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POLLINATION BIOLOGY OF *TURNERA SUBULATA* (BACKER, 1951) (TURNERACEAE): PLANT-INSECT INTERFACE

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ABSTRACT

Results from the general observational data to assess forager activity and density proved that *T. subulata* has a high potential in attracting a diverse group of insects. A total of 345 individuals associated with *T. subulata* were sampled using hand nets and yellow pan traps. These insects represent eight orders, namely Hymenoptera, Diptera, Coleoptera, Orthoptera, Lepidoptera, Homoptera, Collembola and Hemiptera. Hymenoptera comprising 33 species has been found as major pollinators as well as visitors of *T. subulata*. Within this group, *Trigona sp.* was the most common species found. At least 38 visitations were accomplished by all observed insects to a single flower of *T. subulata* from the total number of 10 available flowers during the observation period. From the data, it is estimated that there might be at least 380 visitations made by the insects to the overall 10 observed flowers if every single flower has a constant number of visitation. The higher rates of foraging and visitation show that these *T. subulata* has the required resources such as pollen and nectar that would be needed by insects for different purposes. Flowering behavior and pollination systems of *T. subulata* was unique and interesting. The ability to produce much nectar, and were respectively visited by numerous insect species makes *T. subulata* an efficient plant in attracting and harboring a diverse group of insects.

. Key words: Pollinator, visitor, Hymenoptera, parasitic Hymenoptera, forager

ABSTRAK

Hasil daripada pemerhatian am bagi menilai ketumpatan serta aktiviti pencari makanan telah membuktikan bahawa T. subulata sangat berpotensi dalam menarik kepelbagaian kumpulan serangga. Sejumlah 345 individu yang berasosiasi dengan T. subulata telah diambil sampel menggunakan jaring tangan dan 'yellow pan trap'. Kumpulan serangga ini terdiri daripada lapan order iaitu Hymenoptera, Diptera, Coleoptera, Orthoptera, Lepidoptera, Homoptera, Collembola dan Hemiptera. Hymenoptera yang terdiri daripada 33 spesies telah dikenal pasti sebagai pendebunga serta pelawat utama pada T. subulata. Daripada kumpulan ini, Trigona sp. merupakan spesies yang paling kerap ditemui. Terdapat sekurang-kurangnya 38 lawatan telah dilakukan oleh serangga yang diperhati pada satu bunga daripada keseluruhan 10 kuntum bunga yang terdapat semasa pemerhatian dijalankan. Daripada data tersebut, dianggarkan akan terdapat 380 lawatan dilakukan oleh serangga terhadap keseluruhan 10 kuntum bunga jika setiap satu daripada bunga tersebut mempunyai jumlah lawatan yang tetap dan terus menerus. Kadar pencarian makanan serta kadar lawatan yang tinggi menunjukkan T. subulata mempunyai sumber yang diperlukan seperti debunga dan nektar yang diperlukan oleh serangga untuk pelbagai tujuan. Sifat pembungaan dan sistem pendebungaan T. subulata adalah sangat unik dan menarik. Kebolehan untuk menghasilkan nektar serta kekerapannya dilawati oleh pelbagai spesies serangga membuatkan T. subulata sangat sesuai sebagai tumbuhan yang mampu menarik serta melindungi pelbagai kumpulan serangga.

Kata kunci: Pendebunga, pelawat, Hymenoptera, Hymenoptera parasitik, pencari makanan

1.0 INTRODUCTION

Pollination biology is a broad and a unique subject that takes into account interactions between plants and animals. This interaction generally determines the success of pollination. Although there are other pollinating agents such as wind, the role of animals as pollinators significantly affect the life span of the plants, thus maintaining the stability of biological ecosystem.

There are numerous examples of interactions between plants and insects. Many plants need their insect associates to survive or propagate. The usual benefits that plants derive from insects include pollination, seed dispersal, protection and supply of nutrients. In exchange for these benefits, plants offer insects foods and shelter. This association can be called as insect-plant mutualisms (Simpson & Neff, 1983).

Pollination plays a major role in angiosperm life history (Neff & Simpson, 1992). Commonly, it has been argued that the diversification of pollination systems has been one of the significant factors in the radiation and success of flowering plants (Regal, 1977; Crepet, 1984; Willemstein, 1987; Neff & Simpson, 1992). There are strong relationships between plant diversification and the diversity of the pollinator found in modern plant communities (Neff & Simpson, 1992). The specificity of the floral hosts to the diversity of the pollinator gives an opportunity for rapid generation of reproductive isolation mechanisms (Neff & Simpson, 1992). This unique connection would lead to the changes in evolutionary process for better and fittest generations. The importance of diversity in pollinating systems also needs to be stressed because it is obvious that plant diversity is dependent on various pollinators.

In the usual type of zoophilous pollination, the pollination act proper is generally not the direct objective of the pollen vector but is an accompanying, secondary result of other activities such as feeding or egg-laying (Galil, 1973). The contact between pollen-presenting and receiving organs of the plant and the body of the visiting animal is determined by the arrangement of floral parts. The visitor's body becomes incidentally dusted with the pollen which is used in pollination. This is also the case in pollen-eating insects and in bees which deliberately pack pollen onto certain parts of their body for delivery to the nest. In bees the purposefully collected pollen does not generally serve for the pollination act proper (Galil, 1973).

Generally, insects from the order Hymenoptera, Coleoptera, Diptera, Lepidoptera and Hemiptera are well established pollinating agents in all plant communities and each plant species is usually visited by more than two insect orders (Herrera, 1994; Lloyd & Barret, 1994).

Turnera subulata is a weed species with creamy-flowers. This creamy *T. subulata* from the family Turneraceae is an herb with a woody stem base, erect, unbranched and reaching a height from 20 to 100 cm. There are about 150 species of this family that are now widely dispersed in Asia (Bremekamp, 1941). *T. subulata* was chosen for this study because of the natural potential of this species to attract many insects from different orders to visit its showy flowers.

The main aim of this research was to determine and identify the diversity of insects from different orders that are attracted to *T. subulata* either as potential pollinators or visitors (forager, predator, etc.). The results from the main purpose can be used to distinguish whether this species has the potential to attract more insects from various orders to visit it. A detailed study from the main objective can be used to achieve the minor purpose; trying to identify the target species which are parasitic Hymenopterans. These parasitoids are among the natural biological control agents in the natural ecosystem. According to LaSalle (1992), repeated biological control successes have proven that hymenopterous parasitoids can play a crucial role in pest population regulation and, by extrapolation, suggest that they have an equally important role in the natural regulation of populations of phytophagous insects. The large number of parasitic Hymenoptera species, together with their ability to react in a density-dependent manner to the population size of their hosts, makes them crucial to the maintenance of ecological balance and a contributing force to diversity in other organisms (LaSalle & Gauld, 1992).

2.0 METHODOLOGY

The present study was conducted at the UNIMAS campus, Kota Samarahan, where many *Turnera subulata* plants are grown for ornamental purposes in avenues.

Observation was carried out for 15 days constantly on 10 flowers. Data was recorded once the flower started to bloom (0800 hrs) until it closed (1100 hrs). A simple blank working table with appropriate columns (Appendix 8.1) was used as a field record. Video tape was also used to record the insects that visited the flowers on the same number of flowers. Further analysis from the video tape was used to compare the data from the observation and the data taken from the video tape analysis. Finally, data from the observation and the video tape were gathered to assess the insect activities and their density with regard to the study flowers.

Table 2.1 Methods for evaluating forager activity and density in relation to flowers

Variable	Method
Index of visitation rate	No. of total visits at the observation period / no. of available flowers at this period
Visitation rate	No. of visits / flower x hours
Foraging rate (=pollination efficiency)	No. of flowers visited / time unit

Samplings of the pollinators for further identification were also carried out. For collecting insects, a net with a short handle and a ring diameter of about 7 inches was used.

The bag for this net consists of fine-mesh bolting cloth. Killing jars were used during the field works to kill and preserve the insects. Ethyl acetate is used as the killing agent. A few eyedroppers of the acetate were placed on the plaster or cotton in killing jar before the killing jar became effective.

For microscopic insects, three yellow pan-traps were set up to collect the insects by filling the yellow container (yellow pan-trap) with 1/3 of water. The container was set up beneath the bush of the study plants. The insects that were attracted to the color would approach the container and got trapped on the surface of the water. The insects collected from the yellow pan-trap were preserved in ethanol 95% for further identification. The samples that have been collected were recorded together with the locality, date and the name of the collector.

All of the samples were preserved dry on pins except for the microscopic samples that were preserved in ethanol 95%. Labeling was done after all of the specimens were pinned. All of the specimens were labeled with the locality, date of the capture and the collector's name.

Insect identification was based on Arnett and Jaques (1981), Austin *et al.* (1986), Borror and White (1970), Borror *et al.* (1981), Borror *et al.* (1989), Bouček (1988), Easton (1993), Hill and Cheung (1978), Hill (1982) and reference to the UNIMAS insect collection.

The species and individuals of insect captured were recorded to detect species diversity. Program Divers version 1.2 modified by Laman (2001), was used to measure species diversity and determines the significant different between each insects order.

3.0 RESULTS

3.1 General Observational Results

The following section describes the observations that have been carried out to monitor the activities of the insects on the flowers of *Turnera subulata*. Data from field observations (Appendix 8.1) were used in the calculation to assess the effectiveness of *T. subulata* as an attractant to many insect species.

Table 3.1.1 shows the index of visitation from three observations that have been done. The results indicate that at least 38 visitations were accomplished by the insects to a single flower of *T. subulata* from the total number of 10 available flowers during the observation period. From the data, it is estimated that there might be at least 380 visitations made by the insects to the overall 10 observed flowers if every single flower has a constant number of visitation.

Table 3.1.1 Evaluation of total visit by the insects to indicate the insect visitation activities on *T. subulata*

Variable	Observation	Value
Index of visitation	1	39.7
	2	35.36
	3	37.36
	Mean	37.61 ≈ 38

Visitation rate from Table 3.1.2 explains the number of visits done by the insects to the flower in a three hour observation period. From the data gathered, it is estimated that at least 13 visitations per hour were done by the insects on one flower. Assuming that the number of host is constant, therefore, there would be a total of 130 numbers of visits for 10 observed flowers in 1 hour. There would be a 390 number of visits for 10 observed flowers performed by the insects.

Table 3.1.2 Assessment of the rate of visitation by the insects in relation to *T. subulata*.

Variable	Observation	Value
Visitation rate	1	13.23
	2	11.92
	3	12.45
	Mean	$12.53 \approx 13$

The number of observed flowers and the period of observation were constant for the three observations conducted. Therefore, the calculations for these three observations are equally the same. Table 3.1.3 shows that the foraging rate is equal at 0.06 flowers per minute. It can be assumed that, 1 of 10 observed flower will require 17 minutes to be foraged by the insects and at least 4 flowers will be involved in these foraging activities in an hour. In a three hour observation period, it is predicted that there might be 12 foraging activities made by the insects from the total of 10 available flowers and 2 out of 10 flowers will be foraged twice if the foraging activities performed by the insects are constant.

Table 3.1.3 Appraisal of foraging activities by the insects to *T. subulata* for a three hour observation period.

Variable	Observation	Value
Foraging rate	1	0.06
	2	0.06
	3	0.06
		Mean 0.06

3.2 Diversity of Species Collected

Generally, a total of 345 individuals from different insect orders were sampled using hand nets and yellow pan traps. Hand nets were used to collect macroscopic insects and yellow pan traps were used to gather microscopic insects. A collection of macroscopic insects were further investigated to determine the pollinator and the visitor (Table 3.2.2 & Table 3.2.3). Eight insect orders (Table 3.2.1) were identified from the samples. These consist of Hymenoptera, Diptera, Coleoptera, Orthoptera, Lepidoptera, Homoptera, Collembola and Hemiptera. These 30 families were represented by 57 insect species found on *T. subulata*.

Figure 3.2.1 shows the number of various species found on *T. subulata* taken at the UNIMAS campus, Kota Samarahan. Species from the order Hymenoptera and Diptera were extremely abundant on *T. subulata* with Hymenoptera comprising of 33 species (57.9%) and Diptera with 10 species (17.5%). The total of these two orders represent seventy five percent of the overall number of species. In contrast, the numbers of species associated with

Table 3.2.1 The diversity of insects collected from *T. subulata*

Taxa	No. of species		No. of individual	
Hymenoptera		33		275
Apidae	1		30	
Megachilidae	3		58	
Andrenidae	2		2	
Xylocopidae	1		1	
Vespidae	6		19	
Sphecidae	4		12	
Chalcididae	4		7	
Chrysididae	2		2	
Eurytomidae	1		1	
Formicidae	7		141	
Ceraphronidae	1		1	
Torymidae	1		1	
Diptera		10		46
Sarcophagidae	3		26	
Calliphoridae	2		3	
Conopidae	1		13	
Micropezidae	1		1	
Syrphidae	1		1	
Bibionidae	1		1	
Chloropidae	1		1	
Coleoptera		4		4
Scarabaeidae	2		2	
Phalacridae	1		1	
Coccinelidae	1		1	
Homoptera		3		5
Aphididae	1		3	
Pseudococcidae	1		1	
Cixiidae	1		1	
Collembola		3		8
Entomobryidae	3		8	
Lepidoptera		2		5
Arctiidae	1		3	
Hesperiidae	1		2	
Hemiptera		1		1
Lygaeidae	1		1	
Orthoptera		1		1
		57		345

T. subulata were considerably lower in the remaining orders: Coleoptera with four species (7%); Homoptera and Collembola with three species (5.3%) each, and Lepidoptera with two species (3.5%). The number of species from the order Hemiptera and Orthoptera were genuinely low with only one species (1.8%) each found on *T. subulata*. Apparently, hymenopterans were dominating *T. subulata* in a vast number of species. The indexes of species diversity (Table 3.2.2) shows that the Hymenopterans are highly diverse compared to the other insect order. A comparison between Hymenoptera with the other seven orders (Table 3.2.3) shows a significant difference in species diversity.

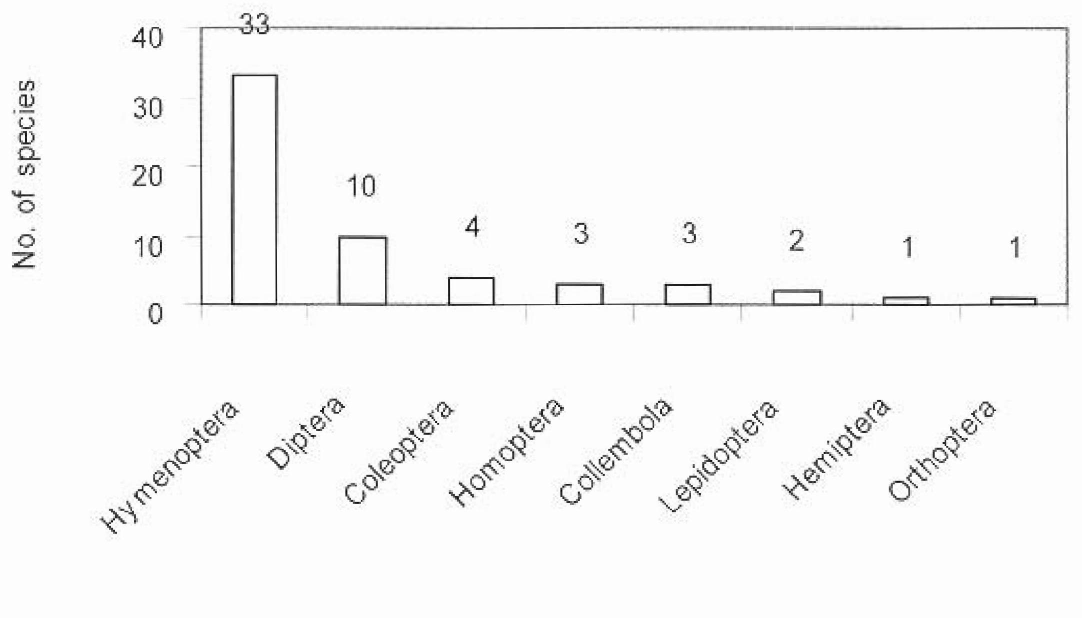

Figure 3.2.1 Comparison in the number of species found on *T. subulata*

Table 3.2.2 Index of species diversity for eight orders gathered from *T. subulata*

Order	No. of species	Shannon-Weiner index (H')
Hymenoptera	33	1.01644
Diptera	10	0.61475
Coleoptera	4	0.60206
Homoptera	3	0.41270
Collembola	3	0.46999
Lepidoptera	2	0.29229
Hemiptera	1	0.0
Orthoptera	1	0.0

Table 3.2.3 Comparison in species diversity between orders

Order	t-calculated	t-critical	conclusion
Hymenoptera vs Diptera	4.799668135	2.074	significant
Hymenoptera vs Coleoptera	4.586982973	2.306	significant
Hymenoptera vs Homoptera	12.08130706	2.042	significant
Hymenoptera vs Collembola	10.93488959	2.042	significant
Hymenoptera vs Lepidoptera	11.47034129	2.06	significant
Hymenoptera vs Hemiptera	20.3397551	2.042	significant
Hymenoptera vs Orthoptera	20.3397551	2.042	significant

The total number of insect individuals collected also indicates a large difference between the orders. From the total of 345 individuals collected, 79.7% of the total numbers of individuals with a sum of 275 were represented by the order Hymenoptera. This figure was almost four times the total number of individuals of the other seven orders. The remaining seven orders were represented by less than 50 individual each. Diptera was the only order represented by more than 30 individuals that is 46 individuals (13%). The other six orders were represented by less than 10 individuals each and these include Collembola with 8 individuals (2.3%), Homoptera and Lepidoptera with 5 individuals each (1.4%), and Coleoptera with a total of 4 individuals (1.2%). The number of individuals from the order Hemiptera and Orthoptera were the lowest with only 1 individual (0.3%) collected for each of the order.

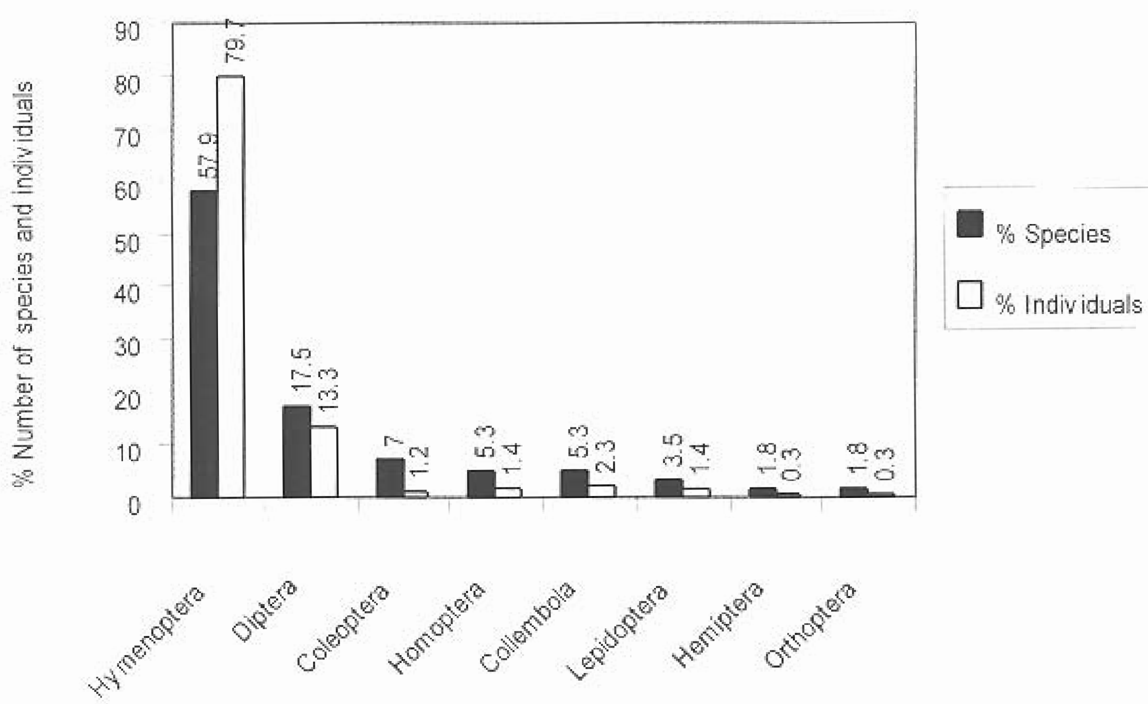

Figure 3.2.2 Percentage representation of species and individuals of the insect orders collected from *T. subulata*

The pollinator and non-pollinator were distinguished by the amount of pollen attach to their bodies. In this study, the identified insect was classified as a pollinator or a potential pollinator if there was substantial amount of pollen sticking to their body. The insect was categorized as a non-pollinator or visitor if no pollen was found on the insect.

Table 3.2.4 shows that 33 species were considered as potential pollinators of *T. subulata,* involving four different orders. Among all the orders, Hymenoptera was found as the major potential pollinator of *T. subulata* comprising of 21 species (64%). The second largest order was Diptera with 9 species (27%). Coleoptera was the second lowest of the insect species that pollinate *T. subulata,* represented by two species (6%). The least number of pollinator species of *T. subulata* came from the order Orthoptera with one species (3%). Shannon-Weiner index for measures species diversity shows that the Hymenoptera was the major group of potential pollinator to *T. subulata* with a significant difference to other insect groups.

Table 3.2.4 The diversity of insect pollinator collected from *T. subulata*

Taxa	No. of species		No. of individual	
Hymenoptera		21		123
Apidae	1		30	
Megachilidae	3		58	
Andrenidae	2		2	
Xylocopidae	1		1	
Vespidae	4		1	
Sphecidae	4		12	
Chalcididae	4		7	
Chrysididae	2		2	
Diptera		9		45
Sarcophagidae	3		26	
Calliphoridae	2		3	
Conopidae	1		13	
Micropezidae	1		1	
Syrphidae	1		1	
Bibionidae	1		1	
Coleoptera		2		2
Scarabaeidae	2		2	
Orthoptera		1		1
		33		171

Table 3.2.5 Index of species diversity of pollinator gathered from *T. subulata*

Order	No. of species	Shannon-Weiner index (H')
Hymenoptera	21	0.89971
Diptera	9	0.58191
Coleoptera	2	0.30103
Orthoptera	1	0.00000

Table 3.2.6 Comparison in species diversity for pollinator insects

Order	t-calculated	t-critical	conclusion
Hymenoptera vs Diptera	3.715247219	2.201	significant
Hymenoptera vs Coleoptera	14.37015845	2.080	significant
Hymenoptera vs Orthoptera	21.59580286	2.080	significant

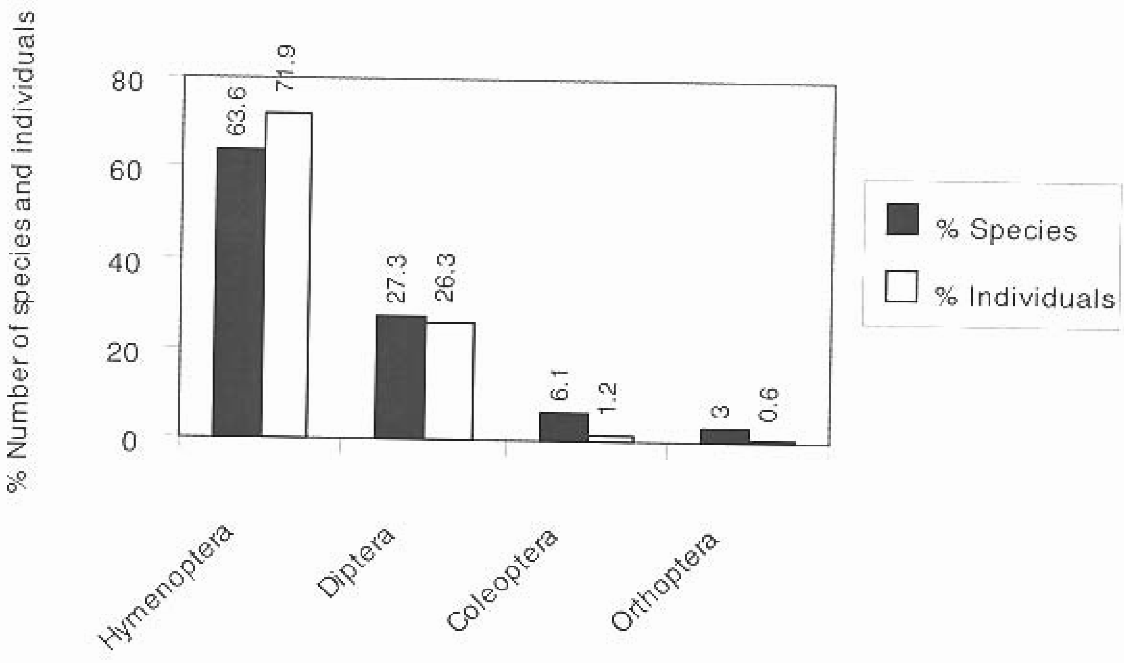

Figure 3.2.3 Percentage representation of species and individuals of the insect pollinator collected from *T. subulata*

As shown in Table 3.2.7, only 8 species comprising 17 individuals were identified as visitors (non-pollinator) to *T. subulata*. These involve five different orders with 6 families. Hymenoptera with a total of three species remained a major group of insects that were attracted to *T. subulata*. Lepidoptera with two species, Coleoptera, Diptera and Homoptera were represented by one species each. Table 3.2.9 shows that when Hymenoptera was compared with the other visitors, the comparison shows that only Lepidoptera has no significant difference with Hymenoptera.

Table 3.2.7 The diversity of insect visitors collected from *T. subulata*

Taxa	No. of species		No. of individual	
Hymenoptera		3		9
Vespidae	2		8	
Eurytomidae	1		1	
Diptera		1		1
Chloropidae	1		1	
Lepidoptera		2		5
Arctiidae	1		3	
Hesperiidae	1		2	
Coleoptera		1		1
Coccinellidae	1		1	
Homoptera		1		1
Cixiidae	1		1	
		8		17

Table 3.2.8 Index of species diversity of visitor gathered from *T. subulata*

Order	No. of species	Shannon-Weiner index (H')
Hymenoptera	3	0.41908
Diptera	1	0.00000
Coleoptera	1	0.00000
Lepidoptera	5	0.29229
Homoptera	1	0.00000

Table 3.2.9 Comparison in species diversity for insect visitors

Order	t-calculated	t-critical	conclusion
Hymenoptera Vs Diptera	6.644708568	2.262	significant
Hymenoptera Vs Coleoptera	6.644708568	2.262	significant
Hymenoptera Vs Homoptera	6.644708568	2.262	significant
Hymenoptera Vs Lepidoptera	1.714916476	2.160	not significant

Yellow pan traps were used to collect microscopic insects because it was difficult to collect the samples using hand nets. As a consequence of using water as trapping medium to trap the insects, the collected species cannot be used to determine whether they were pollinator or visitor. However, these insects were nevertheless important in studying the insect diversity associated with *T. subulata*.

Table 3.2.10 shows the diversity of insects taken from *T. subulata* using yellow pan-traps. A total of 16 species from five orders were sampled. These groups of insects were represented by Hymenoptera, Homoptera, Collembola, Hemiptera, and Coleoptera. As show in Figure 3.2.5, an obvious difference in number of species between the Hymenoptera with the other orders collected was found. It shows that there was over 56% of the total number of species collected from the yellow pan traps were hymenopterans. Collembola, was the second largest order with three species (18.8%) sampled from the yellow pan traps while Homoptera was represented by two species (12.5%). The least number of species collected were Hemiptera and Coleoptera, each comprising one species (6%). However, only Hemiptera and Coleoptera show a significant difference in species diversity when compared with Hymenoptera (Table 3.2.12).

Table 3.2.10 Insects collected from *T. subulata* using yellow pan trap

Taxa	No. of species		No. of individual	
Hymenoptera		9		143
Formicidae	7		141	
Ceraphronidae	1		1	
Torymidae	1		1	
Homoptera		2		4
Aphididae	1		3	
Pseudococcidae	1		1	
Collembola		3		8
Entomobryidae	3		8	
Hemiptera		1		1
Lygaeidae	1		1	
Coleoptera		1		1
Phalacridae	1		1	
		16		157

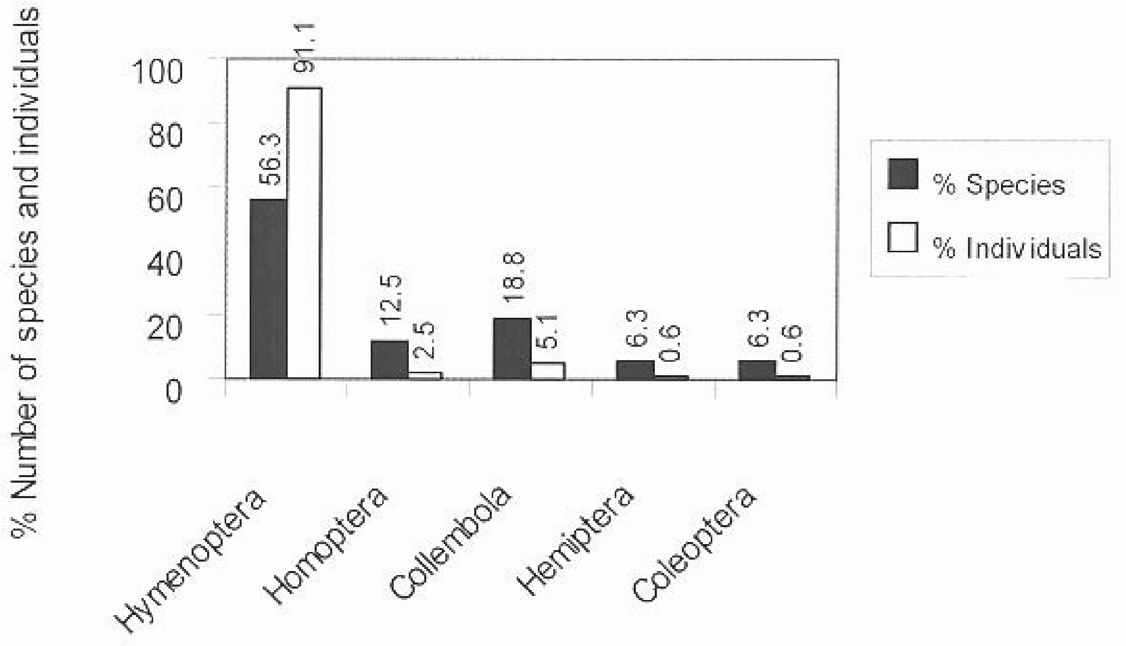

Figure 3.2.4 Percentage representation of species and individuals of the insect orders collected from *T. subulata* using yellow pan traps

Table 3.2.11 Index of species diversity for nine orders gathered from *T. subulata*

Order	No. of species	Shannon-Weiner index (H')
Hymenoptera	9	0.47643
Homoptera	2	0.24422
Coleoptera	1	0.00000
Collembola	3	0.46999
Hemiptera	1	0.00000

Table 3.2.12 Comparison in species diversity for insect collected from yellow pan traps

Order	t-calculated	t-critical	conclusion
Hymenoptera vs Homoptera	2.139616479	2.571	not significant
Hymenoptera vs Coleoptera	14.31518357	1.984	significant
Hymenoptera vs Collembola	0.150361946	2.021	not significant
Hymenoptera vs Hemiptera	14.31518357	1.984	significant