogamy is assured by an adaptive device; the corolla as well as the stamens bend inwards at about 1800 hr and the anthers of the five longer stamens gain contact with the stigma. Pollination in either case could result in 100% fruit-set. Though there is no need of insect activity for the reproductive success of *T. terrestris*, it encourages insects to visit its yellow flowers and provides them sustenance, thereby helps the insects foragers to maintain in the ecosystem until required by other sympatric taxa for service in pollination.

Key Words: **Breeding system, Pollination, Floral biology**, *Tribulus, Apis, Camponotus*

Introduction

The genus *Tribulus* L. is ubiquitous throughout the tropics (Turril 1953). Most of the species are weedy occupants of dry disturbed habitats. Among the different species of *Tribulus, T. cistoides* is the most common, but *T. terrestris* is remarkably widespread and often very abundant (Ridley 1930). In India the former has a restricted distribution, whereas the latter occurs throughout the country (Hooker 1874)

It has been regarded that the flowers of *T. cistoides* are protogynous and those of *T. terrestris* are protandrous and Porter (1971) suggested that in Galapagos Islands both *T. cistoides* and *T. terrestris* might be pollinated by *Xylocopa darwinii* and was of the opinion that there might be natural hybridization between them. Austin (1972) observed an interaction between *Apis mellifera* and *T. cistoides* in Southern Florida. The present paper deals with the observations on breeding structure and pollination ecology of *T. terrestris*.

Materials and Methods

Natural populations of *Tribulus terrestris* L. (2n=12) inhabiting the roadsides and vacant land in the Andhra University campus, and in the Botany Experimental Farm six km from the University were chosen as the experimental material. The phenology of flowers was based upon 25 flowers and observed on five different occasions under different situations. The pollen output of anthers was determined from 10 mature and undehisced anthers, dabbing each on a separate microscope slide in lactophenol-aniline-blue. The grains were counted after spreading the pollen mass uniformly. In the same way, the pollen content of anthers as well as the pollen deposit on the stigmas were simultaneously determined at 2-hourly intervals from the time of anther dehiscence till 1800 hr.

The various insect visitors were identified by the CAB Identification Service, Commonwealth Institute of Entomology, England. They were photographed during foraging by Canon FTB Camera with closeup attachment. The length of foraging visits of some of the insects was recorded with the help of stop watch. The number of pollen that could be transported in a single visit was determined, based on 50 flowers which were protected from insect visitation. From 0800 hr onwards, insects were allowed to visit these flowers, and then the stigmas of the flowers receiving the first visit by particular type of insect were plucked and examined for pollen deposit.

The occurrence of apomictic phenomenon was assessed by the chopping of stigmas of 50 flowers and emasculation of another 50 flowers before anthesis. The extent of inbreeding was determined by selfing 60 flowers and geitonogamy was assessed by cross-pollinating 95 emasculated flowers with the pollen of the same parent. The outcrossing (xenogamy) was estimated by cross-pollinating 45 emasculated flowers with the pollen of the male parent. All these flowers were then covered with butter-paper bags. Concurrently, 100 flowers were observed for open pollination.

Results and Discussion

Floral morphology

Tribulus terrestris is seen all through the year provided enough moisture is available; often it disappears in the summer months of March–May. When once started to bloom, it blooms throughout its life.

The dish-shaped blossoms are solitary and pseudoaxillary. The sepals are concave at the base. The petals are yellow. The stamens are 10, free, inserted at the base of the disc in two whorls, obdiplostemonous; the five longer ones (4.5–5.0 mm) are opposite to the petals with their anthers at the same height as that of stigma, and the other five shorter ones (3.5–4.0 mm) alternating with the petals but opposite the sepals and their anthers are well below the stigma level. Anthers introrse and dehisce longitudinally. Intrastaminal glands are located at the base of each of the shorter stamen. The style is short (1.0–1.2 mm), stout and slightly furrowed. The stigma is pyramidal (0.8–1.0 mm) and the lobes are papillate.

Floral phenology

The different phenological events are summarised in figure 1. Anthesis begins from 0600 hr and is complete by 0800 hr on sunny days, but the process is delayed by one hour and more than one hour in cloudy and rainy days, respectively (table 1). Within 15 min of anthesis, the anthers in a flower dehisce synchronously. Stigma receptivity and pollen viability last for more than 12 hr from the time of anthesis. This is evident by the fruit-set in the flowers kept unpollinated until 1800 hr but hand pollinated

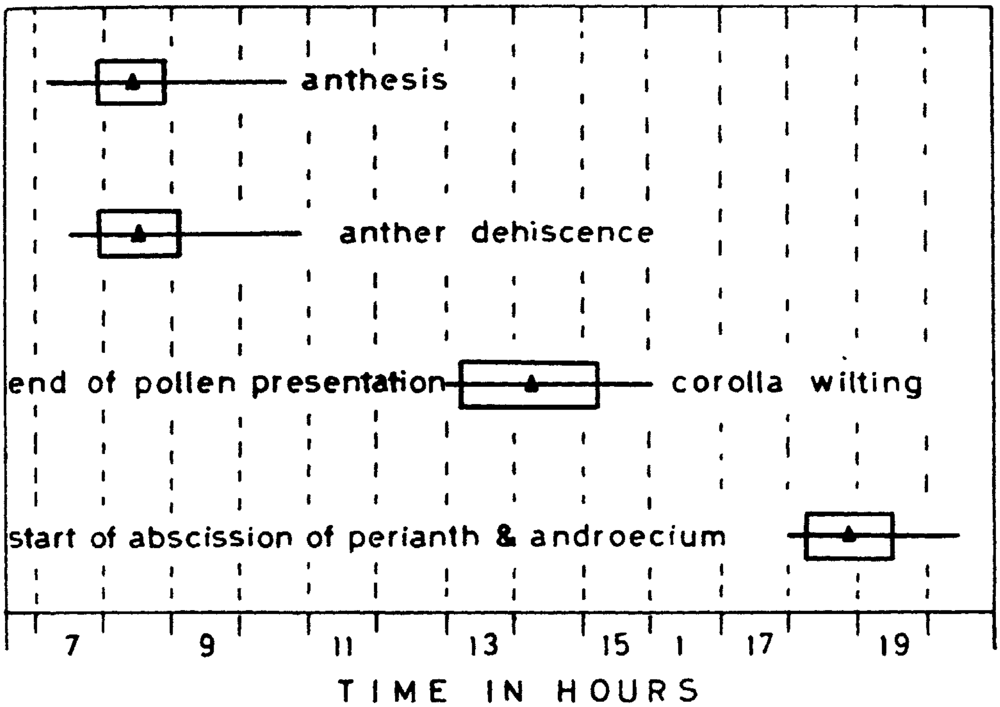

Figure 1 Temporal distribution of different floral phenological events of *Tribulus terrestris*

at that time. In the normal course, the margins of the petals curl inwards by about 1800 hr and the lobes as well as the stamens subsequently bend and eventually meet the gynoecium. Consequently, the anthers of the longer stamens invariably touch the stigma. In case pollination has been over before this time, corolla closure also commences early. This has been substantiated by the controlled experiments when the process occurred after three hours of hand pollination. Abscission of calyx, corolla and androecium takes place the next day at any rate before 0700 hr.

Breeding systems

The results of breeding experiments (table 2) indicate that both inbreeding and outcrossing are prevalent in *T. terrestris* with apomixis being totally absent.

Floral reward to the insect visitors

Both pollen and nectar are offered to the insect visitors. Pollen vary numerically between 1400–2000 per anther, the average being 1800±240. Regarding pollen presentation, *T. terrestris* comes under the morning group of Percival (1955). The five intrastaminal glands are nectariferous, and the nectar production is in tune with the anthesis and continues until the corolla closes. The nectar is deposited in the hollow of the base of each sepal, and the overlapping corolla hides the same from being exposed. Attempts to quantify the nectar failed because of the thrips feeding activty.

Insect visitors

The different kinds of insect visitors are provided in table 3 and figure 2. The relative frequency of visits by each group of insects observed on five different occasions is given in table 4. Of the Hymenopterans, *Apis dorsata*, *A. cerana indica*, *A. florea* and *Ceratina* forage on both pollen and nectar while *Camponotus* on nectar only. The *Apis* species alight on the flower top, and move about collecting pollen, and rotate as they probe successive nectaries. In *T. cistoides* it has been mentioned that *A. mellifera* approaches the flower both from front and backsides (Austin 1972). But in *T. terrestris* no backside approach is noticed. Pollen deposition on these insects is sternotribic. During foraging the honeybees always touch the stigma with their ventral surface as well as legs because of their relatively larger body size. *Ceratina* and other undetermined small bees work along the whorl of anthers and very rarely contact the stigma. *Camponotus* usually grasps the style and anthers with its legs, and its abdomen as well as legs invariably touch the stigma and anthers. Ant-body washings revealed considerable number of

Table 1 *Temporal variation in blooming (%) under different weather conditions*

Time (hr)	Weather Conditions				
	Sunny day		Cloudy day		Rainy day
0600	0	0	0	0	0
0700	87	95	34	20	0
0800	13	5	60	78	46
0900	0	0	6	2	40
1000	0	0	0	0	14

Table 2 *Fruit-set (%) in different pollinations*

Treatment	Sample size (No. of flowers)	Fruit-set (%)
AUTOGAMY	60	100
ALLOGAMY		
Geitonogamy	50	100
Xenogamy	45	100
APOMIXIS		
Emasculated	50	0
Stigmas excised	50	0
Open pollination	100	100
Under insect exclosures	100	100

Table 3 *Insect foragers on* Tribulus terrestris

Forager type	Forage type
HYMENOPTERA	
Apidae	
Apis dorsata	Pollen and nectar
Apis cerana indica	Pollen and nectar
Apis florea	Pollen and nectar
Ceratina sp.	Pollen and nectar
Scolidae	
Campsomeris sp.	Nectar
Formicidae	
Camponotus	Nectar
DIPTERA	
Calliphoridae	
Rhyncomya viridaurea	Nectar
Syrphdae	
Eristalinus laetus	Nectar
COLEOPTERA	
Curculionidae	
Microlarinus sp.	Delicate part of gynoecium base
'Unidentified'	Delicate part of gynoecium base and pollen
LEPIDOPTERA	
Lycaenidae	
Tarucus callinara	Nectar
THYSANOPTERA	
Thripidae	
Thrips sp.	Nectar

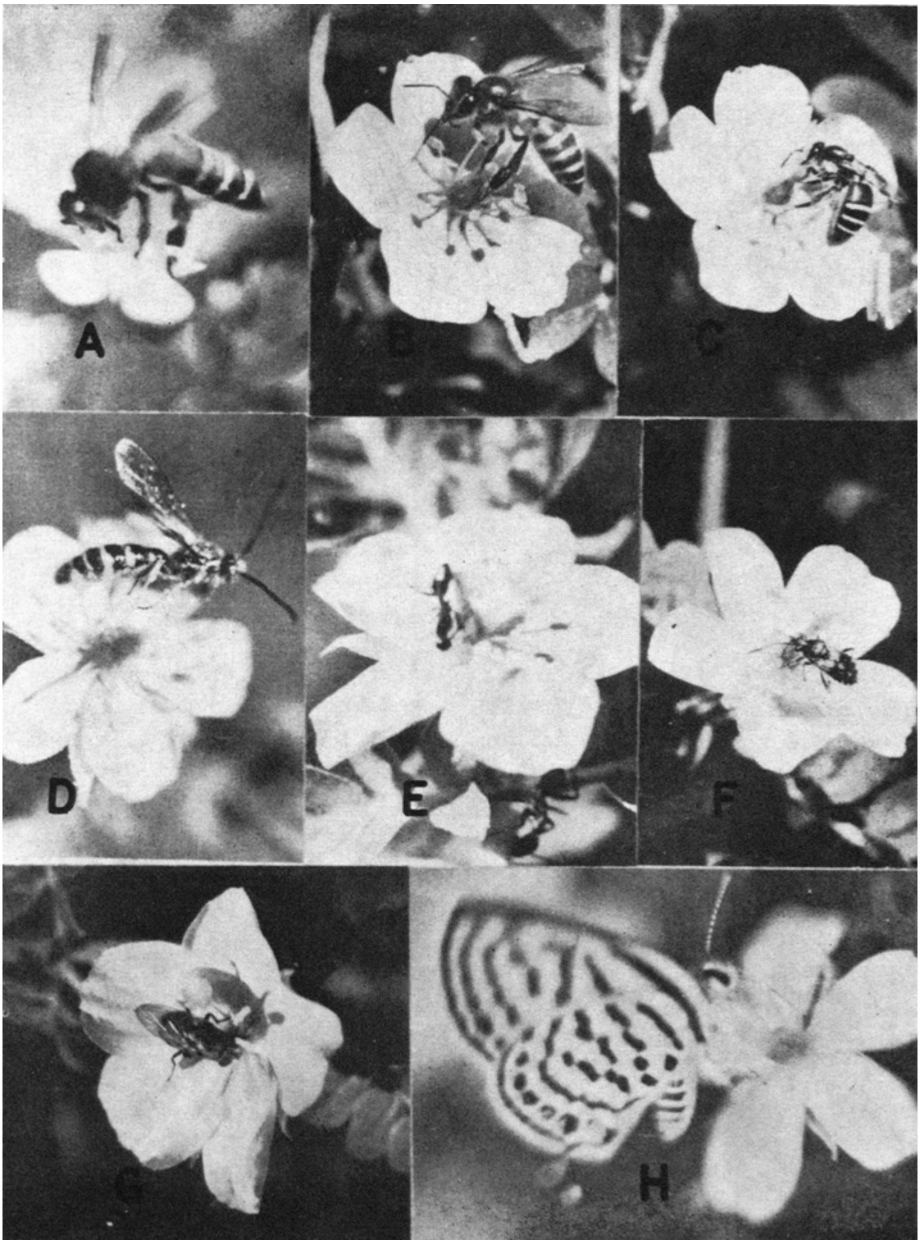

Figure 2 Photographs of different insects foraging on the flowers of *Tribulus terrestris*: A, *Apis dorsata*; B, *Apis cerana indica*; C, *Apis florea*; D, *Campsomeris*; *E*, *Camponotus* sp.; F, 'Unidentified'; G, *Rhyncomya virudaurea* and H, *Tarucus callinara*

Table 4 *Insect census on* Tribulus terrestris

Date	Hymenoptera	Diptera	Coleoptera	Lepidoptera	Sympatric taxa in bloom
28-9-1979	61	14	0	0	*Antigonon leptopus* and *Croton bonplandianum* in peak flowering
21-10-1979	86	25	7	2	*Antigonon*, *Croton* in sparse flowering;
23-10-1979 (Rainy day)	43	9	0	0	*Sapindus emarginatus* in starting phase of flowering
29-11-1979	13	2	0	3	*Sapindus* in peak flowering; *Antigonon* and *Croton* in sparse flowering
28-12-1979	82	16	4	14	*Sapindus* in ending phase; *Antigonon* and *Croton* in sparse flowering

pollen (320±210; 110–730) adhering to the body. The Dipterans land on the corolla lobes and work for nectar, and during this process their body may come in contact with anthers but rarely the stigma. The Lepidopterans land on the periphery of the corolla and suck the nectar by their slender proboscises, and rarely touch the anthers, but never the stigma. The Coleopterans, feeding on the delicate tissues at the base of the ovary, are not come into contact either with anthers or stigma. However, one undetermined beetle feeding on the pollen is seen contacting the stigma now and then. The Thysanopterans feeding on nectar are hardly seen unless the corolla is disturbed.

Length of visits and the pollen amounts transferred on to stigmas in the first visit

The pollen transfer efficiency of a particular insect is directly proportional to its body size irrespective of the time the pollinator spends on the flower. In other words, the greater the body size the greater are the chances of contacting the stigma while foraging. These points are evident from the amount of pollen transferred by the pollinators during their first visit (table 5).

Table 5 *Length of visit of different insects and the pollen amount transported to stigmas in their first visit to the flowers under observation*

Kind of visitor	Mean length of visit (sec.)	Mean number of pollen transpoted
Apis dorsata	7 ± 3	103 ± 53
Apis cerana indica	8 ± 3	64 ± 35
Apis florea	10 ± 4	43 ± 27
Camponotus sp.	37 ± 21	38 ± 32

Temporal variability in insect visitors' activity

The frequency of different visitors in relation to time (as observed on five different occasions) is presented in figure 3. It is evident that the honeybee activity on these flowers almost ceases by noon, while that of others by 1500 hr after which the availability of open flowers becomes a rarity.

Pollen depletion from anthers vs deposition on stigmas

The pollen loads of anthers as well as stigmas observed as a function of time is given in table 6. There is a negative relationship between the pollen content of anthers and pollen deposition on stigmas during foraging. Even as late as 1800 hr floral phenology, considerable quantity of pollen still remained in the pollen-sacs. The degree of pollen depletion and deposition could be positively correlated with the Hymenopteran activity (figure 3).

Foraging preference of honeybees

A very few honeybees visit *T. terrestris* in September, but the ants are abundant. During this month, *Antigonon leptopus* and *Croton bonplandianum* also flower, and the bees are more active on these taxa. Obviously, these two taxa are preferred over *Tribulus.* By about the beginning of October, the bees start visiting *Tribulus* in increasing numbers once again because the blooming period of *Antigonon* and of *Croton* nearly ends during this period. During November to mid-December no bee visits are noticed on *Tribulus,* but at the same time bees are observed in large numbers on *Sapindus emarginatus* which display flowers in lavish manner. From mid-December the blooms of *Sapindus* decline and the bees once again appear more frequently on *Tribulus.* Thus it is apparent that the honeybees visitation rates on *Tribulus* are not constant, and are largely influenced by the flowering of other sympatric taxa.

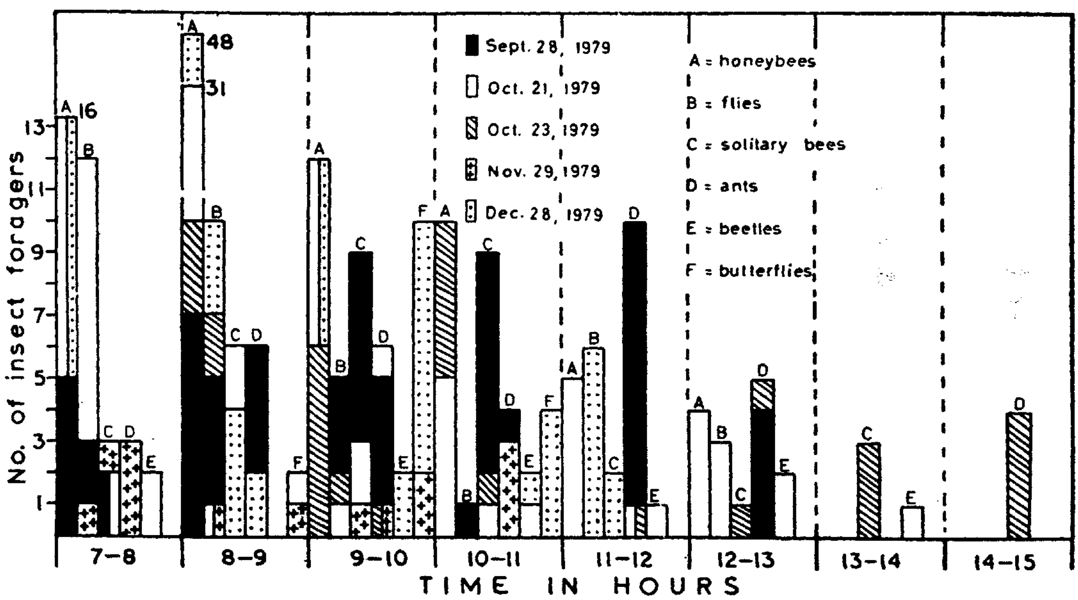

Figure 3 Temporal variation in the frequency of different insect visitors to the flowers of *Tribulus terrestris*

Table 6 *Pollen content of anthers and pollen deposition on stigmas as a function of time*

Pollen loads of		Time in hours 0600	0800	1000	1200	1400	1600	1800
Anther	$\bar{X}$	1800	1425	1040	860	740	650	400
	R	(1408–2006)	(1235–1674)	(890–1351)	(715–1272)	(598–1045)	(550–864)	(289–610)
	S D	237	187	132	145	138	93	100
Stigma	$\bar{X}$	0	26	98	159	181	214	221
	R	0	(0–41)	(12–139)	(73–289)	(85–346)	(80–355)	(81–350)
	S D	0	12	38	75	93	120	112

$\bar{X}$ = Mean; R = Range; SD = Standard deviation;
Sample size: Anthers 10; Stigmas 20

Pollination

Of the different kinds of insects foraging on *T. terrestris*, the honeybees bring about 'mess and soil' pollination because of their relatively larger body size; the ants also aid similarly due to their prolonged activity on the flower; the other insects are less frequent and their behavioural patterns preclude significant contact with the stamens and the anthers. The flowers are bisexual and homogamous, and thus the legitimate insect activity promotes auto-, geitono- and xenogamy. In the absence of legitimate insect activity, it is observed that an interesting mechanism operates ensuring autogamy. The corolla of the flowers with styles unpollinated till 1800 hr closes; consequently the anthers of the five longer stamens are brought into intimate contact with the stigma resulting in pollen transfer; this also yields 100% fruit-set. Similar flexibility in pollination mechanism has been recorded in other taxa (Cruden 1973, Estes & Thorp 1974). Though *Tribulus* does not normally need the intervention of insects for its reproductive success, it does encourage various insects to visit its yellow flowers which stand out conspicously against the green background of the vegetative parts so as to provide the necessary basis for variability, in terms of adaptation in its survival, as a uni- or biparental species of the wild. Obviously, the varied insects obtain their nourishment from *Tribulus*; as such the existence of the species of this kind in a community is paramount to the functioning of the ecosystem, in that the insect populations supported by such taxa are important to the pollination of other sympatric plant species (see Baker et al. 1971).

Acknowledgements

The authors are highly grateful to Professor P V Bhiravamurty, Head, Department of Environmental Sciences, for his unfailing interest and encouragement. They are thankful to Professor H Y Mohan Ram and Dr C R Babu, Botany Department, University of Delhi, who read the manuscript and offered suggestions. One of us (E U B R) is thankful to the Council of Scientific and Industrial Research New Delhi, for financial assistance.

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