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RESEARCH ARTICLE :

A review on natural enemies of phytophagous mites

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BACKGROUND AND OBJECTIVES

Biological control agents(BCAs) have a range of attractive properties that include host specificity, lack of toxic residue, no phytotoxic effects, human safety, and the potential for pest management to be self-sustaining. Many are able to actively locate their prey. BCAs can also be produced locally which can be important in terms of choosing and matching natural enemies to small scale needs. Successful use requires fundamental knowledge of the ecology of both the natural enemy and the pest. When this condition is satisfied, and the agent is used firmly within IPM, then biological control can sometimes be more cost effective than purely chemical control.

A long term example of a classical biological control project using fungi is the program targeting the cassava green mite (CGM), *Mononychellus tanajoa* (Bondar) in Africa. It was in 1988, that exploration for potential natural enemies in Brazil revealed that the entomophthoralean *N. tanajoae* was one of the most important natural enemies of CGM in northeastern Brazil.

The influence of resident predatory and pathogenic biota on *A. hystrix* population dynamics within grassland systems is largely undetermined. Three *Hirsutella spp.*, including *H. thompsonii* Fisher, and *Verticillium lecanii* (Zimm.) were recorded on half of 40 ryegrass swards examined in the U.K., causing mortality of up to 16% (Lewis *et al*., 1981).

Predatory mites of the family Phytoseiidae are valued natural enemies that provide effective pest control in greenhouses and on agricultural crops. Mass-reared phytoseiids are occasionally associated with microorganisms and although their effects are not always apparent, some are pathogenic and reduce host fitness. Invertebrate pathogens are encountered more frequently in mass production systems than in nature because rearing environments often cause overcrowding and other stresses that favour pathogen transmission and increase an individual's susceptibility to disease.

The selection of highly virulent fungal pathotypes offers considerable potential for classical biological and microbial control, if commercial production and formulation technology can be developed more fully.

With respect to the predator groups, only the impact of the tydeids has been studied quantitatively. Because of this, the tydeids appear to be the most promising for implementation as biological control agents against the Eriophyoideae. However, as more research is conducted, other potential predators likely will be identified. In this review, one recognizes that the vast majority of the studies report predation upon vagrant mite species. Secondarily, there has been some work done with the bud mites, whereas the gall-forming mites have had less attention. The bud- and gall-forming mites in many cases have environments which protect them from the generalist predator. In these "enemy-free space" situations, it is clear that the size of the predator has tremendous impact on its success. The small size of the tarsonemids and tydeids afford certain opportunities to search the protected environments of galls, erinea and small leaf crevices. On the other hand, the larger arthropods (for example the cecidomyiids) may be able to destroy such environments, enabling them to prey successfully on the eriophyoids within. The moderately-sized predators may be at a distinct disadvantage. Perhaps a combination of natural enemies may be useful to the biological control practitioner.

Diptera :

Cecidomyiid larva, *Arthrocnodax occidentalis* Felt, was found feeding on eriophyoids in fig trees (Baker, 1939), and this species has been found in colonies of other species of Eriophyidae (Baker, 1939). Rathman and Brunner (1988) observed larvae of *Medetera* species (Dolichopodidae) feeding on apple rust mite, *Aculus schlechtendali* (Nalepa), as well as on aphids in an apple orchard in Washington State, U.S.A. They concluded, however, that these fly larvae probably did not have a significant impact on the pest populations. More recently, Schliesske (1992) included the cecidomyiid *Arthrocnodax fraxinella* (Meade) and syrphids, *Syrphus* spp., in a list of predators and parasites attacking free-living eriophyoids on pome and stone fruits. These predators were reported to suppress developing populations of eriophyoids.

Coleoptera :

The coccinellid *S tethorus nanus* LeConte has been reported feeding on rust mites (Yothers and Mason, 1930); however, there was no appreciable impact on the population density of the eriophyoids. Another coccinellid, *Delphastus pusillus* (LeConte), was reported in citrus orchards feeding on whiteflies and "apparently on *P. oleivora*" (Muma *et al.*, 1961).

Relative quality of mites as prey :

David *et al.*(2009) reviewed that Stethorini as predators of tetranychid and tenuipalpid mites on various pests in India as shown in Table 2. Stethorini attack a large number of tetranychid species on many different crops. Although it appears that most feed on multiple tetranychid prey species, some species are more specialized than others and some tetranychid prey are

Table 1 : Insect Natural Enemies of Mites (Perring *et al.*, 1996)

Insect predators	Natural enemies	Mite pests	Crops	References
Diptera	*Arthrocnodax occidentalis* (Cecidomyiid)	*Phyllocoptruta oleivora*	Fig tree	Baker, 1939
	Medetera spp. (Dolichopodidae)	*Aculus schlechtendali*	Apple	Rathman and Brunner (1988)
	Arthrocnodax fraxinella (Cecidomyiid) and Syrphid	Free living Eriophyiids	Pome and stone fruits	Schlieske, 1992
Coleoptera	*Stethorus nanus* LeConte(Coccinellid)	Rust mite	Citrus	Yothers and Mason, 1930
	Delphastus pusillus LeConte (Coccinellid)	*P. oleivora*	Citrus	Muma *et al.*, 1961
Neuroptera	*Chrysopa spp.*	Rust mite and eriophyoid mites	-	Yothers and Mason, 1930
Thysanoptera	*Leptothrips mali* Fitch	tomato russet mite, *Aculops lycopersici* Massee	Tomato	Bailey and Keifer (1943) and Anderson (1954)
	Scolothrips sexmaculatus Pergande	*A. lycopersici*	-	Abou-Awad, 1979
Hemiptera	*Orius vicinus* Ribaut (Anthocorid)	*A. Schlechtendali* and *Eriophyes fraxinivorus* Nalepa	Apple	Heitmans *et al.* 1986 Fauvel *et at.*, 1975

less suitable than others. For example, *S. punctillum* and *S. gilvifrons* do not readily feed on or reproduce on the tetranychid mites of the genus Bryobia.

Neuroptera :

The earliest report of a neuropteran feeding on eriophyoid mites was a species of *Chrysopa* feeding on rust mites (Yothers and Mason, 1930).

Thysanoptera :

Bailey and Keifer (1943) and Anderson (1954) noted *Leptothrips mali* (Fitch) feeding on tomato russet mite, *Aculops lycopersici* (Massee). Although this thrips fed on the mites, the authors observed that predation had little effect on mite numbers because the thrips were hampered by the glandular hairs of tomato plants. Another thrips species, *Scolothrips sexmaculatus* (Pergande), was observed in association with *A. lycopersici* colonies (Abou-Awad, 1979), but there was no information given on the predation by this thrips on the eriophyid mites.

Hemiptera :

An anthocorid has been recognized as a predator of eriophyoid mites in Europe. Heitmans *et al.* (1986) determined that *Orius vicinus* Ribaut fed almost exclusively on apple rust mites, and they concluded that this predator could be an important factor in controlling outbreaks of *A. schlechtendali* in an apple orchard. The fact that O. *vicinus* also consumed phytoseiid mites was not considered detrimental to rust mite control because of the low incidence of phytoseiids in the anthocorid's diet as indicated by electrophoretic analysis. In addition, this eriophyid was a preferred food for development and oviposition of O. *vicinus* (Heitmans *et al.,* 1986). This predator also was common in the galls of *Eriophyes fraxinivorus* Nalepa (Fauvel *et at.*, 1975). Although the authors considered the anthocorid to be predaceous on the mites, they also suggested that it might be a "hyperpredator" in that it fed on other natural enemies of the eriophyid, including phytoseiid mites.

Sagata and Gupta (2016) recorded total 75 species of mites (under 29 genera, 12 families and 3 orders) has been recorded from 38 medicinal plants grown in four districts of South Bengal, India (Table 3). The results documented 35 species of phytophagous, 37 species of predatory and 3 species of fungal feeding mites. Of these, 8 species *Tetranychus sayedi*; *Tetranychus ludeni*; *Eutetranychus africanus*; *Eutetranychus orientalis; Brevipalpus melichrus*; *Bdellodes angustifolius*; *Euseius prasadi*; *Euseius pruni* shows new host records.

Fungal pathogens affecting mites :

Fungal biocontrol agents, including 10 isolates of *Beauveria bassiana*, *Metarhizium anisopliae*, and *Paecilomyces fumosoroseus* were bioassayed for their lethal effects on the eggs of the carmine spider mite, *Tetranychus cinnabarinus* (Shia *et al.,* 2004). Results confirmed the ovicidal activity of the three fungal species and suggested the feasibility to search for more ovicidal isolates from fungal species that may serve as biocontrol agents against spider mites such as *T. cinnabarinus*. Two isolates of entomopathogenic fungi, *Beauveria bassiana* SG8702 and *Paecilomyces fumosoroseus* Pfr153, were also bioassayed against *T. cinnabarinus* eggs (Weibin *et al.*, 2004).

Table 2 : Stethorini as predators of tetranychid and tenuipalpid mites on various pests in India, (David *et al.*, 2009)

Predator	Prey	Crop or plant	Reference
Parastethorus histrio	*Eutetranychus orientalis*	Citrus	Dhooria (1981)
Parastethorus Indira	Tetranychidae	Taro	Kapur (1950)
Stethorus gilvifrons	*Oligonychus coffeae*	Tea	Sarmah and Bhattacharyya (2002)
	Tetranychus urticae	Castor bean	Mathur (1969)
Stethorus keralicus	*Raoiella indica*	Arecanut palm, coconut	Puttaswamy and Rangaswamy (1976)
Stethorus parcempunctatus	*Raoiella indica*	Coconut palm	Gupta (2001)
Stethorus pauperculus	*Oligonychus indicus*	Sorghum	Kapur (1948) Puttaswamy and
	Oligonychus neocaledonicus	Papaya, castor bean and various	Channabasavanna (1977)
	Tetranychus ludeni	crops	Puttaswamy and
	Tetranychus ludeni	Eggplant	Channabasavanna(1980)
		Water hyacinth	Ansari and Pawar(1992)

Table 3 : Diversity of predatory mites collected from different medicinal plants in different areas (Sagata and Gupta., 2016)

Name of the mite species	Host plants	Habitat status	Locality
I. Order: Prostigmata Family: Tydeidae Species			
1. *Pronematus flechneri*	*Ricinus communis*	B	Chingrighata
2. *Pronematus sextoni*	*Ocimum gratissimum*	B	Malancha
3. *Parapronematus camelia*	*Piper nigrum*	B	Narendrapur
4. *Parapronematus murshidabadensis*	*Piper nigrum*	B	Narendrapur
5. *Tydeus wallachi*	*Ocimum sanctum*	B	Narendrapur
Family: Cunaxidae Species			
1. *Cunaxa setirostris*	*Ricinus communis*	B	Narendrapur
2. *Cunaxa mangiferae*	*Ocimum tenuifolium*	C	Narendrapur
3. *Cunaxa capreolus*	*Justicia adhatoda*	B	Mathpukur
Family: Stigmaeidae Species			
1. *Agistemus sp.*	*Ferula assafoetida*	A	Narendrapur
2. *Agistemus terminalis*	*Hibiscus rosa-sinensis*	B	Narendrapur
3. *Agistemus industani*	*Piper nigrum*	B	Narendrapur
4. *Agistemus unguiparvus*	*Ficus carica*	C	Salt lake
5. *Agistemus obscura*	*Rosa sp.*	B	Tamgra
6. *Agistemus histrix*	*Ficus carica*	C	Salt lake
7. *Agistemus gamli*	*Rauvolflia tetraphylla*	B	Narendrapur
8. *Agistemus edulis*	*Ricinus communis*	B	Beliaghata
Family: Bdellidae Species			
1. *Bdellodes angustifolius* *	*Morinda citrifolia*	C	Narendrapur
II. Order: Astigmata Family: Acaridae Species			
1. *Tyrophagus potrescenteae*	*Mikania micrantha*	C	Bhojerhat
2. *Tyrophagus longior*	*Ocimum sanctum*	B	Narendrapur
	Family: Saproglyphidae Species		
1. *Suidasia nesbitti*	*Justicia adhatoda*	C	Tangra
III. Order:Mesostigmata Family: Phytoseiidae Species			
1. *Amblysieus paraerialis*	*Shorea robusta*	B	Narendrapur
2. *Amblysieus largoensis*	*Ficus carica*	A	Salt lake
3. *Amblysieus herbicolus*	*Passiflora caerulae*	A	Ghatakpukur
4. *Amblysieus mcmurtryi*	*Nerium oleander*	B	Narendrapur
5. *Euseius alstoniae*	*Ricinus communis*	A	Salt lake
6. *Euseius ovalis*	*Moringa oleifera*	A	Bhojerhat
7. *Euseius eucalypti* *	*Nyctanthes arbor-tristis*	A	Bantala
8. *Euseius finlandicus*	*Nyctanthes arbor-tristis*	B	Bantala
9. *Euseius prasadi* *	*Nerium oleander*	B	Mecheda
10. *Euseius pruni* *	*Polyanthia longifolia*	B	Minakhan
11. *Phytoseius wainsteini*	*Mangifera indica*	C	Kanta tala
12. *Phytoseius minutes*	*Nyctanthes arbor-tristis*	C	Joynagar
13. *Paraphytoseius multidentatus*	*Ocimum sanctum*	A	Joynagar
14. *Paraphytoseius scleroticus*	*Ocimum gratissimum*	C	Narendrapur
15. *Paraphytoseius orientalis*	*Ocimum gratissimum*	B	Gosaba
16. *Neoseiulus longispinosus*	*Hibiscus sp.*	A	Narendrapur
17. *Phytoscutella salebrosus*	*Ficus carica*		Narendrapur
18. *Typhlodromips syzygii*	*Citrus limon*	B	Mathpukur
19. *Typhlodromips sukaensis*	*Paederia foetida*	B	Narendrapur
Family: Ascidae Species			
1. *Melichares sp.*	*Ficus carica*	C	Narendrapur

A= abundantly occurrence, B= occasional occurrence, C= casual occurrence, * = new host records

Sreenivas *et al.*(2005) conducted studies on the efficiacy of entomopathogenic fungi against red spider mite, *Tetranychus neocaledonicus Zacher* showed the relatively lower pathogenicity. Among the three entomopathogenic fungi tested *Metarhizium anisopliae* @ 1.2 x 108 CFU/ml registered higher per cent mycosis but, it was statistically on par with remaining two fungi *Beauveria bassiana* and *Verticillium lecanii*. However, all the three pathogens were evaluated proved their superiority over water dipping/spraying and untreated control treatments both under laboratory and glass house condtions.

Muraleedharan, (2002) evaluated thee entomopathogenic fungi for the control of red spider mite, *Oligonychus coffeae* (Nietner) (Tetranychidae). Formulations of the entomopathogenic fungi *Verticillium lecanii, Paecilomyces fumosoroseus* and *Hirsutella thompsoni* were tested against this pest in the laboratory and field. Data from the laboratory on the pathogenicity of the fungi are given in Table 16. The study revealed that there was a distinct difference in the susceptibility of nymphs and adults to different fungal pathogens. A very high nymphal mortality of 95.9% was observed when leaf discs were treated with *V. lecanii*. When *P. fumosoroseus* was applied, nymphal mortality was 82.4 % and in the case of *H thompsonii* it was 75.3 %. The overall mortality of adults was low when compared to that of nymphs. The study also showed that mortality increased with the increase in spore concentration. Efficacy of the suspension @ 10^7 spores/ml was comparable to that of 10^8 spores/ml. Both the dosages were more effective than the lower dosage rates and caused highest nymphal and adult mortality. Data from the field trial revealed that the application of *V. lecanii, P. fumosoroseus* and *H. thompsonii* @ 3500 g formulation per ha significantly reduced the population density of red spider mites. Though all the three formulations of fungal pathogens were equally effective in controlling this pest in the field, *P. fumosoroseus* inflicted slightly higher mortality towards the third and fourth weeks, after application.

McCoy, 1996 reports in the literature of entomopathogenic fungi infecting eriophyoid mites attest to the prevalence of these associations Since eriophyoids are so small as to be almost invisible to the unaided eye (mostly 100-250 ~mm in length), pathogenic fungi are extremely difficult to observe macroscopically during collection in the field and, most likely, they are frequently overlooked. Three fungal genera, *Paecilomyces, Verticillium* and *Hirsutella,* have been reported to contain species infectious to eriophyoid mites. Among the genus *Hirsutella* Pat. includes about 50 entomopathogenic fungi attacking a wide range of insects, At least seven known mononematous and synnematous species infect mites; five species have been recorded from eriophyoid mites. The well-known species *H. thompsonii* Fisher causes spectacular natural epizootics in populations of the citrus rust. The fungus has worldwide distribution on different eriophyoid hosts infesting citrus, blueberry, coconut, poison ivy, tomato, oil palm, guayaba, ryegrass and an unknown vine.

Conclusion :

Many factors influence the outcome of a particular biological control program, the use of predators and pathogen-free natural enemies is the foundation for success. Invertebrate pathogens are often overlooked in scientific studies. It is essential to use pathogen-free beneficial arthropods in scientific studies if quality control testing is to have meaning. Perhaps a combination of natural enemies may be useful to the biological control.

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