This chapter discusses the findings of the present study in view of the previous observations. The results of checklist, data on new species, new records on host and locality, illustrated diagnostic keys, multimedia enabled species diagnosis and database on cereal associated mites are critically analysed, laying emphasis on their advancement over others.
5. DISCUSSION

The present study focused on the objectives of conducting surveys of rice, wheat, maize, pearl millet and sorghum agroecosystems of Punjab, Haryana and Delhi with special reference to major mite pests, conducting biosystematic studies of cereal associated mites, developing illustrated diagnostic keys for identification of the most important cereal mite pests and databasing and digitizing the inventory of their faunistic diversity culminating in a computer aided diagnostics. This study has achieved the following:

A comprehensive checklist of 283 species of mites under 92 genera and 30 families of Acari known from the cereal agroecosystems has been compiled. This checklist encompasses all critical details that will be required for an efficient management of mite biodiversity in terms of details of species diversity in relation to the cereal agroecosystems enriched with all salient taxonomic details.

This checklist provides the platform for taxonomic studies culminating in detailed morphology of 22 species under 17 genera in 13 families, which is by far the most complete monograph on the mites from the Indian cereal agroecosystems with more than 350 illustrations and 22 photographic images integrated with diagnostic keys for the families, genera and species in a completely illustrated format at all the taxonomic hierarchical levels. The addition of 3 new species and 5 new records is a significant achievement towards the mite biodiversity aspects of the agroecosystems. The diagnostics of the species of mites in the cereal agroecosystems has been developed in an unique way incorporating illustrated keys at all the hierarchical levels. The taxonomy of these species has been updated towards their classification and synonymy. This basic information along with that of their biology, ecology and distribution has been compiled, consolidated and comprehended to provide a database. With these outputs, it is now possible that one can address all the biodiversity problems associated with mites of the cereal agroecosystems in a more efficient and professional manner.

These significant achievements are explained herein, in the background of the earlier contributions. The checklist, taxonomy, biology and other ecology details,
diagnostics at family levels and the elaboration at different hierarchial levels, place the
taxonomy of the genera and species on a standardized platform. The data generated in the
form of taxonomic characters, their illustrations, focused diagnostics and the compiled
information on the biology and ecology and their digitization has paved the way for a
holistic computer aided diagnostics for the mites associated with cereal agroecosystems.
The details explained and consolidated herein are compared with the earlier available
contributions and a discussion brought out which is as follows.

5.1 Checklist

The checklist developed now encompasses details of mites associated with cereal
agroecosystems. Results of detailed analysis of the checklist taking into account different
aspects reveal the following:

As indicative from Table 1, 71.7% of the total mite fauna reported from cereals
fall under Prostigmata. This group includes mostly the phytophagous mites. Hence, it is
very evident from this analysis that the cereal ecosystems are under constant stress owing
to infestation by various phytophagous mites. The mite fauna on cereals far outnumbers
the predatory mite numbers and thereby substantiates the economic loss that could be
caused by their population upsurge. These findings also demonstrate the complexities of
species diversity of mites associated with cereal agroecosystems.

Further, in the mite families of Prostigmata, the maximum species diversity is of
the families Tetranychidae, Tarsonemidae, Cheyletidae and Eriophyidae (Table 2). Of
these, mites belonging to the families Tetranychidae, Tarsonemidae and Eriophyidae are
phytophagous and are mostly observed on plant parts. The mites in the family
Cheyletidae are mostly predatory or free-living. This analysis further substantiates that
phytophagous mites outnumber all other categories of mites and these are primarily
responsible for crop damage and yield loss.

Amongst the families of Mesostigmata maximum number of species are recorded
from the predatory mite family Phytoseiidae (Table 3). Thus, even though Mesostigmata
comprises of only about 14.8 % of the mites reported on cereals, majority of species are
predatory and play a vital role in controlling or regulating the population of
phytophagous mites. Hence, it is indicative of the fact that if they are properly deployed, then can serve as good biocontrol agents.

Cereal grains in storage facilities are prone to infestation by mites and insects. Amongst the families of Astigmata the maximum number of species is recorded from Acaridae (Table 4). These are mainly storage mites. Thus, diversity amongst storage mites is immense and as these are responsible for grain deterioration in storage facilities and measures towards proper storage are essential in cereal associated storage systems for maintaining grain quality.

Analysis of host plant relationships in terms of various cereals reveal that majority of mites are associated with rice agroecosystems followed by wheat and maize (Table 5). Rice, wheat and maize are the staple food crops and are grown worldwide. Climatic conditions present immense opportunities for species diversity to grow, acclimatize and propagate on the various cereals. As the growth and output of these cereals are constantly monitored, any incidence of mite infestation is readily detected and reported.

The analysis of host plant relationships of mites on cereal agroecosystems reveal that maximum number of mites was observed from farm fields mostly from Prostigmata followed by Mesostigmata (Table 6). Most of the prostigmatid mites are phytophagous. Thus, with the inferences drawn from this data, it could be concluded that as the mites of Prostigmata increases in the fields, predatory mites are also equally observed. This analysis further ascertains and confirms the predator-prey interaction between phytophagous mite of Prostigmata and predatory mites of Mesostigmata. The ecological relationships in terms of predator prey interactions become more evident and these could be exploited for any kind of field applications and management strategies.

Maximum number of species had been recorded from storage facilities such as granaries, warehouses, flat storage areas and godowns, which belong to Astigmata followed by Mesostigmata and Prostigmata. As astigmatid mites are mostly parasites, fungivores or saprophytic in habitat, conditions of high humidity and temperatures usually prevalent in storage areas facilitate their growth and development as substantiated by this analysis (Table 6). This analysis also provides the salient details of mite
biodiversity which could be explored in terms of variations in the spectrum of species diversity. It is of significance for those who handle storage facilities of cereals, and for plant quarantine aspects.

Analysis of the distribution of cereal associated mites from within India and Indian subcontinent revealed that the number of prostigmatid mites was by far the largest with approximately 30.5% distributed within Indian subcontinent, of which 20.6% is known to occur from India. Of the total mesostigmatid associated with cereals, distribution of 60% spanned the Indian subcontinent, and all of these were reported from India too. The Astigmata reported from the Indian subcontinent accounted to nearly 42.1% of which 60.5% species also occurred in India (Table 7). Zoogeographic distribution analysis reveals that maximum number of mites from cereal agroecosystems are reported from India (Table 8).

It may be inferred from the above analysis that the geographical position and climatic conditions of India and its subcontinental countries support mite propagation. Geographically, India is situated north of the equator and is further identified under two zones. While the southern half lies in the Torrid Zone the northern half lies in the Temperate zone. The temperature varies from moderate to extreme as one move forward, from south to north India. The country also experiences plenty of rainfall and thus supports diverse vegetation. Also, India is an agricultural land and rice, wheat, maize, sorghum and pearl millet are its staple crops and are grown across the country as per season. Thus abundance of food resources, diverse and ambient climatic conditions provide ideal conditions for mite propagation and distribution.

From the checklist, information on ecology and bionomics are available for 47 species of Prostigmata, 15 species of Mesostigmata and 17 species of Astigmata. Statistics reveal that though many mites have been reported on cereals, such information on biology and ecology is generally lacking for all known cereal associated mites. A plausible reason for the lack of research on these applied aspects could be the difficulty in simulating natural conditions in laboratory to facilitate mite culture and rearing. Thus information on ecology and bionomics of about 27.9% of mites reported from cereals are only available for ready reference.
Thus, it is evident from the above analysis that 283 species of mites in 92 genera under 30 families have been reported from cereal agroecosystems from across the globe. Of the 92 genera, majority of the phytophagous mites belonged to the genera *Oligonychus*, *Tetranychus*, *Tarsonemus*, *Steneotarsonemus* and *Aceria*. The predatory mites in the genus *Neoseiulus* were predominantly found in the crop fields. Amongst the astigmatids, mites in the family Acaridae and the genera *Caloglyphus* and *Tyrophagus*, in particular, were prevalent both in storage facilities and farm fields.

5.2 Comparative analysis

Perusal of literature reveals that there is no specific work done thus far to compile and present data on mites seen in association with cereal crops. While some concentrated work by Rao *et al.* (1999) and Joshi *et al.* (2002) had been done to compile literature on mite associated with rice agroecosystems, these are now obsolete with respect to their classification and nomenclature contents. Comparative analysis of the data on mites occurring in rice agroecosystems alone with that reported previously by Rao *et al.* (1999) and Joshi *et al.* (2002) reveal that more number of species are now identified, described and reported from rice in the past two decades. Rao *et al.* (1999), in the first comprehensive report of mites from cereals from India, enumerated 61 species under 32 genera in 14 families of which, excluding soil mites, 60 mite species in 31 genera under 13 families were listed from rice agroecosystems. Joshi *et al.* (2002) prepared a similar checklist in which they enumerated 125 species under 68 genera, 29 families and 4 suborders and excluding soil and aquatic mites, a total of 86 species of mites in 46 genera under 16 families were listed. In the present checklist, soil mites and aquatic mites are not incorporated, excluding which, 134 species from 55 genera under 23 families are reported from rice agroecosystems.

Rao *et al.* (1999) listed 36 species and Joshi *et al.* (2002) listed 53 species in Prostigmata respectively from rice agroecosystems as against the 90 species presently listed. Thus, about 69% increase has been recorded in the occurrence of prostigmatid mites from rice agroecosystems. Similarly, Rao *et al.* (1999) listed 9 species and Joshi *et al.* (2002) listed 20 species of Astigmata, as against the present record of 21 species from rice, thereby marking an increase of 5%. Amongst the mesostigmatid mites, Rao *et al.*
(1999) listed 14 species and Joshi et al. (2002) listed 13 species. The current checklist records 23 species of Mesostigmata, accounting to about 76% increase. Thus, from rice agroecosystems alone, 56% increase has been recorded from the previous records of Joshi et al. (2002), which seem to be a significant addiction in terms of information on the biodiversity of mites associated with cereal agroecosystems.

Faunistic survey of Rao et al. (1999) showed maximum representation of Tarsonemidae (19 species) in the rice cropping system, followed by Phytoseiidae (8 species) and Tetranychidae (6 species). Joshi et al. (2002) depicted maximum from Tetranychidae and Acaridae (16 each), followed by Tarsonemidae (15) and Cheyletidae (9) as associated with rice agroecosystems. In the present checklist, Tarsonemidae (29), Tetranychidae (20) and Phytoseiidae (12) show greater species diversity from rice agroecosystems.

Thus, the present study is the first of its kind as far as the compilation and consolidation of the faunistic diversity of mites associated with cereal agroecosystem. There is no doubt that this will beneficial for all those who wish to study cereal mites and harvest these towards better crop management.

5.3 Classification and nomenclature

A comparative analysis of the present checklist with Joshi et al. (2002) reveals that there have been changes to some species with respect to their nomenclature and classification. These changes of critical importance emanating from the results of the present study are discussed below:

In Astigmata, Lepidoglyphus destructor (Schrank) has been shifted from the family Acaridae to the family Glyciphagidae; Rhizoglyphus callae Oudemans has been synonymised under Rhizoglyphus echinopus (Fumose and Robin). In Mesostigmata, Indiraseius extremus (Daneshvar) in the family Ascidae is now listed as Lasioseius extremus as the genus Indiraseius had been synonymised with Lasioseius; in the family Laelapidae, Ololaelaps is now being considered and listed as subgenus of Pseusoparasitus Oudemans; in the family Phytoseiidae, the subgenus Neoseiulus and Euseius have been elevated to the status of genus and hence the species Amblyseius
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(\textit{Neoseiulus}) fallacis (Garman), \textit{Amblyseius (Neoseiulus)} longispinosus and \textit{Amblyseius (Euseius)} ovalis (Evans) are listed accordingly; the species \textit{Amblyseius paraibensis} Moraes and Mcmurtry is now placed under genus \textit{Neoseiulus}; the species \textit{Amblyseius (Paraphytoseius)} multidentatus (Swirski and Schechter) has been synonymised under \textit{Paraphytoseius orientalis} (Narayanan, Kaur and Ghai); the species \textit{Gnorimus chaudhrii} Wu is being listed under the family Ascidae, under \textit{Lasioseius} owing to generic synonymy; \textit{Neoseiulus oryzacolus} Daneshvar has been synonymised under \textit{Neoseiulus imbricatus} (Corpuz-Raros and Rimando); \textit{Leiodinychus krameri} in the family Uropodidae is now listed under family Trematuridae, as synonym of \textit{Trichouropoda orbicularis} (Koch). In Prostigmata, \textit{Chelachecaropsis bakeri} Attiah, of the family Cheyletidae is listed as \textit{Chelacheles bakeri} (Attiah) and \textit{Hemicheyletia vescus} Qayyam and Chaudhri is listed as \textit{Cheletomimus (Hemicheyletia)} vescus (Qayyam and Chaudhrii); the cunaxid mite, \textit{Pseudocunaxa (Coleoscieus)} mardi Mohammad is listed as \textit{Coleoscirius mardi} (Inayatullah and Shahid); \textit{Acarophenax tribolii} Newstead and Duvall of the family Pyemotidae has now been placed in family Acrphopacidae; \textit{Siteroptes graminum} (Reuter) of the family Pyemotidae is now listed under Pygmeophoridae as synonym of \textit{Siteroptes avenae} (Muller); \textit{Tarsonemus fuzhouensis} Lin and Zhang of the family Tarsonemidae is listed as synonym of \textit{Tarsonemus bilobatus} Suski and \textit{Eutrombidium trigonum} (Herman) of the family Trombididae is listed as synonym of \textit{Eutrombidium rostratus} (Scopoli).

Thus it is evident that owing to taxonomic changes taking place, some species and generic names have become obsolete and that the present checklist provides the most up-to-date nomenclature for the mites associated with cereals, and provides an authentic and valid classification.

5.4 Taxonomic studies

During the course of this research work, a total of 22 species belonging to 16 genera in 13 families, collected from Delhi, Haryana and Punjab, have been analysed. Out of these 22 species, 3 are new to science, namely \textit{Euseius sunilii} (Phytoseiidae), \textit{Abacarus sorghi} (Eriophyidae) and \textit{Pronematus oryzae} (Tydeidae) and 5 species are first records from India, namely \textit{Coleoscirius buartsus} den Heyer (Cunaxidae),
Pseudopygmeophorus near shanghaiensis Zou, Gao and Ma (Neopygmeophoridae), Siteroptes graminicola Mitrofanov, Shabanova and Sevastianov (Pygmeophoridae), Stigmaeus unicus Kuznetsov (Stigmaeidae) and Trochometridium near kermanicum Mortazavi and Hajiqanbar (Trochometridiidae). Of these, description of the new species Pronematus oryzae (Tydeidae) is already published in (Appendix #).

The new record of Trochometridium near kermanicum from the family Trochometridiidae is of particular interest as so far no members of this family has been reported from any plant ecosystem. All the species hitherto known in this genus namely Trochometridium chinensis (Mahunka), Trochometridium tribulatum Cross, Trochometridium kazachstanicum Khaustov and Eidelberg, Trochometridium kermanicum Mortazavi and Hajiqanbar and Trochometridium iranicum Hajiqanbar and Khaustov, are reported as ectoparasites on insects. The only other genus and species in this family, Neotrochometridium sensillum Hajiqanbar and Khaustov, was also observed as phoretic. Hence, it is interesting to find these mites in soil and not on insects as mites of this family are usually associated with insects. Similarly, Khaustov (2010) listed 17 species under the genus Pseudopygmeophorus and none of these are known to be associated with cereal agroecosystems. Both, Trochometridium near kermanicum Mortazavi and Hajiqanbar and Pseudopygmeophorus near shanghaiensis Zou, Gao and Ma are thus being reported from India as new records, which is a new faunistic information.

The cunaxid mite, Coleoscirus buartsus den Heyer is another new record from India. Also the present report is first habitat record from soil of rice and wheat. Previously this species has been known only from Iran and South Africa. The stigmaeid mite, Stigmaeus unicus Kuznetsov has been recorded from India for the first time. This is also the first habitat record from soil of rice and wheat. Previously this species has been reported from Iran and Ukraine. Siteroptes graminicola Mitrofanov, Shabanova and Sevastianov reported in the study is another new record from India. Previously this species has been reported from Russia and Ukraine from barley and wheat soil.

The detailed studies conducted on 22 species of mites collected from rice, wheat, maize, sorghum and pearl millet agroecosystems presented in this contribution bring to light certain interesting points regarding their taxonomic status which are discussed.
herein. Krantz (1978) in the second edition of ‘A Manual of Acarology’, considered Prostigmata, Mesostigmata and Astigmata as suborders with in the subclass Acari. In the past three decades acarologists discovered a multitude of new mite taxa, made major modifications in acarine classification and profoundly altered their understanding of this vast group. Presently, according to the latest classification of Lindquist et al. in (Krantz and Walter 2009), the taxon Mesostigmata has been elevated to the level of order in the superorder Parasitiformes, suborder Prostigmata remains under order Trombidiformes, superorder Acariformes and Astigma or Astigmatina is considered as cohort under suborder Oribatida, order Sarcoptiformes, superorder Acariformes These changes are also reflected in the nomenclature and classification of the subsequent levels in the hierarchy. The major changes in the designation and placement of the families, genera and species of cereal associated mites are discussed below.

In Mesostigmata, the family Blattisociidae, as recently revised, is placed in the superfamily Phytoseioidea along with the Phytoseiidae, Otopheidomenidae and Podocinidae (Lindquist et al., in Krantz and Walter, 2009). It includes two subfamilies and 12 genera (Lindquist and Moraza, 2010). Members of this family were in the past included in the Ascidae (Lindquist and Evans, 1965; Evans and Baker, 1991; Walter and Lindquist, 1997; Halliday et al., 1998) and this classification is still followed by many authors. In the present study, the classifications of Walter and Lindquist (1997) and Halliday et al. (1998) are being followed.

Rao et al. (1999) listed Amblyseius taiwanensis Ehara in their comprehensive compilation on mites associated with rice agroecosystems. Here, it is to be noted that the species name Amblyseius taiwanensis is a misnomer and the actual name as designated by the species author is Amblyseius taiwanicus Ehara. Further, Chant and Mcmurtry (2003a) in their review of the subfamily Amblyseiinae tribe Neoseiulini proposed and placed Amblyseius taiwanicus Ehara under the paspalivorus species group of tribe Neoseiulini. It was suspected that Neoseiulus taiwanicus (Ehara) was a synonym of Neoseiulus paspalivorus (De Leon). However, as this was not adequately proved, it is being listed in the checklist as a distinct species.
Within Prostigmata, Khaustov (2004) considered Siteroptidae as synonym of Pygmerophoridae following Lindquist (1986) and Neopygmerophoridae as very close to Scutacaridae and Microodispidae and together with Pygmerophoridae (=Siteroptidae) form the superfamily Pygme-phoroidea. He did not accept the separation of this group into 2 superfamilies: Pygme-phoroidea (Pygmerophoridae + Siteroptidae) and Scutacaroidea (Scutacaridae + Microdispidae,) proposed by Kaliszewski et al. (1995). In the present study, Siteroptidae, Pygmerophoridae, Scutacaridae, Microdispidae are all considered distinct from each other.

Andre and Fain (2000), in their major revision of the superfamily Tydeoidea, discussed its phylogeny, ontogeny and adaptive radiation, with a reappraisal of morphological characters and placed the genus Pronematus under Iolinidae. However, several workers still follow Krantz’s (1978) classification as does the present study which considers the genus Pronematus in Tydeidae.

In the family Eriophyidae, ChannaBasavanna (1966) reported Abacarus sacchari and Aceria sacchari from Saccharum spp. Aceria sacchari was already described by Wang in 1964 and thus ChannaBasavanna’s designation of the new species becomes null and void. However, Baco et al. (1991) reported Aceria sacchari Wang, from Oryzae sativa. Amrine (personal communication) believes that Abacarus sacchari and Aceria scchari are same and that Baco et al. (1991) committed an error in identifying this sugarcane pest in rice field. While this mite is presently being incorporated in the checklist, Amrine presumes this could probably be an error; and hence this needs to be further verified.

Keifer (1954) wrongly identified the wheat curl mite as Aceria tulipae (Keifer, 1938). The wheat curl mite continued to be named Aceria tulipae (Keifer, 1938a) until publication of Aceria tritici by Shevtchenko et al. (1970). English readers continued to call the wheat curl mite Aceria tulipae until the catalog by Amrine and Stasny (1994) was published, which corrected the name to Aceria tosichella. Amrine and Stasny noted that Keifer (1969) described the wheat curl mite as a distinct species, giving it the name Aceria tosichella Keifer (1969), which has priority over Aceria tritici Shevtchenko (1970). Most researchers now realize that Aceria tulipae is restricted to the Liliaceae:
tulips, onions and garlic. The present study by way of bringing out these changes and placing them in producing an updated inventory provides a standard and updated platform for a concentrated Acarological study in any cereal based agroecosystems.

A diagnostic key to the 13 families of mites collected from cereal agroecosystems has been presented here using Adobe Photoshop Elements® 2.0. Previous keys to families as outlined by Krantz (1978) and Gupta (1985) are relevant in providing the most complete written description for each family. The key proposed by Kethley (1990) exemplifies the families in Prostigmata associated with soil, complete with morphological nomenclature. However, all these keys lacked in providing illustrative examples for each character discussed. Zhang and Macfarlane (1996) developed an illustrated key to the common families of Prostigmata and Mesostigmata but it lacked in the number of characters described and in discussing these at all levels of classification in the hierarchy. Hence, by far, no key presents an illustrative guide to the taxons at all levels of hierarchical classification of the mite families.

The salient feature of the key is that for all the 13 families of mites recorded on cereals, the diagnostic characters have been explored and the details are highlighted using coloured illustrations, making these more user-friendly and simple to comprehend. Such a compendium of information on the classificatory characters will pave the way for a user friendly computer aided diagnostics. The key follows the latest classification as proposed by Lindquist et al. in Krantz and Walter (2009). The diagnostic characters defined for each taxon has been appended from several pertinent literature so as to develop a key with the most complete and comprehensive set of characters for the given taxon at each hierarchical level. This format is uniformly followed for defining all the taxon in the hierarchy from superorder till family. All the characters in the key are depicted with coloured illustrations, each colour specific for a character and highlighting the same on the illustrations. Thus, more than 200 coloured illustrations have been prepared and used in the key for describing the characters defined for the 2 superorders, 3 orders, 3 suborders, 12 superfamilies and 13 families of mites collected from cereal agroecosystems. Preparing the key characters is exemplified and simple characters is a unique approach
and this can only make the basic information in a form that can lead to computer aided diagnostics.

5.5 Computer aided diagnostics and database

The illustrations prepared in the study focus towards the essential diagnostics at various hierarchial levels, provide a unique backdrop for an authentic and quick diagnosis. Preparation of these in the form of a computer aided diagnostics will enable quick identification.

The Microsoft Office Access® 2007 has been deployed to develop a database on details of 283 species known from cereal agroecosystems encompassing data on systematics, distribution, nature of damage, host and bionomics. Efforts have been made to integrate these with computer aided diagnostics so that one can get holistic information on any species that is of significance to cereal agroecosystem. This database shall be useful for anyone who wishes to query and retrieve information on any particular cereal mite. This database is unique in being by far the first of its kind to inventsorise data on cereal associated mites and providing a user friendly retrieval system.

A Microsoft Office Publisher® 2007 based web page has been designed for providing illustrated key to all the 22 species in 17 genera under 13 families and 3 suborders of mites collected from cereals. This format of the key has been adapted from the text book schematic key proposed by Zhang and Macfarlane (1996) and is modified to exemplify all the species collected from cereal agroecosystems. The major diagnostic characters at the level of suborder, family, genus and species are highlighted in coloured illustrations. Also, the database on cereal mites developed using Microsoft Office Access® 2007 has also been hyperlinked into this webpage thereby providing holistic information on all crop associated mites. All the above keys and database are designed as web friendly applications, coded for easy launch on any web interface to facilitate in bridging the gap between taxonomic, biological and ecological studies of mites associated with cereals.