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A REVIEW ON THE BEETLE - POLLINATION IN INDIA

[1]Akash Paul, [1]Rishiraj Debnath, [1]Soudip Karmakar, [1]Rajat Roy,
[2]Sujoy Pal and [1]Bulganin Mitra

[1] Centre for Insect taxonomy & Pollinator Research, [2] Department of Microbiology
Ramakrishna Mission Vivekananda Centenary College, Rahara

****For Correspondence: bulganinmitra@gmail.com***

Abstract:

Cantharophily or beetle- pollination is the love or attractants towards coleopteran species by some specific plants for their cross pollination or successful reproduction and seed set. This review work reports 110 species (identified & unidentified) under 15 families of beetles as visitors/pollinators of 80 plant species (identified & unidentified) under 34 families of plants from India. Coccinellidae with 25 species is the predominant flower visiting beetle family and *Coccinella septempunctata,* found to visit the highest number of plant species (28) in India. Asteraceae with 11 species is the largest beetle visited plant family and *Brassica junecea* found to attract highest number of coleopteran species (14) in India. This communication finds that, majority of the wild plants (26%) are reliant on beetle pollinators in India.

Key words: Bettle, cantharophily, floral traits, host plant, visitors, pollinators, India

INTRODUCTION:

Many kinds of insects can be found on flowers, of them Hymenoptera (wasps, bees, and ants), Diptera (true flies), Lepidoptera (moths and butterflies), Coleoptera (beetles), and

Thysanoptera (thrips) are the most significant pollinators (Thien et al, 2009, Rader et al., 2016). Of these five major groups of pollinating insects, nearly half of all herbivorous insect species (Farrell, 1998) are beetles and most herbivorous beetles are attracted by the angiosperms (McKenna et al., 2019).

The order Coleoptera is arguably the most speciose group of animals, but the evolutionary history of beetles, including the impacts of plant feeding (herbivory) on beetle diversification, remain poorly understood (McKenna et al., 2019). It is already known that the extraordinary diversity of beetles has been attributed chiefly to the adaptive radiation of specialized herbivorous beetles feeding on flowering plants (angiosperms) (Farrell, 1998, McKenna et al., 2009, McKenna et al., 2015, Zhang et al., 2018).

The order Coleoptera includes hard-bodied beetles undoubtedly lie amongst early branches of the Endopterygota. The development of the fore wings as sclerotized rigid elytra, which extend to cover many of the abdominal segments and hind wings are the major derived feature of Coleoptera (Gullan & Cranston, 2010). The modern consensus is that the Coleoptera were derived from some Megaloptera-like ancestor, probably in the early part of the Permian period (Crowson,1960 and Grimaldi & Engel, 2005). On the other hand, molecular studies have suggested that the era of Coleoptera ranged from ~253 to 333 Mya and that the divergences of most modern lineages occurred during the Late Triassic to Cretaceous. Recently, Zhang et al., (2018) suggested that Coleoptera originated in the earliest Permian. They also suggested that divergence of phytophagous beetles may be occurred during the Cretaceous, which indicating that the rise of angiosperms in the Cretaceous may have played an important role in the hyper diversification of beetles.

Scientific publications detailing the role of beetles as pollen vectors in world have been obtainable late than other insect- mediated pollination. It may be due to most of the earlier works on insect pollination largely dependent on european tradition, where tropical flora was less. The study on beetle pollination or cantharophily was also not given that much of importance in comparison to melittophily, myophily, psychophily, phalaenophily etc. in India (Chatterjee and Mitra, 2004).

This present work is the first of its kind review, compiling all the published literature on the beetle visitors/pollinators, to provide consolidated information on cantharophily from India.

An effort has been made to summarize the beetle - pollination in India, though, there may be unintentional omissions. This present communication will not only serve as the first comprehensive database on beetle- mediated pollination from India but also provide an insight for future research and management on beetle pollinators across the different ecosystems in India. This communication also provides the morphology, behavioral ecology, biology and habitats of the beetle pollinator families in brief.

COEVOLUTION OF BEETLES AND PLANTS:

Schenider et al., (2002) speculate that cycad pollination evolved from "accidental" to "symbiotic" pollen transfer by insects. The intricate interrelationships between herbivorous beetles and reproduction/ defense strategies in cycads could be interpreted as an indication of an old co-evolution. Favouring this view is the notion that cycads already existed in the Jurassic/ Cretaceous as did their pollinating beetles, which belong to basal families of Curculionoidea (Oberprieler, 1995, 1999). Although it is well documented that cycads were diverse and abundant during the mid-Mesozoic but little is known about their biogeography and pollination before the rise of angiosperms. Labandeira et al., (2007), Peris et al., (2017) and Cai et al., (2018) reported a specialized beetle-mediated pollination mode from the mid-Cretaceous of Myanmar, wherein a new boganiid beetle, *Cretoparacucujus cycadophilus*, (Family Boganiidae) with specialized pollen-feeding adaptations in its mouthparts and legs, was associated with many pollen grains of Cycadopites. Moreover, Peris et al. (2017) documented four insect pollination modes on gymnosperm hosts during the mid-Cretaceous angiosperm radiation. One of these pollinator modes is beetle chewing. Peris et al. (2017) provide the first direct evidence exemplified by the beetle *Darwinylus marcosi* of the family Oedemeridae (False blister beetles), which had an earlier gymnosperm (most likely cycad) host association, later shifted onto angiosperms (Lawrence, 2010). All these studies uncover the earliest definitive fossil evidence of the relationship between cycads and beetles. Cycads are a group of unusual evergreen gymnosperms that may have been the first insect-pollinated plants.

1. FLORAL TRAITS FOR BEETLE POLLINATION

The visit of beetles on the flowers are usually dependent on size & shape, color, odor, and other characteristic features as follows.

1a.) Flower size & Shape: Size of the flowers is not the first choice for beetles, since flowers preferred by beetles can be large or small and clustered (Weber et al., 2020). Beetles are generally clumsy and rough fliers, compared to more delicate and/or agile flying insect pollinators like, butterflies, bees, and flies. To accommodate these clumsy fliers, beetle-pollinated flowers tend to be large, flattened, dish shaped or bowl-shaped, as these features provide them an easy platform for landing and often a good place for shelter (Weber et al., 2020).

1b) Flower color: Although many beetles can see color and UV light, they use color mostly as a short-distance cue for floral choice. Usually, majority of the beetles are preferred dull-colored, sometimes greenish, white, and reddish-brown flowers (Waser & Price, 1983).

1c) Floral odor: Odors that serve as primary beetle attractants are numerous and not always pleasurable, including smells of decaying plant or animal material, fermented fruits, or spices. Indeed, when locating flowers, beetles are attracted to a variety of scents. Therefore, those flowers that do depend on them are typically characterized by the presence of detectable fragrances that acts as a primary long-distance attractant (Weber et al., 2020).

1d) Rewards for beetles: Many beetle species eat pollen, so it is understandable that plants they frequent produce plenty of easily accessible pollen. In addition to pollen, beetle flowers often apply heat as a reward for pollination. This heat is believed to help further spread the scent, but the infrared light produced by this heat may also be visible to insects during the dark night, and act as a shining beacon to attract them (Korotkova and Barthlott, 2009). Some incredible plants can produce heat, which attracts and likely increases the activity level of beetles while visiting their flowers (Weber et al., 2020).

2. MOUTH PARTS OF FLOWER VISITING BEETLES:

Adaptation to flower-visitation has led to behavioral and learning developments, elaborate sensory mechanisms (Barth, 1991; Lunau, 1996), increased flight abilities (Dudley, 2000) and morphological specialization of mouthparts.

2a) Nectar feeder: Generally, mouth parts in most of the beetles are vertical, this position limits the length of the mouth parts, and they are only able to lick up nectar from open flat blossoms (Roubik, 1995). Their unspecialized mouthparts normally are prognathous (Kevan

and Baker, 1983) and only slightly modified from the orthopteroid composition having bristles on the mandibles and setose maxillary and labial structures. Scarabaeid beetles load nectar using sweeping movements of setose maxillary structures in a manner resembling pollen collection (Johnson and Nicolson, 2001). Several taxa of the family Meloidae possess elongated mouthparts that are adapted for feeding from flowers with concealed and partially concealed nectaries (Handschin, 1929; Schremmer, 1961; Kaszab, 1962; Chaudonneret, 1990).

2b) Pollen feeder: In many beetles, the mouthparts are prognathous and may serve equally for pollen and nectar uptake. Since the mouthparts are short, beetles are usually found on flowers with exposed pollen. However, small, and slender beetles can exploit flowers with concealed food sources by crawling or pushing their way into the flower (Barth, 1991). Characteristic for many pollens feeding Coleoptera are several modifications of the mandibles such as hairiness, a soft lacinia mobilis and a postmola which kneads and conveys pollen (Schremmer, 1961; Fuchs, 1974; Nel and Scholtz, 1990). The mandibles may have reduced biting capacity and serve for pollen manipulation. The apical parts of the maxillae bear pads and tufts of bristles, which help take up pollen and transport it to the mouth in conjunction with movements of the labrum/epipharynx unit, labium, and hypopharynx. Pollen-harvesting structures such as comblike bristles and/or specially shaped bristles to which pollen grains adhere were described in Scarabaeidae, Oedemeridae, Cerambycidae, Cantharidae, Bruchidae, Meloidae and Mordellidae. The bristles may be spatulate, spoon-shaped or with various other apical widenings (Fuchs, 1974).

2c) Petal feeder: Petal-feeding beetles belong mainly from the families Nitidulidae, Curculionidae, and the Scarabaeidae. They are attracted by the fruity odor of flower-petals particularly of basal angiosperms such as Annonaceae. The flowers of these plants trap the beetles inside where they feed on the fleshy tissue of the petals and become covered with pollen (Gottsberger, 1989,1990, 1999). The beetles have well-sclerotized mandibles to bite off and chew small pieces of tissue, while maxilla and labium manipulate the food (Proctor et al., 1996). Similarly, meloid beetles of the genus *Mylabris* are reported to predominantly feed on petals and have unmodified chewing mouthparts (Scholtz and Holm, 1985).

3. COLOUR VISION OF INSECTS:

Very few information on colour vision of beetles is known. The number of different spectral receptor types found in one insect species can be as high as six. The spectral range covered by these photoreceptors differs widely between species (Briscoe and Chittka,2001). Beetles preferred colours, as judged from colour traps, are yellow, red, and orange, matching the colour of the flowers of choice (Picker & Midgle, 1996).

Results:

Table.1. List of beetle visitors/pollinators and their host plants of India

No	Species (Reported as)	Valid name	Plant species	Plant family	Role	State	Source
1. Family Buprestidae							
1	*Agrilus* sp.		*Rosa webbiana*	Rosaceae	P	HP	Chatterjee & Mitra (2004)
2. Family Cantharidae							
2*	*Cordylocera livida* (Hope)	*Cordylocera livida* (Hope, 1831)	*Mangifera indica*	Anacardiaceae	P/V	UK	Singh (1997)
3. Family Carabidae							
3	*Brachinus* sp.		*Decalepis hamiltonii*	Apocyanaceae	P	ANP	Raju & Ramana (2009)
4. Family Chrysomelidae							
4*	*Phyllotreta striolata* Fabricius, 1801	*Phyllotreta striolata* Fabricius, 1801	*Brassica juncea*	Brassicaceae	V	WB	Roy et al (2016)
5	*Tachys* sp.		*Brassica juncea*	Brassicaceae	V	WB	Roy et al (2016)
6*	*Altica cyanea*	*Altica cyanea* Weber, 1801	*Eugenia discifera*	Myrtaceae	V	KE	Rajkumar et al (2015)
			Malus domestica	Rosaceae	P	J & K	Riyaz et.al., (2018)
7	*Altica* sp.		*Malus sp.*	Rosaceae	P	HP	Sharma & Mitra (2012)
8	*Altica* sp.		*Actinidia deliciosa*	Actinidiaceae			
9	*Altica* sp.		*Prunus amygdalus*	Rosaceae			
10	*Altica* sp.		*Prunus persica*	Rosaceae			
11	*Altica* sp.		*Pyrus communis*	Rosaceae			
12	*Altica* sp.		*Brassica juncea*	Brassicaceae	P	WB	Roy et al (2016)
13*	*Aulacophora femoralis*	*Aulacophora femoralis* (Motschulski, 1857)	*Cucurbita maxima*	Cucurbitaceae	V	TN	Kumar et al (2012)
14*	*Aulacophora foevicollis* Lucas	*Raphilopalpa foevicollis* (Lucas, 1849)	*Lagenaria siceraria*	Cucurbitaceae	P	ANP	Subhakar & Sreedevi (2015)
			Luffa acutangula	Cucurbitaceae	P/V		
			Momordica charantia Linn	Cucurbitaceae	P/V	ANP	Subhakar et.al., (2011)
	Raphilopalpa foevicollis (Lucas, 1849)		*Coriandrum sativum* L.	Apiaceae	V	HAR	Chaudhary & Singh (2007)
			Foeniculum vulgare Mill.				
15*	*Aulacophora intermedia* Jacoby	*Aulacophora intermedia* Jacoby, 1892	*Mangifera indica var amrapali*	Anacardiaceae	P	BI	Vishwakarma & Singh (2017)
16	*Aulacophora*		*Brassica juncea*	Brassicaceae	P	WB	Roy et al (2016)

	sp.						
17	*Aulacophora* sp.		*Cucumis pubescens*	Cucurbitaceae	P	KR	Balachandran et al (2017)
18	*Aulacophora* sp.		*Cucumis sativus*	Cucurbitaceae	P		
19	*Aulacophora* sp.		*Luffa acutangula*	Cucurbitaceae	V		
20	*Clytra sp*		*Commelina sp.*	Commelianaceae	P	GUJ	Mitra (2004)
21	*Dercetina* sp.		*Anthemis cotula*	Asteraceae	P	HP	Chatterjee & Mitra (2004)
22*	*Monolepta signata* (Olivier,1808)	*Monolepta signata* (Olivier,1808)	*Mangifera indica*	Anacardiaceae	P	ARP	Tayeng & Gogoi (2016)
			Citurs reticulata Blanco	Rutaceae	P		
5. Family Coccinellidae							
23	*Anisolemnia* sp.		*Brassica juncea*	Brassicaceae	P	WB	Roy et al (2016)
24*	*Brumoides suturalis*F.	*Brumoides suturalis* (Fabricius, 1798)	*Daucus carota* L.	Apiaceae	P/V	HAR	Singh et al. (2017)
			Capsicum anum	Solanaceae	V	PUN	Kaur & Sangha, (2016)
25*	*Cheilomenes sexmaculata*	*Cheilomenes sexmaculata* (Fabricius, 1781)	*Daucus carota* L.	Apiaceae	P/V	HAR	Singh et al. (2017)
			Brassica juncea (L.)	Brassicaceae	P	HP	Devi et al (2017)
			Mangifera indica L.	Anacardiaceae	P	MAH	Munj et al. (2017)
			Brassica napus L.	Brassicaceae	V	J & K	Bajiya & Abrol (2017)
	Menochilus sexmaculatus (Fabricius, 1781)		*Litchi chinensis* Sonn.	Sapindaceae	P/ V	BI	Srivastava et al. (2017)
			Helianthus annuus L.	Asteraceae	V	ANP	Jadhav et al (2011)
			Rhizophora mucronata	Rhizophoraceae	V	KR	Chatterjee et al, (2008)
			Tagetes patula	Asteraceae	V	WB	Roy & Mitra, (2012)
			Capsicum anum L.	Solanaceae	V	PUN	Kaur & Sangha, (2016)
			Mangifera indica	Anacardiaceae	P/V	UK	Singh (1997)
			Sorghum sp.	Poaceae	V	RAJ	Srivastava & Srivastava (2020)
26*	*Coccinella magnifica*	*Coccinella magnifica* Redtenbacher, 1843	*Abelmoschus esculentus*	Apiaceae	P	TN	Muthudivya & Rose (2017)
27*	*Coccinella septempunctata* (Linnaeus, 1758)	*Coccinella septempunctata* (Linnaeus, 1758)	*Litchi chinensis* Sonn.	Sapindaceae	P/ V	BI	Srivastava et al. (2017)
			Daucus carota L.	Apiaceae	P/V	HAR	Singh et al. (2017)
			Actinidia deliciosa	Actinidiaceae	P	HP	Sharma & Mitra (2012)
			Malus spp.	Rosaceae	P		
			Prunus amygdalus		P		
			Prunus domestica L.		P		
			Prunus domestica L.		V	HAR	Wadhwa & Sihag, (2015)
			Prunus persica		P	HP	Sharma & Mitra (2012)
			Prunus salicina		P	HP	Sharma & Mitra (2012)
			Pyrus communis		P	HP	Sharma & Mitra (2012)

			Litchi chinensis	Sapindaceae	P/ V	UK	Rai et al. (2017)
			Litchi chinensis	Sapindaceae	P/ V	BI	Srivastava et al (2017)
			Coriandrum sativum	Apiaceae	V	HAR	Chaudhary & Singh (2007)
			Foeniculum vulgare	Apiaceae	P	HAR	Chaudhary (2006)
			Brassica juncea	Brassicaceae	P	HP	Devi et al (2017)
			Brassica juncea	Brassicaceae	V	WB	Roy et al (2014b)
			Brassica juncea	Brassicaceae	V	WB	Roy et al (2016)
			Helianthus sp.	Asteraceae	V	WB	Roy et al (2014a)
			Brassica napus	Brassicaceae	V	J&K	Bajiya & Abrol (2017)
			Guizotia abyssinica	Asteraceae	V	CG	Painkra et al (2015)
			Mangifera indica L. *var.* amrapali	Anacardiaceae	P/V	UP	Chauhan et al., 2018
			Capsicum anum .	Solanaceae	V	PUN	Kaur & Sangha (2016)
			Mangifera indica	Anacardiaceae	P/V	UK	Singh (1997)
			Sorghum sp.	Poaceae	V	RAJ	Srivastava & Srivastava (2020)
			Malus domestica	Rosaceae	P	J&K	Riyaz et. al., (2018)
	Coccinella punctata	*Coccinella septumpunctata* (Linnaeus, 1758)	*Tribulus terrestris*	Zygophyllaceae	V	U.P	Ganaie (2011)
			Cucumis sativus	Cucurbitaceae	V	J & K	Dorjay et al. (2017)
			Memordica charantia				
28*	*Coccinella transversalis*	*Coccinella transversalis* Fabricius, 1781	*Coriandrum sativum*L.	Apiaceae	V	ANP	Ranjitha et.al., (2019)
			Momordica charantia Linn	Cucurbitaceae	P/V	ANP	Subhakar et.al., (2011)
			Brassica juncea	Brassicaceae	V	WB	Bhowmik et al, (2014)
29	*Coccinella* sp.		*Actinidia deliciosa*	Actinidiaceae	P	HP	Sharma & Mitra (2012)
30	*Coccinella* sp.		*Malus* spp.	Rosaceae			
31	*Coccinella* sp.		*Prunus amygdalus*				
32	*Coccinella* sp.		*Prunus persica*				
33	*Coccinella* sp.		*Pyrus communis*				
34	*Coccinella* sp.		*Allium cepa* L.	Amaryllidaceae	V	HAR	Devi et al (2014)
35	*Coccinella* sp.		*Mangifera indica var amrapali*	Anacardiaceae	P	BI	Vishwakarma & Singh (2017)
36	*Coccinella sp*		*Brassica spp.*	Brassicaceae	V	WB	Vishwakarma & Chand (2017)
37*	*Coelophora unicolor* Fabricius	*Phrynocaria unicolor* (Fabricius, 1792)	*Brassica juncea* (L.)	Brassicaceae	V	WB	Roy et al (2014b)
38	*Henosepilachna* sp.		*Momordica charantia*	Cucurbitaceae	P	KR	Balachandran et al (2017)
39	*Henosepilachna* sp.		*Luffa acutangula*	Cucurbitaceae	P		
40	*Henosepilachna* sp.		*Brassica spp.*	Brassicaceae	V	WB	Vishwakarma & Chand (2017)
41*	*Hippodamia variegate*(Goeze)	*Hippodamia variegata*(Goeze, 1777)	*Brassica juncea* (L.)	Brassicaceae	P	HP	Devi et al (2017)
			Malus domestica	Rosaceae	P	J&K	Riyaz et.al. (2018)

42	*Hippodamia sp.*		*Litchi chinensis* Sonn.	Sapindaceae	P/ V	BI	Srivastava et al. (2017)
43*	*Illeis cincta*Fab.	*Illeis cincta* Fabricius, 1798	*Momordica charantia*	Cucurbitaceae	P/V	ANP	Subhakar et.al. (2011)
44*	*Micaspis discolor*	*Micraspis discolor* (Fabricius, 1798)	*Avicenia officinalis*	Acanthaceae	V	KR	Chatterjee et.al. (2008)
			Coriandrum sativum	Apiaceae	V	ANP	Ranjitha et.al. (2019)
45	*Oenopia* sp.		*Brassica juncea* (L.)	Brassicaceae	P	HP	Devi et al (2017)
46	*Oenopia* sp.				V	WB	Bhowmik et.al. (2014)
47*	*Pullus pyrochilus*	*Scymnus pyrocheilus* Mulsant, 1853	*Tagetes patula*	Asteraceae	V	WB	Roy & Mitra (2012)
6. Family Curculionidae							
48*	*Elaeidobius kamerunicus* Faust, 1898	*Elaeidobius kamerunicus* Faust, 1898	*Elaeis guineensiss* Jacq.	Arecaceae	P	KE	Dhileepan (1992, 1994)
			Elaeis guineensiss Jacq.	Arecaceae	P	KE	Sambathkumar & Ranjith (2011)
49	*Derelomus* sp.		*Cycas sphaerica* Roxb.	Cycadaceae	P	ANP	Raju & Jonathan (2010 a.)
50	*Derelomus* sp.		*Cycas circinalis*	Cycadaceae	P	KE	Radha & Singh (2014)
51	*Derelomus* sp.		*Cycas annakailensis*	Cycadaceae	V	KE	Radha & Singh (2014)
52*	*Hypolixus truncatulus*	*Hypolixus truncatulus* Fabricius,1798	*Sorghum* sp.	Poaceae	P/V	RAJ	Srivastava & Srivastava (2020)
53*	*Myllocerus discolor* Boheman, 1834	*Myllocerus discolor* Boheman, 1834	*Helianthus annuus*	Asteraceae	V	ANP	Jadhav et al (2011)
54	*Myllocerus sp*		*Sorghum* sp.	Poaceae	P/V	RAJ	Srivastava & Srivastava (2020)
55	*Calandra sp.*	*Sitophilus sp.*	*Cycas circinalis*	Cycadaceae	P	KE	Radha & Singh (2014)
7. Family Erotylidae							
56	*Pharaxonotha? nigra* (Gorham)		*Cycas annakailensis*	Cycadaceae	P	KE	Radha & Singh (2014)
8. Family Histeridae							
57*	*Carcinops troglodytes* (Paykull)	*Carcinops troglodytes* (Paykull, 1811)	*Cycas annakailensis*	Cycadaceae	P/V	KE	Radha & Singh (2014)
			Cycas circinalis				
9. Family Leiodidae							
58	*Ptomaphaginus* sp.		*Theriophonum infaustum*	Araceae		KE	Sivadasan & Raghavan (2005)
10. Family Lyctidae							
59	*Lyctus* sp.		*Amorphophallus bulbifer* (Roxb.) Blume	Araceae		MAH KR, GOA	Punekar & Kumaran (2010)
11. Family Meloidae							
60*	*Cylindrothorax pictus*	*Cylindrothorax pictus* (Laporte,1840)	*Sorghum* sp.	Poaceae	V	RAJ	Srivastava & Srivastava (2020)
61*	*Mylabris himalayensis* Saha, 1977	*Mylabris himalayensis* Saha, 1977	*Wrightia tinctoria*	Apocynaceae	P	GUJ	Mitra (2004)
			Momordica diopsea	Cucurbitacae			
			Solanum xanthocarpum	Solanaceae			

			Holorrhena antidysenterica	Apocyanaceae			
62*	*Mylabris pustulata*	*Mylabris pustulata* (Thunberg, 1821)	*Senegalia senegal*	Fabaceae	P	DEL, RAJ	Tandon & Shivana (2001)
63	*Mylabris* sp.		*Buddelia paniculata*	Scrophulariaceae	P	HP	Chatterjee & Mitra (2004)
64	*Mylabris* sp.		*Lantana camara*	Verbenaceae			
65	*Mylabris* sp.		*Senecia nudicaulis*	Asteraceae			
12. Family Nitidulidae							
66*	*Aethina (Circopes) subquadrata* (Motschulsky,1858)	*Aethina (Circopes) subquadrata* (Motschulsky,1858)	*Phaseolus vulgaris*	Fabaceae	V	AS	Dasgupta et.al. (2017)
67	*Aethina* (*Circopes)* sp.		*Annona sp.*	Annonaceae	V	KR	Dasgupta et.al. (2017)
68	*Aethina (Idaethina) sp*		Ipomoea sp.	Convolvulaceae	V	KR	Dasgupta et.al. (2017)
69*	*Carpophilos domidiatus*	*Carpophilus dimidiatus* (Fabricius, 1792)	*Annona squamosa*	Annonaceae	P	ODI	Kishore et.al. (2012)
70*	*Carpophilos hemipterous*	*Carpophilus hemipterus* (Linnaeus, 1758)	*Annona squamosa*		P	ODI	Kishore et.al. (2012)
71*	*Carpophilus marginellus* Motschulsky	*Carpophilus marginellus* Motschulsky,1858	*Annona sp.*		V	KR	Dasgupta et.al. (2017)
72*	*Carpophilus plagiatipennis*	*Carpophilus (E) plagiatipennis* Motschulsky, 1858	*Monoon tirunelveliense*		P	TN	Viswanathan et.al. (2019)
73*	*Epuraea (Haptoncus) ocularis* Fairmaire	*Epuraea (Haptoncus) ocularis* Fairmaire, 1849	*Neolamarckia cadamba*	Rubiaceae	V	WB, UP	Dasgupta et.al. (2017)
74*	*Epuraea (Haptoncus) motschulskyi* (Reitter)	*Epuraea (Haptoncus) motschulskyi* (Reitter, 1877)	*Lagenaria siceraria*	Cucurbitaceae	V	WB	
			Cucurbita maxima	Cucurbitaceae	V	WB	
75*	*Epuraea (Micruria)* viraktamathi	*Epuraea (Micruria) viraktamathi* Dasgupta, Pal, Hegde,2016	*Camellia sinensis*	Theaceae	V	WB, AS	
76	*Epuraea* sp (1)		*Pisum sativum*	Fabaceae	V	KR	
			Rosa sp.	Rosaceae	V	KR	
			Hibiscus rosa-sinensis	Malvaceae	V	KR	
77	*Epuraea* sp (2)		*Datura* sp.	Solanaceae	V	WB	
78	*Epuraea (Haptoncurina)* sp.		*Amorphophallus bulbifer* (Roxb.) Blume	Araceae	P	MAH, KR & GOA	Punekar & Kumaran (2010)
			Amorphophallus commutatus (Schott) Engl. *var. commutatus*				
			Amorphophallus commutatus var. wayanadensis Sivad. and Jaleel				

			Amorphophallus konkanensis Hett., S.R. Yadav and K.S. Patil				
			Amorphophallus sylvaticus (Roxb.) Kunth				
79*	*Haptoncurina motschulskii* (Reitter)	*Haptoncurina motschulskii* (Reitter,1873)	*Amorphophallus hohenackeri*			KE	Sivadasan & Sabu (1989)
80	*Lasiodactylus* sp.		*Neolamarckia cadamba*	Rubiaceae	V	WB	Dasgupta et.al. (2017)
81*	*Pria ceylonica* Grouvelle	*Pria ceylonica* Grouvelle,1902	*Solanum melongena*	Solanaceae	V	WB , TRI	
			Solanum sisymbriifolium Lamarck				Dasgupta et.al. (2017)
82*	*Taenioncus cylindricus* (Murray)	*Taenioncus cylindricus* (Murray,1864)	*Ficus glomerata* Roxb	Moraceae	V	UP	
83*	*Urophorus humeralis* Fab	*Urophorus humeralis* (Fabricius, 1798)	*Neolamarckia cadamba* (Roxb.)	Rubiaceae	V	WB	Dasgupta et.al. (2017)
							Dasgupta et.al. (2017)
13. Family Scarabaeidae							
84*	*Clinteria spilota*(Hope)	*Clinteria spilota* (Hope, 1831)	*Cirsium wallichi*	Asteraceae	P	HP	Chatterjee & Mitra (2004)
			Castanea sativa	Fagaceae			
85*	*Protaetia neglecta* (Hope)	*Protaetia neglecta* (Hope, 1831)	*Senecia nudicaulis*	Asteraceae			
86*	*Anomala lateralis* Hope	*Ischnopopillia lateralis* (Hope, 1831)	*Cirsium wallichi*	Asteraceae			
			Castanea sativa	Fagaceae			
87*	*Anomala bengalensis*	*Anomala bengalensis* (Blanchard, 1850)	*Sorghum* sp.	Poaceae	P/V	RAJ	Srivastava & Srivastava (2020)
88	*Anomala* sp.		*Eugenia discifera*	Myrtaceae	V	KE	Rajkumar et al. (2015)
89*	*Mimela heterochropus* Blanchard	*Mimela heterochropus* Bla nchard, 1850	*Castanea sativa*	Fagaceae	P	HP	Chatterjee & Mitra (2004)
90*	*Popillia propinqua* Arrow, 1913	*Popillia madrasicola (Machatschke,* 1972)	*Sonneratia caseolaris*	Lythraceae	V	KR	Chatterjee et.al. (2008)
91	*Popillia* sp.		*Aegiceras corniculatum*	Primulaceae	V	ODI	Mitra (2018)
92*	*Popillia feae* Kraatz	*Popillia feae* Kraatz, 1892	*Anthemis cotula*	Asteraceae	P	HP	Chatterjee & Mitra (2004)
			Castanea sativa	Fagaceae	P		
93*	*Popillio impressipyga* Ohaus	*Popillio impressipyga* Ohaus, 1897	*Syzygium alternifolium*	Myrtaceae	V	ANP	Raju et.al. (2014)
94*	*Apogonia*	*Apogonia*	*Sorghum* sp.	Poaceae	P/V	RAJ	Srivastava &

	ferruginea	*ferruginea* Fabricius, 1781					Srivastava (2020)
95*	*Maladera castanea*	*Maladera (Cephaloserica) castanea* (Arrow, 1913)	*Schima wallichii*	Theaceae	V	MIZ	Kumar & Khanduri (2016)
96*	*Onthophagus bonasus*	*Digitonthophagus bonasus* Fabricius, 1775	*Sorghum* sp.	Poaceae	V	RAJ	Srivastava & Srivastava (2020)
97*	*Oxycetonia jucunda* (Faldermann)	*Gametis jucunda* (Faldermann, 1835**)**	*Cirsium wallichi*	Asteraceae	P	HP	Chatterjee & Mitra (2004)
			Castanea sativa	Fagaceae			
98*	*Oxycetonia versicolor* Fab.	*Gametis versicolor* (Fabricius, 1775)	*Senegalia Senegal* (L.) Britton	Fabaceae	V	DEL& RAJ	Tandon & Shivanna (2001)
			Helianthus annuus L.	Asteraceae	P	ANP	Jadhav et al (2011)
			Capsicum anum	Solanaceae	V	PUN	Kaur & Sangha (2016)
99*	*Peltonotus nasutus*	*Peltonotus nasutus*, Arrow, 1910	*Sorghum* sp.	Poaceae	P/V	RAJ	Srivastava & Srivastava (2020)
14. Family Staphylinidae							
100*	*Anotylus latiusculus*(Kraatz)	*Anotylus latiusculus* (Kraatz, 1859)	*Theriophonum infaustum*	Araceae	V	KE	Sivadasan & Raghavan (2005)
101*	*Anotylus rubidus* Cameron	*Anotylus rubidus* Cameron, 1930	*Theriophonum infaustum*	Araceae			
102	*Anotylus* sp. nr. *A. rubidus* (Cameron)		*Theriophonum infaustum*	Araceae			
103	*Atheta* sp.		*Theriophonum infaustum*	Araceae			
104*	*Paederus fuscipes* (Curtis)	*Paederus fuscipes* Curtis, 1826	*Capsicum anum*	Solanaceae		PUN	
105*	*Philonthus flavocinctus* Motschulsky	*Philonthus flavocinctus* Motschulsky, 1858	*Theriophonum infaustum*	Araceae		KE	
106*	*Oxytelus incisus* Motschulsky	*Oxytelus incisus* Motschulsky, 1857	*Theriophonum infaustum*	Araceae			
15. Family Tenebrionidae							
107	*Alphitobius* sp.		*Cycas beddomei*	Cycadaceae	P	AP	Raju & Jonathan, (2010 b), Radha & Singh (2014)
108	*Gonocephalum* sp.		*Brassica juncea*	Brassicaceae		WB	Roy et al. (2016)
109*	*Tribolium castaneum*(Herbst)	*Tribolium castaneum* (Herbst,1797)				HP	Devi et al (2017)
110	*Tribolium* sp.		*Cycas annakailensis*	Cycadaceae		KE	Radha & Singh (2014)
			Cycas circinalis				

Abbreviations used: Andhra Pradesh (ANP), Arunachal Pradesh (ARP), Assam (AS), Bihar (BI), Chhattisgarh (CG), Delhi (DEL), Goa (GOA), Gujarat (GUJ), Haryana (Har), Himachal Pradesh (HP), Jammu & Kashmir (J & K), Karnataka (KR), Kerala (KE), Maharashtra (MAH), Mizoram (MIZ), Odisha (ODI), Punjab (PUN),

Rajasthan (RAJ), Tamil Nadu (TN), Tripura (TRI), Uttarakhand (UK), Uttar Pradesh (UP) and West Bengal (WB)

In World:

Review of published literature uncovers that only 36 families of beetles are found as pollinators of 55 plant families in the world. Among them, the plant family Apiaceae invites highest number of beetle families (21), whereas the family Scarabaeidae of the order Coleoptera is reported as a leading pollinator groups and visited the highest number of plant families (21).

In India:

This present communication reports 110 species (identified/unidentified) under 15 families of order Coleoptera as visitors/pollinators of 80 species(identified/unidentified) under 34 families of plants in India (Table.1). The predominant flower visiting beetle family is Coccinellidae (25 species) and *Coccinella septempunctata* is having the highest number of host plants (28). This review also observed that, Asteraceae (11species) and *Brassica juncea* (14) are the most attracted plant family and species respectively in India (Table.1). Unfortunately, a good number of species are unidentified up to species level. In this communication, we shall discuss briefly only on 56 identified beetle species (marked with * in table.1) under 10 families reported as pollinators from India (Fig.2).

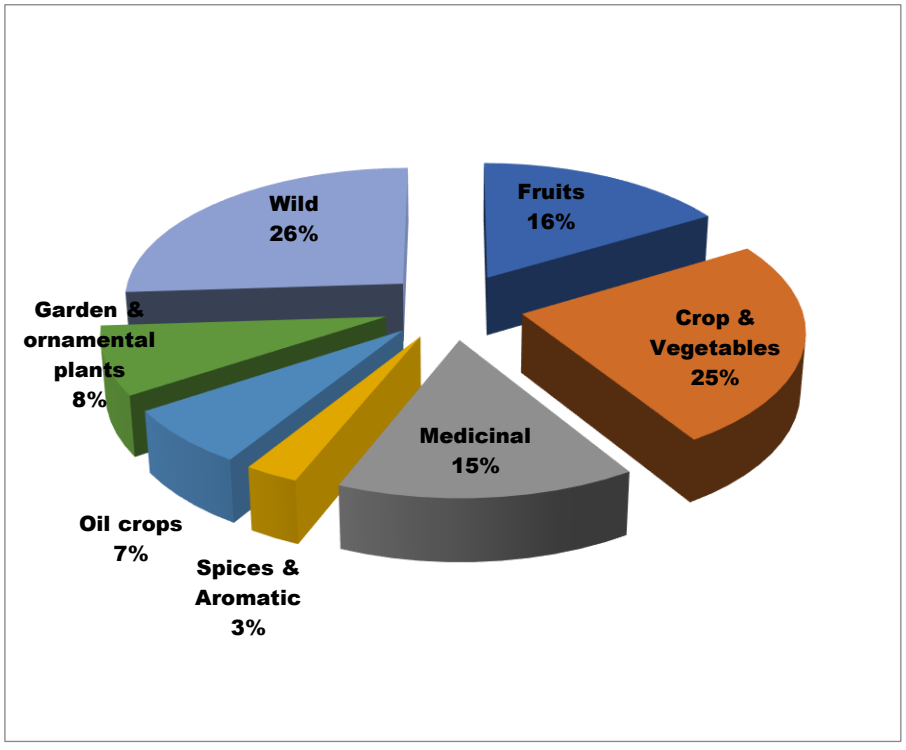

Fig.1. Economically important flora and their beetle pollinators (in %)

Considering the economic importance of the plants, the beetle visiting plants can be divided in 7 categories (Fig.1). This communication reports that wild plants (26%) and crops & vegetables (25%) are largely dependent on beetles for their reproduction (Fig.1).

Fig. 2. Most preferable flower color of beetle visitors in India

This present communication reveals that majority of the beetle species preferred yellow (29 species) and white (27 species) colour flower and minimum colour preference to Red (3) and Pink (1) in India (Fig.2).

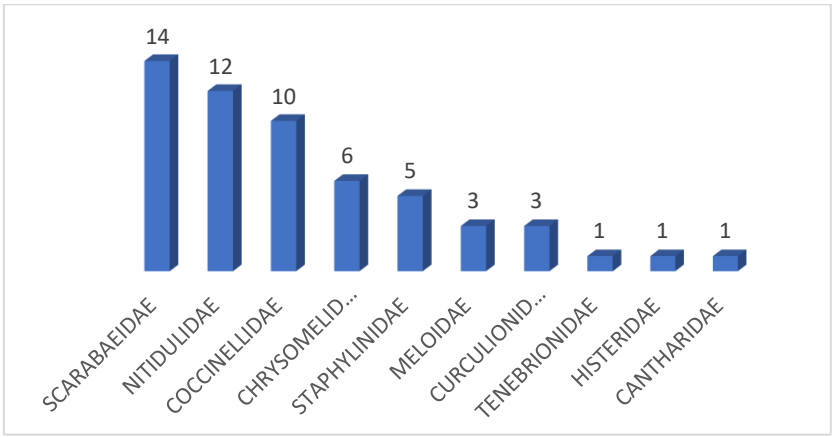

Fig.3. Identified Flower visiting beetle species diversity (Familywise)

Description of the families and their diversity in India:

1. Family Cantharidae:

Soldier beetles are relatively soft bodied, small to medium in size (1 to 15 in length), elongated and parallel sided beetles with squarish prothorax. Adult females laid eggs in

clusters in the soil. The larvae are velvety, coated with dense bristles, and have antenna-like projections on their head. Larvae are carnivorous, feeding mostly on soil arthropods. Larvae hibernate in damp soil, leaf litter and loose bark. *Cordylocera livida* of this family is reported as visitor/pollinator of *Mangifera indica* from India (Table.1 & Fig.3).

2. Family Chrysomelidae:

Leaf beetles are mostly phytophagous, strong fliers, elongated, but sometimes cylindrical to flat, oval (1-20mm in length) and coloured varied and bright. Third tarsal segment bilobed and antennae short to medium in length and without club are the distinctive characters of the leaf beetles (Sengupta,2005). Only 6 species of this family are known as visitors of 12 host plants (7 families) from India (Table.1 & Fig.3).

3. Family Coccinellidae:

Lady bird beetles are round and convex, minute to medium in size (1-10mm) beetle. Often conspicuously coloured with yellow, orange, or red with small black spots on their wings. Legs, heads, and antennae are black (Sengupta,2005). Only 10 identified species are reported as visitors/ pollinators of 24 plant species (12 families) from India (Table.1 & Fig.3).

4. Family Curculionidae:

Weevils or Snout beetles are recognized by their distinctive long rostrum and geniculate antennae with small clubs, sizes 1-35mm in length, colour varied, usually blackish or brownish (Sengupta,2005). Only 3 species are observed as visitors/pollinators from 3 host plants (3families) in India (Table.1 & Fig.3).

5. Family Histeriidae:

Hister beetles are minute to moderately large (0.5-10mm in length), hard and compact, oval, cylindrical or flattened, black, bronze, or green metallic colour beetle. Antennae geniculate and club shaped, elytra short and exposing one or two last abdominal tergites. Only a single species, *Carcinops troglodytes* (Host plants: *Cycas annakailensis, Cycas circinalis*) is identified as visitor/pollinator from India (Table.1 & Fig.3).

6. Family Meloidae:

Blister beetles can be easily recognised by their elongated soft bodies (3 to 30mm in length), vertical head with narrow neck constriction, brightly coloured with yellow and black.

Cylindrothorax pictus, Mylabris himalayensis & *M. pustulata* are reported here as visitors/pollinators of 6 plant species (6 families) from India (Table.1 & Fig.3).

7. Family Nitidulidae:

Sap beetles are small (1.5 to 12mm in length), ovoid, usually dull-coloured, with knobbed antennae. Some have red or yellow spots or bands. In India, 11 plant species of 8 families are dependent on 12 species of nitudilids for their pollination and reproduction (Table.1 & Fig.3).

8. Family Scarabaeidae:

Dung beetles are distinctly recognised with robust body (2 to over 100 mm in length) and lamellate- type of clubbed antenna. Flower visiting species of this family are often colourful. In India, the highest number of beetle species (14) are reported from this family. Moreover, 11 species of plants (11families) are dependent on these beetles for their successful pollination in India (Table.1 & Fig.3).

9. Family Staphylinidae:

Rove beetles can be easily recognised by their truncated elytra exposing a large part of the abdomen. Shape is generally narrow- elongated (1 to 20 mm), colour black, brown, yellowish, bluish, reddish etc. Only five species of this family are reported as pollinators from two plant species in India (Table.1 & Fig.3).

10. Family Tenebrionidae:

Darkling beetles are a versatile group, found almost in all habitats, varied in shape and size (2-35mm in length), generally smooth, brown, or black, antennae may be filiform, moniliform or weakly clubbed. They eat exposed pollen on the anthers, while other pollen grains adhere to their legs. *Tribolium castaneum* or rust-red flour beetle (Host plant: *Brassica juncea*) is only identified species of this family reported as pollinator in India (Table.1 & Fig.3).

Discussion:

Beetles are common flower-visitors, though they are often not considered to be as abundant, diverse, or important as species from the other major orders on flowers (Kevan and Baker 1983). But it is true that, cantharophily probably played the earliest and longest lasting, key pollinator roles, and might have acted as pollinators since their first appearance during the

Permian (Labandeira et al., 2007). Moreover, recent work has revealed that flowers in tropical rainforests attract a very high density and diversity of beetles (Kirmse et al. 2003; Ødegaard and Frame 2007; Wardhaugh et al. 2012, 2013a). Wardhaugh et al. (2013b, 2015) showed that the host specificity of flower-visiting beetles could be relatively high, introducing the possibility of high regional and global diversity as well. Indeed, beetles may constitute the second most important group of insect pollinators after bees in tropical forests (Wardhaugh, 2015).

Current knowledge of beetle mediated pollination in India is summarized herein based on the available literature and published documents. Considering the role and importance in pollination of the beetles, it can be said that much less studied have been made on flower visiting beetles in India. It is true, that several works on beetle pollination have been made in the different states of India, but the information is inadequate and scattered. Moreover, proper identification of the taxa is also posed problems to ascertain the actual number of species involved in the pollination. So, more efforts to identify beetle species beyond the level of order or family will also enhance our knowledge on cantharophily in India.

Usually, floral scent as the primary attractant of pollinating beetles, but in a recent study, it has been established that monkey beetle relies on visual signals (van Kleunen et al, 2007). Generally, majority of the beetles are attracted to dull-colored, greenish, or white, and reddish-brown flowers. But based on this communication, it appears that, yellow and white flowers are the most preferable colour for beetle visitors (Fig.3).

This communication reveals that there are huge gaps in our knowledge on beetle pollinators compared to other insect pollinators in India. More field studies on flower visiting beetles will certainly lead to a better understanding of the functional aspects of cantharophily in India.

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