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Fig A Microcosm: Elucidation Of Association Of Fig (Moraceae) And Fig Wasps (Hymenoptera: Chalcidoidea)

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ABSTRACT

The fig–fig wasp interaction represents one of the most fascinating examples of co-evolution and ecological specialization in nature, where fig trees (Ficus spp.) and their pollinating wasps (Family: Agonidae) maintain a highly specific and mutualistic relationship. The study investigates the ecological interactions between fig trees and their associated faunal diversity, with special emphasis on fig- fig wasp relationships among four Ficus species: *Ficus racemosa*, *F. benghalensis*, *F. religiosa*, and *F. benjamina*. Field observations and laboratory analysis were conducted over a period of three-months in and around Jnanasiri campus, Tumkur University. Different developmental phases (A–E) of syconia were dissected and examined to document floral morphology, wasp developmental stages, and faunal associations. A total of 35 faunal species of invertebrates and vertebrates were recorded to be interacting with Ficus trees, highlighting its role as ecological hubs and keystone species. Hymenopterans (fig wasps) constituted the most diverse group, comprising pollinating fig wasps (PFWs) and non-pollinating fig wasps (NPFWs) exhibiting parasitic, gall-inducing, inquiline, and parasitoids behaviours. Species specific pollination mutualisms were confirmed, by *Ceratosolen fusciceps* with *F. racemosa* and *Eupristina masoni* with *F. benghalensis*. The study emphasized on fig- fig wasp systems as intricate micro-ecosystems governed by highly specialized and co-evolved interactions, while simultaneously supporting various faunal diversity. These findings reinforce the ecological significance of Ficus as keystone species and highlight the utility of fig - fig wasp systems as versatile models for evolutionary and micro-ecological research.

Keywords- Ficus, Fig wasps, Microcosm, Co-evolution, Keystone species

I INTRODUCTION

Microcosm is a small, self-contained ecological system which serves as efficient models for analyzing ecological processes. Natural examples like pitcher plants, moss patches, and rock pools permits for the investigation of biodiversity and ecosystem functioning under controlled still in realistic conditions (Srivastava et al., 2004). A similar system is represented by inflorescences of Ficus species- Syconium, which acts as a natural microcosm (Cook and Lopez-Vaamonde, 2001) and it supports diverse communities of pollinators, parasites, and other allied organisms within a confined space. This makes it an optimal model for studying coevolution, ecological interactions and multitrophic relationships (Borges et al., 2020).

The genus Ficus (family Moraceae) distributed in tropical and subtropical regions of the world includes over 800 species globally and about 89 species in India (Koutsoukos et al., 2025; Satheesan and Santhosh, 2019). *Ficus* species are characterized by a unique enclosed urn-shaped syconium containing numerous small male and female flowers, in which female flowers being more abundant and variable in structure whereas male is restricted near ostiole region (Borges, 2021). In monoecious species, imperfect heterostyly does not strictly determine seed or wasp development. In gynodioecious species exhibit clear functional differentiation between seed and gall flowers (Verkerke, 1989). This structural specialization plays indispensable role in enabling interactions with fig wasps.

The development of the fig syconium needs approximately 60 days through five distinct phases. These include the (A) pre-receptive stage, followed by the (B) receptive phase where pollinating female enter. This is fulfilled by the (C) inter-floral phase, where wasp larvae develop and nematodes reproduce, and the (D) dispersal phase, marked by the emergence of adult wasps carrying nematode offspring. The final stage (E) involves seed maturation and dispersal (Galil and Eisikowitch, 1968).

Fig pollinators display strong sexual dimorphism, with winged females adapted for fig entry and dispersal, while males are wingless and persist within the syconium (Weiblen, 2002).Specialized morphological features exhibit by females that enable them to enter the fig through the ostiole and ease pollination and oviposition (Priyadarsanan, 2000).In supplement with pollinators, Ficus supports a diverse group of non-pollinating fig wasps (NPFWs), which includes gallers, inquilines, and parasitoids, each differing in their mode of resource deployment (Kerdelhue et al., 2000). These groups impact the fig - wasp interaction through parasitism, competition, and trophic regulation, thereby adding intricacy to the system (Ghara and Borges, 2010; Bain et al., 2013). However high diversity of fig wasps has been recorded in India, only a limited number of pollinator associations are documented (Satheesan and Santhosh, 2019).

Female pollinating wasps visit both gall and seed-producing flowers within the syconium, but their larvae develop takes place only in gall flowers as a brood site (Weiblen, 2002).Both seed and gall development occur within the same syconium in monoecious species, whereas in dioecious species, male trees produce galls and pollen while female trees produce only seeds, hindering wasp reproduction. The wasp life cycle is completed within the syconium, where mating occurs, and females disperse pollen to colonize new figs during its emergence (Bain et al., 2013; Borges, 2021). Pollination happens through active mode with active pollination involving specialized adaptations for deliberate pollen transfer and passive mode occurs incidentally (Kjellberg et al., 2005). These reproductive and pollination strategies emphasize the tight co- evolution and co-dependency between figs and their pollinators.

Ficus species support diverse insect interactions beyond their association with pollinating fig wasps in trophical ecosystem. Ants habitually form mutualistic relationships with sap-sucking insects by feeding on honeydew and offering protection to them (Bain et al., 2013). In the meantime ants may also benefit figs by preying on NPFW. These clines the complex multitrophic interactions within the fig systems (Compton & Robertson, 1988). The aim of the present study is to fill the gap of sparse literature that is available to understand the types of PFW and NPFW and their interactions with different species of ficus flora from the region of Karnataka.

II MATERIALS AND METHOD

The study was carried out in various *Ficus* species located in and around Jnanasiri campus, Bidarakatte, and Tumkur University City campus, Tumakuru of Karnataka. Fieldwork was conducted between April and July 2025, with regular visits made on substitute days during morning hours. The collected samples were brought to the laboratory of the Department of Studies and Research in Zoology, Tumkur University for further analysis.

Collected Ficus twigs were used for species identification and confirmed by experts at the Department of Studies and Research in Botany, Tumkur University. Syconia from different study sites were examined based on physical characteristics such as colour, size, and ostiole condition across developmental phases (A–E). Each syconium was dissected and examined under a stereo-zoom microscope (LABOMED-CZM6) to observe floral structures and developmental stages of fig wasps. Adult wasps were documented and collected for further identification (Koutsoukos et al., 2025). Based on basic morphological features the collected adult fig wasps of selected *Ficus* spp. were separately preserved in 80% alcohol. Further fig wasps were identified based on the report of Priyadarsanan (2000). The other faunal species were identified based on their morphological features using- www.antwiki.org (Ants), Spiders of India by Sebastain and Peter, 2009 (Spiders), Birds of India by Salim Ali, 2002 (Aves) and Scalenet (Scale insects).

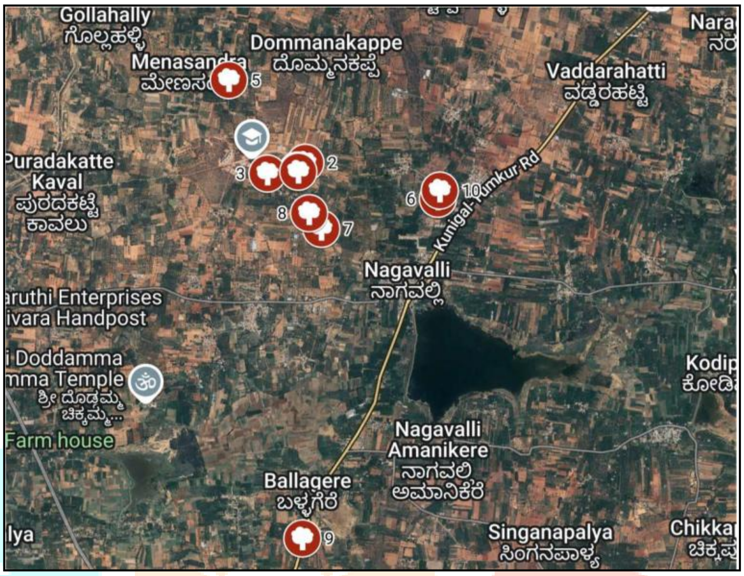

Fig.2.1: Satellite view of study sites in and around Jnanasiri campus, Tumkur University, Tumakuru

III RESULTS

3.1 Interaction between faunal diversity and Ficus species: The study revealed that all four selected *Ficus* species *viz*., *Ficus religiosa*, *F. benghalensis*, *F. racemosa* and *F. benjamina* are monoecious and function as important ecological hubs promoting diverse fauna. A total of 35 species were recorded from both invertebrates and vertebrates (Table 1 & 2). Among these, insects were the most dominant group (63%) (Fig.2), with Hymenoptera showing the highest diversity, particularly the family Pteromalidae i.e. NPFW, followed by Formicidae. Ant species such as *Camponotus*, *Crematogaster*, *Oecophylla*, and *Tetraponera* were observed commonly often associated with sap-sucking insects for honeydew feeding like *Planococcus citri*. Other arthropods including spiders, bees, beetle larvae, and *Drosophila*, were also interacting with fig trees. Class Aves (28%) from vertebrates especially Passeriformes, were prominent frugivores actively feeding on ripened figs, highlighting the ecological importance of *Ficus* species in encouraging faunal diversity.

Table 3.1: List of invertebrate and vertebrate faunal diversity observed from four Ficus spp.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Arachnida	Araneae	Salticidae	*Menemerus*	*M. bivittalus*
	Insecta	Odonata	Libellulidae	*Diplacodes*	*D. trivalis*
		Hemiptera	Pseudococcidae	*Planococcus*	*P. citri*
		Thysanoptera	Phlaeothripidae	*Gynaikothrips*	*G. ficorum*
		Coleoptera	Cerambycidae	*Olenecamptus*	*O.bulobus*
		Hymenoptera	Apidae	*Apis*	*A.mellifera*
			Pteromalidae	*Sycoryctes*	*S.religiosawiebes*
				Apocrypta	*A.westwoodi*
				Apocryptohagus	*A.agraensis*
					A.brevilarus
				Philotrypesis	*P.affinis*
					P.anguliceps
				Otitesella	*Sp.*
				Apocrypta	*Sp.*
				Sycophaga	*S. stratheni*
			Agonidae	*Eupristina*	*E.masonisaunders*
				Ceratosolen	*C.fusciceps*
			Epichysomallidae	*Acophila*	*Sp.*
			Formicidae	*Camponotus*	*C. sericeus*
					C. campressus
				Crematogaster	*C. subnuda*
				Oecophylla	*O. smaragdina*
				Tetraponera	*T. rufonigra*
Mollusca	Gastropoda	Stylommatophora	Helicidae	*Theba*	*T. pisana*
Chordata	Aves	Bucerotiformes	Bucerotidae	*Ocyceros*	*O. birosteris*
		Psittaciformes	Psittacidae	*Psittacula*	*P. krameri*
		Piciformes	Picidae	*Dinopium*	*D.benghalese*
		Coraciformes	Alcedinidae	*Halcyon*	*H.smyrnensis*
		Passeriformes	Timaliidae	*Argya*	*A. caudata*
			Nectariniidae	*Leptocoma*	*L. calcostetha*
			Corvidae	*Corvus*	*C. corax*
			Sturnidae	*Acridotheres*	*A.fuscus*
			Dicruridae	*Dicrurus*	*D. macrocercus*
			Oriolidae	*Oriolus*	*Spp.*
	Mammalia	Rodentia	Sciuridae	*Funambulus*	*F. palmarum*

Table 3.2: Number of faunal species

Sl. No.	Class	No. of species
1	Mammalia	1
2	Aves	10
3	Gastropoda	1
4	Arachnida	1

5	Insecta	22
Total	**5**	**35**

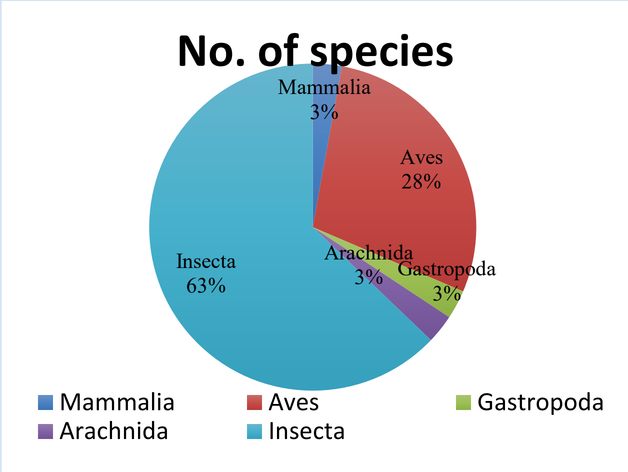

Fig. 3.2: Graphical representation of faunal diversity on *Ficus* spp.

3.2 Fig wasps in selected *Ficus* species: The study revealed that order Hymenoptera species was most associated with Ficus species, comprising five families (Table 1). A total of 12 wasp species belonging to the families Agaonidae, Pteromalidae, and Epichrysomallidae were recorded from syconium. The fig–fig wasp association exhibited multiple trophic interactions, like parasitism, mutualism, and parasitoid relationships involving both pollinating and non-pollinating wasps.

Ficus racemosa: As an indicator for highly species-specific mutualistic relationship, the pollinating fig wasp *Ceratosolen fusciceps* (Agaonidae) (Fig.3A, F, G) was consistently associated with Ficus *racemosa*. Pollinators were mainly retrieved from later developmental phases (D and E), associating with maturation and emergence stages. Beside pollinators, several non-pollinating fig wasps (NPFWs) (Fig.3B, D, E), including *Apocryptophagus* spp. and *Apocrypta westwoodi*, were noted, evidencing parasitic and gall-inducing behavior, particularly during early developmental phases. Floral differentiation between gall and seed flowers with variation in style length facilitates both wasp development and seed formation. The A–E developmental phases emphasized key biological events, with later stages marked by wasp emergence and switch in colour and odour, aiding dispersal and ecological interactions.

Ficus benghalensis: From the research, *Eupristina masoni* (Agaonidae) (Fig.3K) was detected as the pollinating fig wasp, mainly observed during the later developmental phases (D and E), indicating a firmly co-evolved mutualistic relationship. Parallel to pollinators, a diverse assemblage of non-pollinating fig wasps (NPFWs), including *Sycophaga stratheni*, *Apocrypta westwoodi*, and *Philotrypesis affinis* were noted, usually parasitic and gall-inducing behaviors (Fig.3H, I, J, L). NPFWs were regularly noticed ovipositing during early developmental stages (Phase B), showing competition with pollinators (Fig.3B).The wingless male wasps were observed within the syconium, which created exit tunnels for female dispersal, and completing their life cycle inside the syconium. The presence of NPFWs witnessed the complexity of the fig–wasp system, where mutualism is impacted by parasitism and competition.

Ficus benjamina: Even though the syconia with pollinating wasps were not directly recovered, indications of exit holes and empty gall chambers evidenced the successful pollination of syconia. The dissected syconia exposed the presence of non-pollinating fig wasps, particularly parasitoids belonging to *Acophila* (Epichrysomallidae) and *Otitesella* (Pteromalidae) (Table 3 and Fig. 3M), evolving within gall tissues. During later phases of syconium development, these parasitoids were observed at different developmental stages, showing continued activity. The results indicate that *F. benjamina* supports a wasp community ruled by NPFWs during post-pollination stages. The observation evidenced the perseverance of complex multitrophic interactions within the fig system even after pollination.

Ficus religiosa: The syconia with pollinating wasps were not observed, but the presence of exit holes and developed galls showcased that pollination and wasp emergence had already been occurred. Different developmental phases of dissected syconia revealed about parasitoids such as *Sycoryctes religiosa* and *Philotrypesis anguliceps* (Fig. 3N, O) (Pteromalidae). As indication of continued trophic interactions even after pollination, these parasitoids were known to exploit developing larvae within the syconium.

IV DISCUSSION

The Ficus–fig wasp interaction is widely recognized as a model system for studying mutualism and complex ecological networks (Jander and Herre, 2010; Cook and Rasplus, 2003). The selected *Ficus* species (*F. racemosa, F. benghalensis, F. benjamina,* and *F. religiosa*) function as keystone resources, supporting diverse faunal communities, with a total of 35 species recorded, including insects and birds (Shanahan et al., 2001). Insects, particularly Hymenoptera, dominated the interactions, with both pollinating fig wasps (PFWs) and non-pollinating fig wasps (NPFWs) contributing to complex trophic relationships such as mutualism, parasitism, and competition (Mifsud et al., 2012).

Ant–hemipteran interactions were commonly observed, where ants benefited from honeydew while indirectly influencing fig reproductive success by preying on NPFWs and potentially aiding seed dispersal (Bain et al., 2013; Rico-Gray and Oliveira, 2007). Additionally, thrips (*Gynaiko thripsficorum*) induced leaf galls, further contributing to plant–insect interaction complexity. Fig fruits also supported frugivorous birds, particularly Passeriformes, which aid in seed dispersal through consumption of ripened figs (Lomascolo and Levey, 2019).

The syconium functions as a natural microcosm supporting diverse organisms, with variation in faunal composition influenced by species-specific phenology and developmental stages (Cook and Lopez-Vaamonde, 2001). Pollinators such as *Ceratosolen fusciceps* (*F. racemosa*) and *Eupristina masoni* (*F. benghalensis*) exhibited strong host specificity, confirming obligate mutualism (Yadav et al., 2021). In contrast, NPFWs including *Apocrypta*, *Philotrypesis*, and *Sycoryctes* were abundant and functioned as parasites or parasitoids, often influencing pollinator success and fig reproduction.

The abundance and diversity of NPFWs varied across species, sometimes exceeding pollinator populations, particularly in *F. racemosa* and *F. benghalensis* (Cook and Rasplus, 2003). In *F. benjamina* and *F. religiosa*, only later developmental stages were observed, with dominance of parasitoids and limited recovery of pollinators, likely due to phenological constraints. Overall, the findings highlight that fig–fig wasp systems represent highly complex, multitrophic ecological networks where mutualism is shaped by multiple interacting species.

CONCLUSION: The study highlights the complex, species-specific and co-evolved interactions between figs and fig wasps, encompassing pollinators, parasites, and other associated insects. Figs act as natural micro-ecosystems, serving as breeding sites for wasps and supporting diverse insect communities. The dependence of various faunal groups on *Ficus* species underscores their role as keystone species in maintaining ecological balance. These findings also emphasize the potential of figs as model systems for future research aimed at addressing unanswered questions in microecological dynamics.

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Sl.No.	***Ficus***	**Site**	**Fig wasps**				**Trophic regime**
			Family	**Subfamily**	**Genus**	**Species**	
1.	*F. racemosa*	Jnanasiri Campus	Agonidae	Kradibiinae	*Ceratosolen*	*C. fusciceps*	Pollinator (PFW)
			Pteromalidae	Sycoryctinae	*Apocryptohagus*	*A.agraensis*	Parasitoid (NPFW)
						A. brevilarus	
					Apocrypta	*A.westwoodi*	Galler (NPFW)
		Hebbur	Agonidae	Kradibiinae	*Ceratosolen*	*C. fusciceps*	Pollinator (PFW)
2.	*F. benghalensis*	Jnanasiri Campus	Pteromalidae	Kradibiinae	*Philotrypesis*	*P affinis*	Parasitoid (NPFW)
					Apocrypta	*Sp.*	
					Sycophaga	*S. stratheni*	Galler (NPFW)
			Agonidae	Agaoninae	*Eupristina*	*masoni* Saunders	Pollinator (PFW)
3.	*F. benjamina*	Tumkur University	Epichysomallidae		*Acophila*	*sp.*	Parasitoid (NPFW)
			Pteromalidae	Pteromalinae	*Otitesella*	*sp.*	
4.	*F. religiosa*	Jnanasiri Campus	Pteromalidae	Sycoryctinae	*Sycoryctus*	*S. religiosaewiebes*	Parasitoid (NPFW)
					Philotrypesis	*P angulicepswestwood*	

Table 3.3: List of Pollinator and Non-pollinator fig wasps observed from 4 *Ficus* species

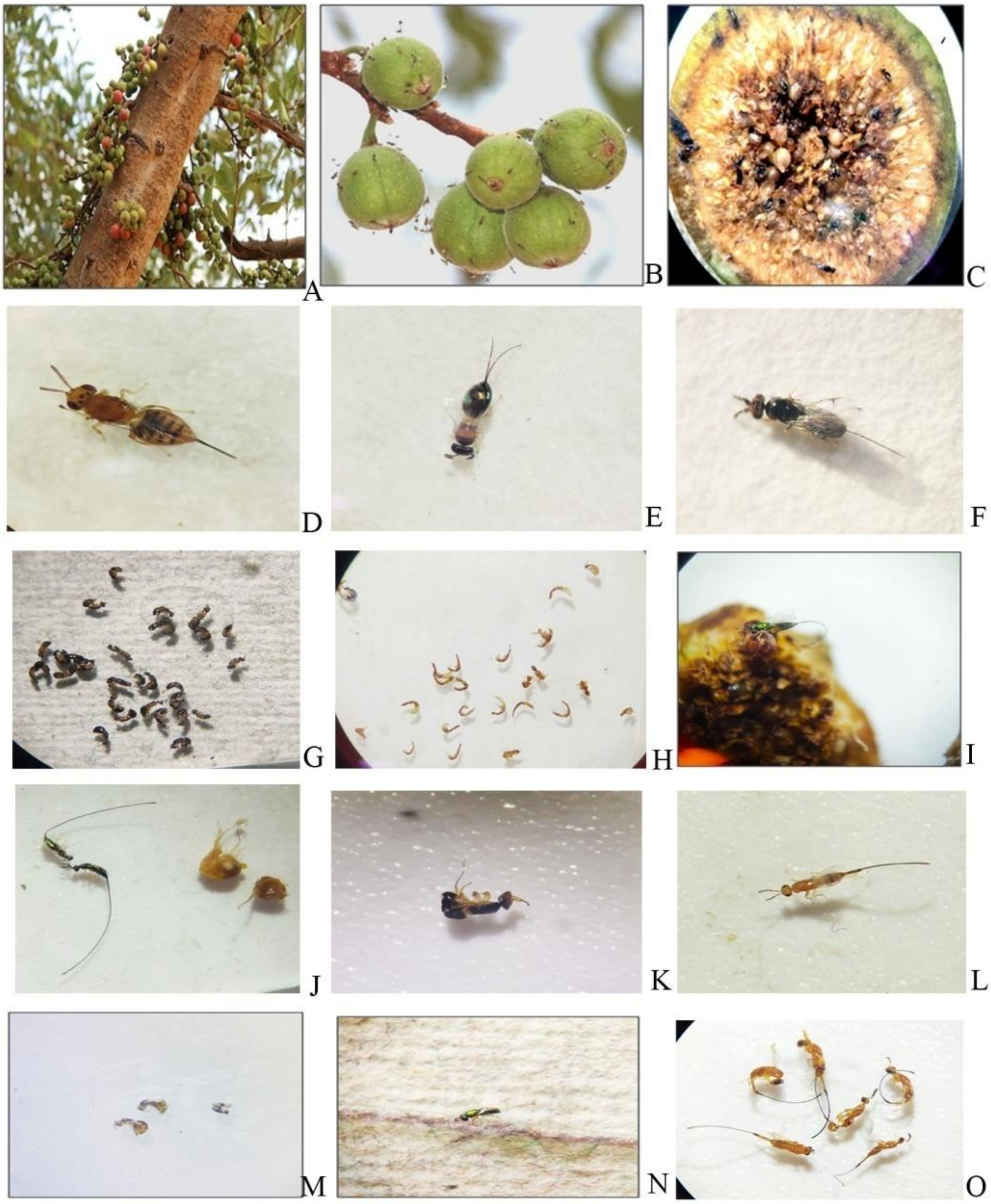

Fig. 3: A. Syconium maturation phases (*Ficus racemosa*), B. Apocrypta westwoodi (NPFWattracting to syconium), C.Cut opened D-Phase, D & E. *Apocryptophagus* spp. (NPFW), F & G. *Ceratosolen fusciceps,* H.Male wasps of NPFW, I. *Apocrypta westwoodi* (NPFW ovipositing into the syconium wall), J. *Apocrypta* sp., K.*Eupristina masoni* Saunders, L.*Philotrypesis affinis,* M.*Acophila* Sp. (NPFW-parasitiod), N.*Sycoryctus religiosae* Wiebes (NPFW-parasitiod), O.*Philotrypesis anguliceps* Westwood (NPFW-parasitiod).