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Research Article

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Species Diversity of Indian Aphids (Hemiptera: Aphididae)

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Abstract: The aphids are tiny sap sucking plant lice that not only infest agricultural and horticultural crops but also spread several viral diseases. They are very fascinating insects as these are thelytokous parthenogenetic viviparous, having short generation time and telescopic generation with polymorphism. Many species of aphids display complex life cycles with alternation of sexual and asexual generations and host plant alternation. Aphids are almost cosmopolitan in distribution, but are most common in temperate areas. Unlike many taxa, aphid species diversity is much lower in the tropics than in the temperate zones. They can migrate great distances, mainly through passive dispersal by winds. At present all true aphids belong to a single family Aphididae which consists of 24 subfamilies. Globally, 5109 species of aphids are described under 527 genera. In India, 794 species of aphids under 208 genera are reported out of which about 385 are endemic. The subfamily Aphidinae constitutes a monophyletic group within the family with about 3100 extant species worldwide with higher diversity in temperate regions. In India, 431 species under 105 genera of this subfamily are reported out of which 192 species are endemic. In this paper, distribution of extant aphid species in different taxa of Aphididae is described.

Keywords: Aphididae, Aphid diversity, Aphid taxonomy, Hemiptera, Virginoparous.

Introduction

Aphids (Hemiptera: Aphididae) are a group of over 5,100 species of small insects that suck the phloem fluid of plants. They vary in size between 0.7 to 7.0 mm in length. Aphids are almost cosmopolitan in distribution, but are most common in temperate areas. Unlike many taxa, aphid species diversity is much lower in the tropics than in the temperate zones (Żyła *et al.*, 2017). They can migrate great distances, mainly through passive dispersal by winds. Many species are economically important as they infest agricultural and horticultural crops. Several biological traits are associated with aphids, such as thelytokous parthenogenetic viviparity, short generation time, telescopic generations, and polymorphism. These reproductive characteristics allow aphids to quickly colonize ephemeral resources and quickly growing plants and make them ideal enemies of crops. Many species of aphids display complex life cycles with alternation of sexual and asexual generations and host plant alternation. Viviparous aphids

(subfamily Aphidinae) constitute a monophyletic group within the family with about 3100 extant species worldwide with higher diversity in temperate regions. Their plant-sap-sucking way of feeding is unique. Once they fasten their piercing mouthparts to a juicy plant, they tend to stay there and begin to suck the sap. They defecate characteristic sticky sweet honeydew that attracts as food for wasps, butterflies, some moths and famously, some species of ants which in return protect them from predators. Many species of aphids transmit viruses to crop plants that have important implications on crop management strategies (Minks and Harrewijn, 1987). Although aphids are the pest of crops, they are extremely important hosts for a number of parasitoids, predators, and an essential meal for numerous other insects, as well as birds. Aphids have a vital role in the chain of life. Keeping aphid populations to manageable numbers on susceptible plants, rather than eradication should be the aim of pest management workers (Singh and Singh, 2016a).

Globally, more than 250 species of aphids are pests of both agricultural and horticultural crops (Verma, 2000). This figure is only about 5% of the estimated world fauna of over 5100 species (Favret, 2019).

Biology of aphids

When an aphid species feed on only a single host plant it is autoecious and that alternate between two host plants of different taxa are called heteroecious. Two distinct kinds of heteroecious life cycles are recognised. Species of the Hormaphidinae, Anoeciinae and Pemphiginae have a type of heteroecy with sexuparae. Other aphid species with host alternation do not have sexuparae, but have a life cycle with winged sexual females and winged males. Moran (1988) reviewed the evolution of host-plant alternation in aphids. The aphids are one of the few groups of animals that undergo cyclical parthenogenesis, i.e., the alternation of one or many generations of asexual (parthenogenetic) reproduction with a single generation of sexual reproduction. Some aphids are anholocyclic (continuously parthenogenetic and produces only asexual morphs), while others living in temperate climates are holocyclic (sexual generation alternates with parthenogenetic reproduction). In a year's time, numerous generations may succeed one another, for even at moderate mean temperatures the nymphs which moult four times at most, complete their development in little more than 10 days.

About 85% of the described species from India are parthenogenetic virginoparous for most of the year but are capable of sexual reproduction with production of eggs. They develop in parthenogenetic female without fertilisation. Even embryos inside parthenogenetic females may contain embryos, i.e., a mother can have in its ovarioles developing embryos which in turn also contain embryos, the future granddaughters. Thus, there is a telescopic generation due to parthenogenesis and viviparity in aphids (Minks and Harrewijn, 1987). This results in reduced postnatal development periods and generation time. All aphids have diploid parthenogenesis and there is no reduction division and development starts from germinal cells with full complement of chromosomes.

Taxonomy of the aphids

Aphid taxonomy is often frustrated by the host alternation and extensive polyphenism displayed by many species. In the literature, some aphidologists (Remaudière and Remaudière, 1997; Blackman and Eastop, 2000, 2007) refer to the families of Heie (1987) as subfamilies. There is no extremely good reason to prefer one categorisation over the other and fortunately this dichotomy in the literature has led to little confusion. However, the use of family designations has the only single advantage of allowing slightly more details in taxonomic hierarchies.

We followed the subfamily classification of Favret (2019) who kept all the extant aphid species under 24 subfamilies, viz. Aiceoninae, Anoeciinae, Aphidinae,

Baltichaitophorinae, Calaphidinae, Chaitophorinae, Drepanosiphinae, Greenideinae, Eriosomatinae, Hormaphidinae, Israelaphidinae, Lachninae, Lizeriinae, Macropodaphidinae, Mindarinae, Neophyllaphidinae, Phloeomyzinae, Phyllaphidinae, Pterastheniinae, Saltusaphidinae, Spicaphidinae, Taiwanaphidinae, Tamaliinae and Thelaxinae. Table 1 summarises the species diversity of aphids in different taxa of Aphididae.

Subfamilywise aphid diversity

Out of 24 subfamilies of Aphididae, only 16 subfamilies are represented in India (Table 1). The most species diversity was observed in the subfamily Aphidinae (431 species) followed by Greenideinae (96 species), Eriosomatinae (64 species) and Hormaphidinae (57 species). Recently, Singh and Singh (2016a, b, 2017a-f, 2018) and Singh *et al.*, (2018) catalogued the Indian aphids and their food plants. Following is the details of different subfamilies of aphids.

i. Subfamily : Aiceoninae

Earlier, the subfamily Anoeciinae is composed of two tribes: Aiceonini and Anoeciini (Ghosh, 1988), however, Remaudière and Remaudière (1997) elevated the tribe Aiceonini to the subfamily Aiceoninae that contains only one genus *Aiceona* Takahashi, 1921 in which 18 species are assigned (Remaudière and Remaudière, 1997). These aphids are unique by having much shorter processus terminalis than base of last antennal segment, apterae with 3-faceted eyes, without lateral abdominal tubercles, and alatae with media of forewings twice branched. In India, only 8 species of Aiceoninae are recorded and all are endemic. The plants species belonging to Araliaceae, Lauraceae, Malvaceae, Menispermaceae, Poaceae and Scrophulariaceae serve as food plant (Singh and Singh, 2016a).

ii. Subfamily : Anoeciinae

The subfamily Anoeciinae live underground and feed on the plant roots. It consists of only two genera *Anoecia* Koch, 1857 that contains 29 species/subspecies and a monotypic genus *Krikoanoecia* Zhang and Qiao (Remaudière and Remaudière, 1997; Neito Nafria *et al.*, 2011). They differ from Aiceoninae by having many faceted eyes in apterae and with lateral abdominal tubercles, alatae with media of forewing once branched. Only 6 species of which 2 are endemic are recorded from India infesting 6 species of plants belonging to mainly Poaceae followed by Solanaceae and Cornaceae (Singh and Singh, 2016a).

iii. Subfamily : Aphidinae

The Aphidinae contains two tribes: Aphidini and Macrosiphini. The Aphidini is one of the 2 tribes of the subfamily Aphidinae, the largest subfamily of the aphids, including about 832 species/subspecies assigned to 33 genera globally. Out of these, only 9 genera and 65 species/subspecies were recorded from India, 14 being endemic, infesting 940 plant species belonging to 138 families, out of which only 19 families are monocot. Indian Aphidini are recorded mostly on the plant family Asteraceae

(102 plant species), followed by Fabaceae (96 plant species), Poaceae (92 plant species), Lamiaceae (46 plant species), Rosaceae (38 plant species), Solanaceae (34 plant species), Apocyanaceae (28 plant species), Rubiaceae (26 plant species), Malvaceae (25 plant species), Rutaceae (22 plant species), Cucurbitaceae (22 plant species), Polygonaceae (21 plant species), etc. Out of 69 described species of Aphidini in India, 15 species are monophagous; 38 species are oligophagous infesting 2 to 20 plant species; and 8 species are moderately polyphagous infesting 21 to 55 plant species while 8 species are highly polyphagous feeding on 55 upto 569 plant species (Singh and Singh, 2016b). Most of the polyphagous species are injurious pests of agricultural and horticultural crops, e.g. cotton aphid *Aphis gossypii* Glover, cowpea aphid *Aphis craccivora* Koch, bean aphid *Aphis fabae* Scopoli etc.

The tribe Macrosiphini is the largest tribe containing about 2263 species/subspecies assigned to 243 genera globally. Out of these, only 96 genera and 366 species/subspecies were recorded from India, 178 being endemic, infesting 810 plant species belonging to 122 families. Indian Macrosiphini is recorded mostly on the plant family Asteraceae (Singh and Singh, 2017a, b, c). Several species of this group are notorious crop pests worldwide, e.g. pea aphid *Acyrtosiphon* (pisum (Harris), leaf curl plum aphid *Brachycaudus helichrysi* (Kaltenbach), cabbage aphid *Brevicoryne brassicae* (Linnaeus), coriander aphid *Hyadaphis coriandri* (Das), turnip aphid *Lipaphis erysimi* (Kaltenbach, 1843), mustard aphid *Lipaphis pseudobrassicae* (Davis), green peach aphid *Myzus persicae* (Sulzer), grain aphids *Sitobion avenae* (Fabricius) and *Sitobion miscanthi* (Takahashi).

iv. Subfamily : Baltichaitophorinae

This subfamily is monotypic represented by only one species *Parachaitophorus spiraeae* (Takahashi) endemic to Formosa, the species however, is not recorded from India.

v. Subfamily : Calaphidinae

The aphids of Calaphidinae are monoecious, oligophagous and mostly associated with trees of Betulaceae, Fagaceae, Ulmaceae, Anacardiaceae, and Juglandaceae and herbaceous plants like Fabaceae, Poaceae and Rosaceae. The Calaphidinae consists of 2 tribes: Calaphidini and Panaphidini. The tribe Calaphidini contains about 77 species assigned to 17 genera while Panaphidini includes 271 species under 46 species globally. In India, Calaphidini is represented by 5 genera and 14 species among which 11 species are endemic. The tribe Panaphidini is represented by 20 genera and 34 species out of which 19 are endemic. All these 48 species feed on 62 plant species (Singh and Singh, 2017d).

vi. Subfamily : Chaitophorinae

The members of subfamily Chaitophorinae have body with conspicuous hairs, processus terminalis equal to or much longer than base of last antennal segment, cornicles are

truncated or ring-like and cauda crescent shaped or knobbed. The subfamily contains 12 genera assigned under two tribes: Chaitophorini (7 genera, 153 species) and Siphini (5 genera, 25 species) comprising 178 species. Chaitophorini is represented in India by 25 species out of which 12 species are endemic infesting over 25 plant species belonging to 11 plant families, mostly of Sapindaceae and Salicaceae. The Siphini is represented in India by only 2 exotic species infesting over 10 plant species out of which 9 belong to Poaceae (Singh and Singh, 2016a).

vii. Subfamily : Drepanosiphinae

The subfamily Drepanosiphinae contains totally 5 genera in which 39 species are assigned (Favret, 2019) out of which only 2 genera, *Drepanosiphum* Koch and *Yamatocallis* Matsumura, having 2 species each are recorded from India. Both species of *Yamatocallis* are endemic. These species can be recognized from others by having winged morphs in parthenogenetic generation exclusively and have long antennae with a very long processus terminalis and ciliated rhinaria, forelegs with enlarged femora, long cylindrical siphunculi and knobbed cauda. They infest plants of two families: Sapindaceae (*Acer* spp.) and Poaceae (*Bambusa* sp.) (Singh and Singh, 2016a).

viii. Subfamily : Eriosomatinae

The members of Eriosomatinae, commonly called as woolly aphids, produce filamentous waxy white covering which resembles cotton or wool. The adults are winged and migrate to new locations where they lay egg masses. The nymphs often form large cottony masses on twigs, for protection from predators. The Eriosomatinae is typically known for inducing galls on primary host plants and displays a heteroecious holocyclic life history, i.e. seasonal host alternation and cyclical parthenogenesis, and host-plant specificity (Thakur and Dogra, 1980; Chakrabarti, 2007). The woolly apple aphid, *Eriosoma lanigerum* (Hausmann) is a widespread pest of fruit trees, feeding principally on apple, but also, pears, hawthorn, ash, alders, elms and oaks (Blackman and Eastop, 2008). Similarly, the rice root aphid, *Tetraneura* (*Tetraneurella*) *nigriabdominalis* (Sasaki) is a major pest of many cereal crops, particular rice and millets. The biology and brief history of taxonomy of these aphids are summarized by Ghosh (1984). Out of 374 valid extant species of world Eriosomatinae assigned to 48 genera, in India only 64 species are reported under 19 genera, out of which 22 species are endemic. Some of them are pestiferous. These aphids feed on 130 plant species belonging to 30 plant families. *Tetraneura nigriabdominalis* was observed highly polyphagous infesting 64 plant species. The most preferred plants for these aphids belong to family Poaceae (76 plant species), followed by Rosaceae (17 species), Saliaceae (9 species), Anacardiaceae (6 species) and Asteraceae (6 species) (Singh and Singh, 2017e).

ix. Subfamily : Greenideinae

The members of the subfamily Greenideinae possess usually elongated and densely hairy cornicles or siphunculi, if short

and truncate then without any hair but with a pair of dorsal process arising from the abdominal tergite 7. Globally, it consists of 179 species under 16 genera (Fevret, 2019). The subfamily includes 3 tribes: Cervaphidini, Greenideini and Schoutedeniini. In India, Cervaphidini is represented by 3 genera and 7 species out of which 2 are endemic, Greenideini is represented by 5 genera and 87 species out of which 64 are endemic, while Schoutedeniini is least diversified containing only 1 genus and 2 species out of which one is endemic (Singh and Singh, 2017f). Host range of Greenideinae in India comprise of 112 plant species belonging to 73 genera and 45 families. The most of the aphid species of Greenideinae are associated with plant orders Fagales (4 plant families, 67 aphid species), Rosales (5 plant families, 20 aphid species), Ericales (6 plant families, 15 aphid species), Malpighiales (3 plant families, 12 aphid species) and Sapindales (4 plant families, 10 aphid species). An analysis of species-wise association reveals that almost 70% of the species feeds on the plants belonging to order Fagales and 52% on only the family Fagaceae. The group is mainly distributed from east to west Himalayas.

x. Subfamily : Hormaphidinae

In Hormaphidinae, the apterae are usually aleuridiform and head is fused with prothorax often a pair of horn. Siphunculi are represented as ring or even absent. Cauda is crescent shaped and variably knobbed. Wax glands are variably developed. The members of Hormaphidinae are also characterized by forming clear galls on their primary host plant and producing a sterile soldier caste. It comprises three tribes: Hormaphidini, Nipponaphidini and Cerataphidini. Almost all genera of Cerataphidini possess second-instar sterile soldiers on their primary host, whereas several genera also produce first-instar soldiers, either sterile or non-sterile, on their secondary host. From the Nipponaphidini, several species have been known to produce altruistic defenders without sterile caste only on their primary host (Ghosh, 1988).

According to Favret (2019), world fauna of Hormaphidinae consists of 230 species under 44 genera (Cerataphidini: 10 genera, 113 species; Hormaphidini: 5 genera, 12 species; Nipponaphidini: 29 genera, 105 species). From India, total 57 species of Hormaphidinae were recorded under 22 genera out of which 27 are endemic (Table 1). Of 57 species, only 8 species are known from south India and rest are known from northern hills or foothills of Himalaya (Ghosh, 1988). Chakrabarti and Debnath (2011) reported 16 species of Hormaphidinae in 12 genera from northwest Himalaya. The host plant association demonstrated that out of 34 species of Cerataphidini, 19 are monophagous and mostly feeding on bamboo; 11 are oligophagous and only 4 species are polyphagous. Hormaphidini includes only 2 monophagous aphid species that feed on 3 species of host plants belonging to 2 families. Nipponaphidini includes 21 aphid species that feed on 17 species of host plants belonging to 9 families. Of 21 species of Nipponaphidini, 14 species are monophagous and mostly feeding on Fagaceae and the rest 7 species are

oligophagous. Most of them feed on plants belonging to Fagaceae and Lauraceae (Singh and Singh, 2018).

xi. Subfamily : Israelaphidinae

This subfamily is not represented in India and only 4 species are described under single genus *Israelaphis* Essig from Israel, Spain and Caucasus.

xii. Subfamily : Lachninae

The Lachninae is recognised as a distinct group of aphids bearing 9 or more ventral hairs on first tarsal segment and having long fine hairs on the body and appendages. It includes five tribes: Eulachnini, Lachnini; Stomaphidini, Tramini, and Tuberlachnini. According to Favret (2019), world fauna of Lachninae consist of 406 species under 17 genera. From India, total 41 species were recorded under 12 genera (Table 1). Total 41 species of Lachninae were recorded from India under 12 genera, of which 16 species are endemic. Tribe Eulachnini includes 21 aphid species that feed on 23 species of host plants belonging to 7 families. The host plant association demonstrates that out of 21 species of Eulachnini, 14 are monophagous and mostly feeding on pinus and 4 are oligophagous. Lachnini includes 10 monophagous species that feed on 30 species of host plants belonging to 10 families. Tribes Stomaphidini is represented by only one species infesting plant of Juglandaceae while Tramini is represented by 2 species infesting mostly plants belonging to Asteraceae. Of 7 species of Tuberlachnini, most of them are monophagous or oligophagous feeding on Rosaceae (Singh *et al.*, 2018).

xiii. Subfamily : Lizeriinae

Total 41 species under 5 genera are described in this subfamily. It is represented in India by only one species *Paoliella nirmalae* (David) feeding on *Terminalia arjuna* (Roxb.) ex DC. Wight & Arn. (Combretaceae) (Singh *et al.*, 2018)

xiv. Subfamily : Macropodaphidinae

The subfamily Macropodaphidinae is not represented in India and only 7 species are described under single genus *Macropodaphis* Remaudière & Davatchi from Siberia and China.

xv. Subfamily : Mindarinae

Only 9 species under single genus *Mindarus* Koch are described in this subfamily. It is represented in India by only two species *Mindarus abietinus* Koch and *Mindarus japonicus* Takahashi feeding on 3 plant species belonging to family Pinaceae (Singh *et al.*, 2018).

xvi. Subfamily : Neophyllaphidinae

The subfamily Neophyllaphidinae is not represented in India and only 18 species are described under single genus *Neophyllaphis* Takahashi.

xvii. Subfamily : Phloeomyzinae

This subfamily is not represented in India and only one species having two subspecies is described under single genus *Phloeomyzus* de Horváth.

xviii. Subfamily : Phyllaphidinae

Only 18 species under 4 genera are described in this subfamily. It is represented in India by only one species *Machilaphis machili* (Takahashi) feeding on 2 plant species belonging to family Lauraceae (Singh *et al.*, 2018).

xix. Subfamily : Pterastheniinae

The subfamily Pterastheniinae is not represented in India and only 5 species are described under 2 genera.

xx. Subfamily : Saltusaphidinae

Total 57 species under 12 genera are described in this subfamily. It is represented in India by only one species

Saltusaphis scirpus Theobald feeding on *Cyperus iria* L. (Cyperaceae) (Singh *et al.*, 2018).

xxi. Subfamily : Spicaphidinae

This subfamily is not represented in India and only 13 species are described under 2 genera.

xxii. Subfamily : Taiwanaphidinae

Only 14 species under single genus *Taiwanaphis* Takahashi are described in this subfamily. It is represented in India by 3 endemic and monophagous species *Taiwanaphis dineni* Mandal, Agarwala & Raychaudhuri feeding on a plant species belonging to family Combretaceae, *Taiwanaphis*

Table 1: Subfamilywise distribution of extant aphid species recorded in India and abroad.

Subfamilies		World		India		Endemic
		Genera	Species	Genera	Species	Species
Aiceoninae		1	18	1	8	8
Anoeciinae		2	30	1	6	2
Aphidinae	Aphidini	33	832	9	65	14
	Macrosiphini	243	2263	96	366	178
Baltichaitophorinae		1	1	0	0	0
Calaphidinae	Calaphidini	17	77	5	14	11
	Panaphidini	46	271	20	34	19
Chaitophorinae	Chaitophorini	7	153	4	25	12
	Siphini	5	25	1	2	0
Drepanosiphinae		5	39	2	4	2
Eriosomatini	Eriosomatinae	14	113	5	21	9
	Fordini	19	83	7	15	6
	Pemphigini	21	178	7	28	7
Greenideinae	Cervaphidini	6	20	3	7	2
	Greenideini	7	152	5	87	64
	Schoutedeniini	3	7	1	2	1
Hormaphidinae	Cerataphidini		10	113	9	3413
	Hormaphidini	5	12	2	2	0
	Nipponaphidini	29	105	11	21	14
Israelaphidinae		1	4	0	0	0
Lachninae	Eulachnini		4	294	2	218
	Lachnini	4	33	4	10	4
	Stomaphidini	1	33	1	1	0
	Tramini	3	31	2	2	1
	Tuberlachnini	5	15	3	7	3
Lizeriinae		5	41	1	1	1
Macropodaphidinae		1	7	0	0	0
Mandarinae		1	9	1	2	0
Neophyllaphidinae		1	18	0	0	0
Phloeomyzinae		1	1	0	0	0

Phyllaphidinae		4	18	1	1	0
Pterastheniinae		2	5	0	0	0
Saltusaphidinae		12	57	1	1	0
Spicaphidinae		2	13	0	0	0
Taiwanaphidinae		1	14	1	3	3
Tamaliinae		1	6	0	0	0
Thelexinae		4	18	2	4	3
Total		527	5109	208	794	385

kalipadi (Raychaudhuri & Ghosh) feeding on *Annona squamosa* L. (Annonaceae) and *Taiwanaphis randiae* Ghosh, Basu & Raychaudhuri feeding on *Randia* sp. (Rubiaceae).

xiii. Subfamily : Tamaliinae

The subfamily Tamaliinae is not represented in India and only 6 species are described under single genus *Tamalia* Baker.

xiv. Subfamily : Thelexinae

Only 18 species under 4 genera are described in this subfamily. It is represented in India by only 4 species out of which 3 are endemic and almost monophagous feeding on plant species belonging to different families (Singh *et al.*, 2018).

Thus, the family Aphididae is composed of total 24 subfamilies that globally include 5109 species under 527 genera. In India, only 16 subfamilies were recognized comprising of 794 species under 208 genera. Among the Indian records, 385 species (7.5%) are endemic. Detail food plant association of Indian aphids was recently updated by Singh *et al.* (2014, 2015, 2018) and Singh and Singh (2016a-d; 2017a-f; 2018). Blackman and Eastop (2000) provided keys for identification of world aphids infesting crops while Blackman and Eastop (2008) catalogued the food plants of aphids infesting herbaceous plants and shrubs of the world.

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