Chapter-5

Discussion

More than 300 insect and non insect pests of mulberry have been well documented from different regions of India. According to an estimate, the pests and diseases cause about 25% loss in foliage production of mulberry, besides deteriorating the nutritive value of leaves. Information on mite fauna invading mulberry and effect of mite infested mulberry leaves on silkworm under temperate climatic conditions of Kashmir is at its infancy (Dar et al., 2012a and Ramegowda et al., 2012a). In this background, the present study on these non insect pests of mulberry was undertaken with a broad objective that the outcome of the study may lead to ways forward that are helpful in reducing mite damage to the mulberry leaf crop and thus increasing/sustaining quality silk production.

Mites are not insects and are members of class Arachnida along with spiders, ticks and scorpions. Mites depict variety of food and feeding habits; they can be phytophagous or carnivorous in nature. Furthermore they can be predators on other species of mites. This condition makes the situation more complicated for conduct of diversity studies on mites and assessment of their economic significance. Phytophagous mites are common pests in landscapes and gardens and can be found feeding on many fruit trees, vines, berries, vegetables, agriculture crops, ornamental plants and wild plants. The spider mites, also called web spinning mites, are the most common and ubiquitous mite pests among all the pests in the gardens and farms. Mites cause damage by sucking cell contents (sap) from the plant leaves. At first, the damage shows up as a stippling of light dots on the leaves; sometimes the leaves take
on a bronze colour. As feeding continues, the leaves turn yellow and drop off. Often leaves, twigs and fruit are covered with large amounts of webbing.

Phytoseiid mites are well known predators and have got immense significance in IPM programme to control different phytophagous mites and other small soft bodied insects and their eggs. Phytoseiid mites have been studied intensively from taxonomic, biological and ecological point of view (Nesbite, 1951). At that time only around 30 species were recognized and little was known about their biology and ecology. But, today over 1700 phytoseiid mite species have been described worldwide and more than 20% of these species are useful in biological control of agricultural pests worldwide and given an industrial status for biological pest management in high value crops. The predatory significance of phytoseiid mites and their role in IPM stimulated lot of studies on their systematics, food habits, life cycles, ecological requirements and economic potential.

Considerable work on both predatory and phytophagous mites occurring on mulberry has been done in tropical India, but more or less no such studies have been performed in Jammu and Kashmir region which is an important state with regard to the sericulture industry is concerned. Present study was aimed to get an idea about diversity of mites (both phytophagous and predatory), their biology and feeding efficiency of predatory ones on mulberry in the Kashmir valley. Outcome of the study may be helpful in reducing mite induced damage to the mulberry leaf crop.

5.1. Diversity of mites in mulberry ecosystem

Present investigations revealed that the mulberry gardens of Kashmir region are primarily inhabited by five species of mites, of which *Tetranychus turkestani* (Ugarov and Nikol.) and *Panonychus ulmi* (Koch) were phytophagous and *Euseius* sp., *Agistemus industani* (Gonzalez) and *Neoseiulus* sp. were predatory in nature.

5.1.1. Influence of mulberry varieties:

*Tetranychus turkestani*: *Tetranychus turkestani* was present on all four varieties of mulberry investigated and was predominant on Ichinose variety followed by KNG,
Goshoerami and least population was recorded on Tr10 mulberry variety throughout the year. Record of this mite on mulberry in India is first of its kind even though it has been reported from other plants. Report of widespread distribution of *Tetranychus* sp. throughout the Kasmir valley (Khan and Nighat, 1991) renders a greater support for record of this mite pest on mulberry. *Tetranychus turkestani* has been reported as a pest of cowpea (*Vigna unguiculata* Walp) in Kashmir valley causing the failure of this important pulse crop (Rather and Lovdari, 2006). A variety of *Tetranychus* spp. have been reported as pests of mulberry throughout the world. *Tetranychus kanzawai* has been reported as a major pest of mulberry in Japan causing considerable damage (Ho, 1993); *T. ludeni* causing significant damage to mulberry in Tamil Nadu (Puttaswamy et al., 1980). Biradar (1989) reported *T. urticae* on mulberry from Karnataka, which causes severe damage to leaf crop. Two spotted spider mite (*T. urticae*) has been reported from Kashmir valley causing significant damage to fruits and leaves in apple orchards (Anonymous, 1993). Studies also revealed that highest population of *T. turkestani* was present on the 2nd, 3rd and 4th leaf of the branch from the top which borrows support from the studies of Chouhan et al. 2011, who has reported *Polyphagotarsonemus latus* as pest on mulberry from Coonoor (Tamil Nadu), Dehradun (Uttarakhand), Delhi and Jammu and Kashmir and witnessed higher population of this mite on tender leaves preferably on 3rd and 4th leaves below the bud. Present investigation revealed a greater variation in feeding preference of *T. turkestani* on different mulberry varieties registering highest population (3.22 and 3.52 mites per leaf, respectively) during 2011 and 2012 years and least population (1.50 and 1.62 mites per leaf) on Tr10 variety. Information generated on the mulberry varietal preference of *T. turkestani* is first of its kind.

*Panonychus ulmi:* *Panonychus ulmi* was recorded on all four varieties of mulberry investigated. It was predominant on Tr10 during 2011, but during 2012 season highest population per leaf was noticed in Goshoerami variety. The investigations are not sufficient enough to provide clear relationship between varietal reaction which may need intensive observations along with weather and crop phenology. However, these results borrow support from the findings of Karmakar et al., (1998) who observed the presence of *P. ulmi* on mulberry from West Bengal India. Earlier
preliminary studies in the same mulberry fields of CSR&TI, Pampore (Dar et al., 2012b) lend greater support to current findings as they witnessed Panonychus sp. causing leaf damage to some of the mulberry varieties. Panonychus citri has been reported as a pest of mulberry from Japan (Ayuzawa et al., 1972) while, P. mori has been reported causing serious damage (Ehara and Gotoh, 1992). Rather (1988) reported P. ulmi from apple orchards in Kashmir valley and found that they lay eggs singly on the lower surface of the leaves. It has been reported on apple in North West Himalayan region comprising Jammu and Kashmir, Himachal Pradesh and Uttaranchal (Bhardwaj and Bhardwaj 2000). Mohanasundaram and Sivagami reported the Aceria mori Keifer from mulberry gardens in Tamil Nadu causing damage to leaf buds also lends support for the mite diversity on mulberry which is not reported from temperate Kashmir climate of India.

Studies revealed that highest population of P. ulmi was present on the 3rd and 4th leaf of the branch from the tip. Irrespective of the season, Tr10 registered highest population followed Goshoerami, KNG and least number of mites per leaf on Ichinose variety. With these little information gathered, it can be provisionally said that, Tr10 is relatively susceptible to the population build up of P. ulmi compared to Goshoerami, KNG and Ichinose, which offered resistance to population build up of P. ulmi in the order. Similar results were documented on mulberry cultivars from West Bengal of which, - cv. Local was found to be highly susceptible to P. ulmi (49.52mites/leaf) and the cultivar KPG-II was least susceptible (3.89 mites/leaf).

5.1.2. Seasonal variation and role of climatic factors on population build-up of T. turkestani and P. ulmi:

Current study revealed that T. turkestani and P. ulmi showed seasonal variations in population build-up on all the four mulberry varieties studied during both the years (2011-12). These tetranychid mites were more abundant in the month of July and August than during rest of the year. July month recorded the peak activity of both T. turkestani and P. ulmi on all the four mulberry varieties particularly during the 2nd fortnight of July, from then started declining and reached the minimum level by the end of October from when leaf fall started. Karmakar et al. (1998) reported that
P. ulmi attain peak population during the second fortnight of March (19.74 mites/leaf) in mulberry gardens of West Bengal under subtropical climatic conditions. Similar results were witnessed on apple plants in Himachal Pradesh where P. ulmi population was highest (number per leaf) in the month of June and started decline August onwards to reach zero level in the month of December (Sharma and Mattu, 2014). In Japan, the incidence of T. kanzawai, Panonychus citri and Eotetranychus suginomensis on mulberry was severe in the summer-autumn rearing season, which is a dry season (Ayuzawa et al., 1972). Damage due to red mite, T. bimaculatus on mulberry was also more during dry season in Japan (Yokoyama, 1975). Population of Tetranychus truncates increases tremendously at the end of wet season in Thailand and overwinters in the egg stage (Sinchaisri and Isarangkul, 1973). In the present study it was observed that climatic conditions viz., temperature, relative humidity, rainfall and number of rainy days in a fortnight, influenced the population build-up of T. turkestani and P. ulmi significantly. Maximum and minimum temperatures and humidity showed highly significant correlations with population build-up of both species on all the four varieties of mulberry. While, rainfall registered a positive but non-significant and rainy days a negative correlation with mite population. Similar results were recorded by (Dar et al. 2012a) where the population of Tetranychus sp. and Panonychus sp. on mulberry in Kashmir valley are highly influenced by weather parameters and observed that population of both these species showed decrease in number as the temperature and relative humidity decreased, when rainfall was more population showed decreased trend.

Population of T. equitorius on mulberry was maximum during March-April and May-June followed by a reduction during August and then remained at lower level up to January-February in mulberry gardens of Tamil Nadu. The sudden fall in mite population from August onwards was attributed to the heavy rainfall during that period (Pillai et al., 1980). Population of mites was also higher during hot seasons in Karnataka and Tamil Nadu on mulberry (Pillai and Jolly, 1986). High temperature (28 to 33°C) coupled with low humidity (45-50%) favours breeding. Low temperature (25.5 to 27°C) and high humidity (85 to 90%) coupled with heavy rain fall affects the population of T. equitorius (Pillai et al., 1980). Population of P. latus which was first
noticed in January started increasing till April, which reduced in May due to cultural operations like, digging, weeding and pruning. Again it slowly picked up to reach higher density during October and November at Conoor in Tamil Nadu (Chauhan et al., 2002) which again declined during December with reduction in temperature. Present investigations are strongly supported by the findings of Pillai et al. (1980) and Chauhan et al. (2002), where in highest and lowest mite populations was obtained during hottest and coldest periods of study, respectively. Present findings are in close conformity with that of Prasad and Singh (2003) who have reported that, the mite population started building up on pumpkin crop from the second fortnight of March and continued to reach maximum during the first fortnight of July. Reports of Sharma and Pandey (1981) on the seasonal activity of T. cinnabarinus and T. neocaledonicus on brinjal at Udaipur Rajasthan lend support to the present findings on mulberry mite activity in Kashmir valley. Both T. cinnabarinus and T. neocaledonicus had almost similar population fluctuation between October and January with a low population level which increased rapidly to reach peak during May on all varieties. Mashue et al. (1998) reported that high temperature and drought conditions favoured the occurrence of mite.

5.1.3. Incidence and Severity of T. turkestani and P. ulmi:

Mites showed a higher degree of variations in damage to leaves with respect to the environmental conditions besides host factors. During May i.e., in the beginning of study the mite incidence (MI) and percent damage index (PDI) was 20.48 percent and 4.42 percent, respectively during 2011, 24.17 percent and 5.42 percent, respectively during 2012, reached to peak during the 2nd fortnight of July MI (49.83%) and PDI (31.78%) during 2011 and MI (58.50%) and PDI (38.56%) during 2012. Both MI and PDI started to decline from August onwards to reach 26.52 percent and 12.25 percent, respectively during 2011 and 39.83 percent and 15.57 percent, respectively during 2012 at the end of October when leaf fall started. Study clearly revealed that mite infestation had a clear-cut seasonal variation in response to climatic changes. It was observed that average temperature of 25 °C and above coupled with morning relatively humidity of 70 percent and above favoured the multiplication of mites leading to gradual increase in mite infestation and damage
from May to August which slowly decreased to reach a minimum in October upon reduction in temperature (and humidity). Both MI and PDI varied with respect to variety and years and were highest in KNG and Ichinose varieties during 2011 but during 2012 Goshoerami and KNG showed higher values. This clearly indicates that KNG even with fairly poor supporter for mite population build-up recorded higher MI and PDI making it as a highly susceptible among the four varieties studied. Of course, the influence of climate and agronomy still hold a share as Ichinose and Goshoerami did not confirm the MI and PDI in response to population build-up. At the same time, Tr10 being a good supporter of mite population build-up during both the years, showed some amount of tolerance to mite damage. Current results are in close conformity with that of (Dar et al. 2012b) who observed highest values for MI and PDI in Goshoerami variety of mulberry which showed fluctuations from June to October. Incidence as well as severity of mites was influenced by weather parameters. Majority of the weather parameters positively influenced the incidence and severity of mites during both years 2011 and 2012. Highly significant and positive correlation existed between mite incidence on all the four varieties and maximum temperature, minimum temperature and relative humidity, during both years, while rainfall and rainy days showed non-significant positive correlation during 2011 and rainy days showed non-significant negative correlation during 2012. Percent damage index (PDI) on all the four mulberry varieties showed highly significant positive correlation with maximum temperature, minimum temperature while, it showed non-significant positive correlation with relative humidity and rainfall. With rainy days, PDI registered non-significant negative correlations on all the four mulberry varieties during the years, 2011 and 2012. Current study gets endorsement from the findings of Dar et al., (2012b) who reported a significant positive correlation of temperature and humidity with mite incidence and percent damage index on Goshoerami variety in Kashmir valley. Similar results were documented by Ramegowda et al., (2012b) for lesser mulberry pyralid, *Glyphodes pyloalis* (LMP) and mulberry looper, *Hemerophila atrilineata* (ML) which are the serious defoliator pests of mulberry in Kashmir valley. These lend support to the current studies as they observed that both pest incidence and PDI-were dependent of climatic factors. Lall and Datta (1959) reported 36.8 to 83.2 percent loss in Okra yield due to spider mites. However,
Rajalakshmi et al. (2009) reported that the average maximum temperature of 25 °C and above, with relative humidity of around 70 percent and above, favoured the multiplication of mites and hence the total population shot up very fast in May/June. From October onwards average minimum temperature fell below 20 °C and hence the population started declining. Similar reports are available with many other species of mites on many agricultural - horticulture crops (Channabasavanna, 1999) in India and abroad.

The multiple regression modules comprising of five weather parameters had significantly higher probability and reliable $R^2$ and adjusted $R^2$ values for both MI and PDI of mite species for Goshoeرامی variety. Module obtained from weather parameters for MI and PDI on KNG variety had a highly significant probability as well as reliable $R^2$ values. Ichinose variety followed the same trend, but in case of Tr10 variety although there was reliable $R^2$ values but, the probability is not significant for MI. The average of mite incidence and severity, irrespective of the varieties too registered higher probability and reliability. Ramegowda et al. (2012b) observed that multiple regression modules showed reliable $R^2$ and higher probability for both LMP and ML with weather parameters in mulberry gardens of Kashmir valley, India.

5.2. Life history parameters of *Tetranychus turkestani*

Studies revealed that, *T. turkestani* egg measured 131.79 µm in diameter. Length and width of larva, protonymph and deutonymph were 237.23 and 152.88 µm, 289.95 and 192.42 µm and 421.74 and 255.68 µm, respectively. While the adult female measured 521.90 µm in length and 313.67 µm in width while, adult males measured 495.54 µm and 260.95 µm in length and width, respectively. Morphometric dimensions observed in the current study are similar to those reported for *T. macfarlanei* on brinjal (Patil, 2005) and they were 130.36 µm diameter in egg, 183.28 and 132.64 µm, 243.72 and 159.92 µm and 381.52 and 232.12 µm, respectively the length and width of larva, protonymph and deutonymph. Adult female measured 467.12 µm in length and 280.04 µm in width while adult males measured 362.6 µm and 183.40 µm in length and width, respectively.
In most poikilothermal animals development and reproduction are affected by temperature. In case of *T. turkestani* too temperature significantly affected the developmental rate, longevity and fecundity. Even though development of *T. turkestani* was successfully completed during all the three seasons in the Kashmir valley, during autumn season developmental duration got prolonged. All developmental stages *viz.*, egg incubation period, larval period, nymphochrysalis, protonymph, deutochrysalis, deutonymph and teliochrysalis differed significantly with respect to seasons. Total development period of immatures during summer was shortest (9.34 days), moderate during spring (12.04 days) and was longest during autumn (13.66 days), irrespective of sex. The current results are in close agreement with that reported by Patil (2005) who witnessed a longest duration in winter and a shortest in summer in different stages of *T. macfarlanei*, *viz.*, egg, larva, nymph and adult. Similar were the findings of Jose and Shah (1989) on cotton with *T. macferlanei*. Similar results have been reported on various host plants (Andres, 1957; Sohrabi and Shishehbor, 2008; Latifi et al., 2010 and Karami-Jamour and Shishehbor, 2012) and it was found that in temperature range of 25 to 30 °C *T. turkestani* completes its development in a shorter duration than at lower temperatures. Nemati et al. (2005) observed on egg (brinjal) plant that the developmental duration of 30.32, 17.41, 9.98 and 5.71 days at 15, 20, 25 and 30 °C, respectively.

Total developmental duration from egg to adult emergence was longer in female (12.04 days) compared to male (11.30), irrespective of seasons and similar trend has been documented for *T. turkestani* (Latifi et al., 2010; Karami-Jamour and Shishehbor, 2012) and *Eutetranychus orientalis* Klein (Imani and Shishehbor, 2009). Findings of Riahi et al. (2013) with *Tetranychus urticae* lend support to the current findings that total developmental period of males is shorter than females at all temperature regimes tested. Kasap (2004) observed that the developmental period of male was one day earlier (14.5) than that of female (15.50 days) in *T. urticae* also endorses the current findings. Importance of temperature and humidity as key regulatory factors influencing arthropod development is well documented and this has
been well established in case of *T. cinnabarinus* on brinjal (Gupta *et al.*, 1972 and 1982), *T. macfarlanei* on okra (Sejalia *et al.*, 1993) and cotton (Jose and Shah, 1989).

Highest survival of immatures to adulthood was recorded during summer (80.77%) followed by spring (63.03%) and was least during autumn (49.62%). Mortality rate of *T. turkestani* at different constant temperatures has been documented in the literature. In a laboratory experiment with *T. turkestani* on bean, Latifi *et al.* (2010) found egg-to-adult mortalities of 19.2, 7.0 and 20.4% at 20, 25 and 30 °C which are lower than the results in the present study. Sohrabi and Shishehbor (2008) conducted a study on the life history of *T. turkestani* on different host plant species and reported a lower immature mortality than those obtained in the current study. These dissimilarities may be attributable for disparities in host plant suitability for *T. turkestani* in addition to differences in experimental conditions. Present study was made in room conditions compared to controlled temperature studies in the earlier studies.

From the studies it was clear that, irrespective of the tested seasons, all the eggs from unmated female formed in to male progeny while, eggs of mated females resulted in both male and female progeny throughout. For all three seasons, female biased sex ratios were consistently observed, ranging from a minimum of 70.66% during spring to a maximum of 76.68% during summer and that during autumn didn’t varied much from that during spring (70.91%). Karami-Jamour and Shishehbor 2012 observed similar female biased sex ratio in *T. turkestani* ranging from 69.00 to 83.01%, which lends support to the present study. Moraes and McMurtry (1987) reported almost an identical pattern in *Tetranychus evansi* (Baker and Pritchard) at temperatures ranging from 15 to 35 °C. Margolies and Wrensch (1996) reported that sex ratio of *T. urticae* females exposed to a high temperature (32 °C) was more male biased (53.6%) than for females exposed to a low temperature (22 °C, 72.7%).

From the study it was witnessed that the hatchability of eggs was highest during summer (87.45%), followed by spring (81.27%) and least during autumn (75.87%). These results are in close agreement with the results of Rani and Jandial (2009) in *T. cinnabarinus* where a maximum 80.97% during April to June followed
Chapter 5

Discussion

by 77.63% (August - October) and 71.97% during mid February to April. Present findings corroborate the findings of Rishi et al. (1996), who have reported 77.3% hatchability in *T. cinnabarinus* on okra.

Life history parameters of adults differed significantly with respect to seasons and were significantly longer during autumn, followed by spring and shortest during summer. Irrespective of sex, adult longevity and total life span recorded in the present study during summer and autumn were higher than those reported at different temperature with other tetranychid mites. Riahi et al. (2013) reported the mean longevity of female as 12.91, 5.92, 3.56 and 6.53 at 25, 27, 30 and 33 °C, respectively for *T. urticae*. Mean longevity of female *T. urticae* was 14.71 and 9.71 days at 23.8 and 29.4 °C, respectively. Kasap (2004) reported the longevity of female *T. urticae* to be 29.9, 25.9, 16.8 and 4.7 days at 20, 25, 30 and 35 °C, respectively. Rajakumar et al. (2005) estimated that at 25 °C female and male *T. urticae* lived for 18.7 and 12.1 days, respectively. Forghani et al. (2006) found that females and males lived for 20.8 and 19.2 days, respectively at 28 °C. Scatter in the developmental durations /longevities among studies may be attributed to multiple factors viz., host plant, mite species, humidity and photoperiod conditions besides, frequency of observations, which too may influence the biology of test organisms.

In the present study highest fecundity was noticed during spring (88.77), summer (85.77) as against a least during autumn (35.77) irrespective of mating. Mated females showed significantly higher fecundity than unmated, irrespective of seasons. Daily egg production was highest during summer and was least during autumn. Patil (2005) found that total egg production in *T. macfarlanei* varied from 55.5 in summer to 43.1 in winter in mated while, 24.9 to 22.3 for unmated females. Compared to this in the present investigations the egg production was towards higher side but, the trend remained same and supports the current study. Similar results were also reported by Manjunatha (1982) and Bhagat and Singh (1999). Higher fecundity of 137 eggs per female *T. macfarlanei* on cotton has been reported by Jose and Shah (1989) Lower fecundity of spider mite on brinjal was evidenced by Gupta et al. (1972). Karami-Jamour and Shishehbor (2012) reported a decreased duration of preoviposition period and increased fecundity and daily egg production with increase in
temperature lends support to the current findings. Similar results have been reported with several other tetranychid species. Average fecundities of *T. urticae* at 27 °C were higher than the presently observed (143.9 eggs/female) on lima bean (Shih *et al.*, 1976); 141 on egg plant (Ju *et al.* 2008) but, higher than (15.1 – 57.6) on almond (Saeidi, 2011). Rishi *et al.* (1996) reported that a single fertilized female *T. cinnabarinus* on an average laid 24.8 eggs on okra, which is much lesser than that in the current study which might be due to the variation in host plant species and environmental conditions.

Intrinsic rate of natural increase (*r*ₘ) and net reproductive rate (*R₀*) describe the growth potential of a population under specific climatic conditions and reflect the overall effect of temperature on development, reproduction and survival. In the present results, intrinsic rate of population increase of *T. turkestani* was strongly influenced by seasons having different average temperature, relative humidity and photo-period and was 0.152, 0.240 and 0.123 during spring, summer and autumn seasons, respectively. Present study borrow support from Karami-Jamour and Shishehbor (2012) where higher *r*ₘ (0.272) at 30 °C and which decreased with the decrease in temperature. Similar results have been reported for this species on egg plant (Nemati *et al.*., 2005) and on bean (Latifi *et al.*, 2010) and for three other tetranychid species, *Tetranychus urticae* and *Eotetranychus carpini* (Bounfour and Tanigushi, 1993) and *Eutetranychus orientalis* (Imani and Shishehbor, 2009). However, in several other tetranychid species, the estimated maximum values of *r*ₘ were recorded at lower or higher temperatures; for example, at 27 °C for *T. urticae* (Riahi, 2011) and at 34 °C for *Tetranychus macdanieli* (Roy *et al.*, 2003). Gotoh and Gomi (2003) found that *r*ₘ in *T. kanzawai* varied with the type of host plants and ranged from 0.187/day in tea strain on tea to 0.283/day in tea and pear strains on mulberry. Sabelis (1985, 1991) made extensive reviews of life-history parameters of tetranychid mites and found that their *r*ₘ value ranged from 0.200 to 0.336/ day at around 25 °C. The *r*ₘ value during summer in the present study falls within this range, but spring and autumn *r*ₘ values are lesser. The two parameters of paramount importance in determining the *r*ₘ value are developmental time and ovipositional rate (Snell, 1978; Wrench 1985). For the *r*ₘ of spider mite, changes in developmental
time are more important than similar changes in oviposition rate (Sabelis, 1985). In the present study with *T. turkestani*, during spring and autumn seasons lesser ovipositional rate and longer developmental time was recorded than during summer season, thus \( r_m \) value of 0.152/day and 0.123/day, during spring and autumn respectively, which was shorter than during summer (0.240/day). Present study revealed that in summer season GRR, \( R_0 \), \( r_c \), \( r_m \), and \( \lambda \) being the highest. The cohort generation time \( (T_c) \), Generation time \( (T) \) and doubling time \( (DT) \) were shortest during summer, followed by spring and longest during autumn. This was due the lower daily rate of offspring production and later peak in reproduction observed during autumn season.

### 5.3. Life history parameters of *Panonychus ulmi*

Biology of *P. ulmi* under varied temperatures on different host plants has been well studied (Herbert, 1981; Osakabe *et al.*, 1990; Karmakar *et al.*, 1998; Khan and Sengonca, 2002 and Gotoh *et al.*, 2003). Present study on *P. ulmi* biology on mulberry with respect to seasons is the first of its kind. Mite pests show a well marked seasonal behaviour in their abundance and distribution on host plants. They are well adapted to seasonal climatic changes and such changes involve anatomical and behavioural changes. Temperate species enter into diapauses to avoid extreme cold, but in tropical species diapauses is usually absent. However, decline in fecundity during the dry season or cold weather has been well documented (Das, 1959).

Significant differences were observed between biological parameters of *P. ulmi* during three different seasons of temperate climate of Jammu and Kashmir, India. *Panonychus ulmi* developed successfully to the adult stage in all the seasons, however in autumn season the survival of immature was very low and all development periods were prolonged. Threshold temperature for *P. ulmi* development was 10.6 °C lends support to the experimental findings. Developmental duration from egg to adult got halved when the mean temperature increased from 15 to 21 °C and developmental duration of males was shorter than that of females at all the temperatures studied (Herbert, 1981). In Kashmir valley, *P. ulmi* reached peak population in 15th August (late summer) and late July (mid-summer) in abandoned
and commercial apple orchards, respectively (Wani, 1999) lends support to the fact that higher temperature reduces the developmental durations as evidenced in the study.

All developmental stages viz., egg incubation period, larval period, nymphochrysalis, protonymph, deutochrysalis, deutonymph and teliochrysalis differed significantly with respect to seasons. Total developmental duration from egg to adult emergence was longer in female (17.94 days) compared to male (14.75). Among seasons, during summer developmental period was shortest (11.64) and longest during autumn (20.95), irrespective of sex. Karmakar et al. (1998) reported the duration of egg incubation, larval, protonymphal, deutonymphal stages of *P. ulmi* as 3.87, 0.92, 0.69 and 0.81 days, respectively and the duration of inactive stages viz., protochrysalis, deutochrysalis and teliochrysalis as 0.77, 0.69 and 0.08 days, respectively and total development period was 9.10 days. The duration reported by Karmakar et al. (1998) are fairly shorter compared to the durations recorded in Kashmir condition, where the egg incubation period being distinctly more which may be due to macroclimatic variations, viz., subtropical and temperate climate. The developmental duration observed in the present study is in conformity with Khan and Sengonca (2002), who have reported a mean duration from egg to adult in *P. ulmi* on apple decreased from 18.1 to 12.8 days for females and from 17.9 to 12.2 days for males when the temperature increased from 25 to 30 °C. The developmental duration of *Panonychus citri* (McGregor) on citrus ranged from nine to 37.2 days at temperatures ranging from 15 to 35 ± 1 °C (Kasap 2009).

Highest survival of immatures to adulthood was recorded during summer (59.60%) followed by spring. This is very low and accounts for less than 2/3rd of the survival recorded at 30-25 °C on mulberry (Osakabe et al. 1990) and 25 °C on apple (Khan and Sengonca 2002).

Sex ratio of *P. ulmi* remained almost the same throughout the study period spanning over three seasons where in, females comprised 67.30, 67.70 and 69.44 percent during spring, summer and autumn seasons, respectively. Khan and Sengonca
(2002) have reported a change in sex ratio from 3:1 to 4:1 with change in temperature from 25 to 35 °C which could not be noticed in the present findings.

Hatchability ranged from 56.60 to 79.89 percent with highest during summer and least during autumn. More than 90 percent hatchability has been documented with *Tetranychus kanzawai* (Kishida) at 25 °C (Gotoh and Gomi, 2003).

Studies confirmed that the life history parameters of adults differed significantly with respect to season and were significantly longer during autumn, followed by spring and shortest during summer. It is clearly evident from the studies that *P. ulmi* completed life faster during summer. Irrespective of sex, total life span of *P. ulmi* was significantly shortest during summer and longest during autumn. Findings of Herbert (1981) for *P. ulmi*, where in duration of pre-oviposition period decreased and number of eggs laid increased with increase in temperature lend support to the present findings. Findings of Khan and Sengonca (2002) too endorse the present findings with respect to reduction in mean duration of pre-oviposition period, oviposition period and adult longevity of female and male *P. ulmi*. Highest fecundity was noticed during summer as against a least during autumn. Mated females showed significantly higher fecundity than unmated, irrespective of seasons. Daily egg production was highest during summer and was least during autumn. Khan and Sengonca (2002) observed a reduction in mean total fecundity from 80 to 51 eggs/female and mean daily fecundity from 5.7 to 4.7 eggs/female with increase in temperature from 25 to 30 °C. Kasap (2009) reported highest daily egg production and total fecundity of *P. citri* at temperature of 25 °C. These findings are in support to the present findings were highest fecundity was observed during summer with average temperature of 25.72±1.94 °C.

Development time, oviposition rate and early peak in oviposition are important determinants of intrinsic rate of natural increase \(r_m\). Studies with spider mites have shown that, \(r_m\) is more dependent upon developmental time than oviposition rate when both values change at similar rates (Sabelis, 1985; Gotoh *et al*., 2003). Intrinsic rate of natural increase \(r_m\) and net reproductive rate \(R_0\) describe the growth potential of a population under specific climatic conditions and reflect the
overall effect of temperature on mite development, reproduction and survival. In the present study both $r_m$ and $R_0$ were higher during summer season than spring and autumn. The $r_m$ obtained during summer season in the present study is comparable with that of Herbert (1981) at a temperature of 21 °C. While the $R_0$ during summer season was lesser than that reported at 15 °C. The variation may be due to the change in experimental conditions (room temperature v/s controlled conditions). Yasuda (1982) reported that 24 °C was the most favorable temperature for the reproduction and development of *P. citri*. Present study revealed that, in summer season GRR, $R_0$, $r_c$, $r_m$ and $\lambda$ being the highest. The cohort generation times (Tc), Generation time (T) and doubling time (DT) were shortest during summer followed by spring and longest during autumn. This was due the lower daily rate of offspring production and later peak in reproduction observed during autumn season. Kasap (2002) reported that at temperature of 24 °C, life table parameters viz., $r_m$, $R_0$ and T of *P. citri* were 0.171 females/female/day, 28.3 females/female and 19.4 days, respectively. This difference may be attributed to difference in host plants, mite population and time of year when the studies were conducted. Two studies by Sabelis (1985, 1991) provide extensive information on the life history parameters of tetranychid mites. The $r_m$ values of *T. kanzawai* reared on four different plants varied from 0.187 (tea) to 0.283 (mulberry) (Gotoh and Gomi 2003). Studies clearly revealed that, all the developmental durations are shortest during summer besides higher survival making the quick pest buildup during summer season which was evident from the field pest populations (Dar et al. 2012a and 2012b).

Present biological investigations on *P. ulmi* and *T. turkestani* on mulberry in temperate climatic seasons of Kashmir valley have generated several useful information. This information can be used in mass-rearing projects of both pest and predatory mites which has been well established in many western countries for the benefit of farming communities. The favorable seasons for development, survival and fecundity for both mite species can be chosen from the present findings which can also be made use in the controlled environmental conditions for large scale ventures. Secondly, findings can be used for the development of population and developmental models for *T. turkestani* and *P. ulmi* which will use an ambient temperature during
favorable season to predict the appearance of various life stages of these pests in the field and to deploy the management tools to target the most vulnerable stage of the pest to achieve efficient pest management.

5.4. Life history of *Euseius* sp. on eggs and immatures of *Tetranychus turkestani* and *Panonychus ulmi*:

Laboratory investigations showed that individuals of the predatory mite, *Euseius* sp. were found to feed on all stages of *T. turkestani* and *P. ulmi* inhabiting mulberry in Kashmir valley during both summer and autumn seasons. All the immature developmental stages viz., egg, larva, protonymph and deutonymph were of shortest duration in summer and longest during autumn season, irrespective of prey source. Egg incubation period varied with prey stage too and was shortest (3.79 days) when fed with *T. turkestani* eggs and longest (5.48 days) when fed on *P. ulmi* females. Shortest periods of protonymph and deutonymph were observed when *Euseius* sp. was feeding on *T. turkestani* immatures. On contrary longest protonymph and deutonymph periods were observed when fed on *P. ulmi* females. In general, larval and nymphal duration of *Euseius* sp. were shorter when fed on eggs of *T. turkestani* and longest when fed on *P. ulmi* females. Similar results obtained previously showed that the development time of *Euseius mesembrinus* (Dean) was significantly affected by food source and developed in 8.5 to 12.5 days after feeding on different kinds of pollen grains (Yue et al., 1994). While Abou-Setta et al. (1997) witnessed that, *Proprioseiopsis rotendus* (Muma) lasted only for 6.58 days when immature stages fed on all stages of *T. urticae*. Thongtab et al. (2001) reported that egg, larval, protonymphal and deutonymphal stages of *Amblyseius longispinosis* (Evans) that fed on *Eutetranychus cendanai* (Rimando), required 2.02, 0.57, 1.07 and 1.16 days, respectively and the total development time was 4.79 days.

Present investigations also revealed that, total developmental periods were significantly shorter (12.70 days) when *Euseius* sp. fed on eggs of *T. turkestani* and was longest (19.18 days) when fed on *P. ulmi* females. Developmental period was more rapid for males than females on all prey stages. Both male and female developmental periods were completed in shorter durations during summer than
autumn season. Similar results were obtained by Abou-Setta et al. (1997) and Mohamed et al. (2008) who reared *P. rotundus* and *Neoseiulus cucumeris* (Oudemens) on mobile stages of *T. urticae* and *P. ulmi*, respectively. Present results are in agreement with that of El-Laithy and Fouly (1992) who witnessed that, male and female life cycle of *E. scutalis* (Athias-Henriot) were 6.8 days and 7.8 days, respectively. Immature stages of *T. urticae* generally accelerated the development of predatory mite more than *E. orientalis*, while immatures stages of *O. afrasiaticus* were least preferred over the other two species. Similarly, Abou-Setta et al. (1997) found that immatures stages of *T. urticae* as a prey accelerated the development of phytoseiid mite, *P. rotundus* among different preys. Nguyen and Shih (2010) observed that all immature stages of *Euseius ovalis* (Evans) developed into adult on all spider mites and pollen diets, but the development was faster on spider mites than on pollen diets. Current findings borrow support from that of Mostafa (2012) who reported shortest protonymph and deutonymph periods in *Euseius metwallyi* when fed on larvae of *T. urticae* and longest stages of both protonymph and deutonymph when fed with *T. urticae* females. Similar results were documented by Raza et al. (2005) who concluded that duration of egg incubation, larvae, protonymph and deutonymph periods decreased as the temperature increased. Abdallah et al. (2001) reported that total developmental time of the immature stages of *Euseius finlandicus* (Oudemans) was the shortest on eriophyid mites, followed by pollen and spider mites. Kasap and Sekeroglu (2004) reported that the total developmental times of *E. scutalis* were 6.7, 4.9 and 4.2 days at 20, 25 and 30 °C, respectively using a diet comprising of all the stages of spider mite, *Panonychus citri* (Mc Gregor)

Regarding adult stages, results showed that, *Euseius* sp. males lived for shorter time than females on all stages of *T. turkestani* and *P. ulmi*. Male lived for 15.51; 14.73; 17.77 and 17.01 days on eggs, immatures, females and males of *T. turkestani*, respectively where as it lived for 16.59, 15.79, 19.07 and 18.28 on eggs, immatures, females and males of *P. ulmi*, respectively. Total life span too fallowed same trend of that of longevity and was shortest (27.48 days) when fed on *T. turkestani* immatures and was longest (19.07 days) when fed on *P. ulmi* females. Both longevity and total life span were significantly longer (38.80 days) for *Euseius* sp. during autumn and
shortest (27.40 days) during summer, irrespective of prey consumed. Current results are in close conformity with that of Al-Shammery (2010) who observed that males of *E. scutalis* lived for shorter time than the females. Similarly Nguyen and Shih (2010) witnessed that *E. ovalis* female feeding on *O. mangiferus* lived 23.77 days, which was significantly different from other food sources used during study. Similar results were reported by Shih *et al.* (1993) who found that, female of *E. ovalis* lived 13.83 days and 9.20 days when they fed on *O. mangiferus* and *T. kanzawai*, respectively.

It was noticed that there was a significant influence of seasons on the hatching of *Euseius* sp. eggs. Hatchability being highest (82.18%) during summer and lowest (54.70%) during autumn and varied with the type of prey stage consumed too and was significantly highest when fed on *T. turkestani* immatures (76.84%) and least when fed on *P. ulmi* females (58.53%). Survival rate of immatures followed same trend line and was 64.38 percent during summer and 37.96 percent during autumn. Irrespective of seasons, prey stage influenced the survival rate and was highest survival on *T. turkestani* eggs (60.39%) and lowest survival on *P. ulmi* females (42.41%). Similar results were obtained by Nguyen and Shih (2010) who have reported that immature survival rate of *E. ovalis* was affected by type of food source and demonstrated significantly higher immature survival rate when fed on *T. urticae* than those fed on other food sources used in study.

Little variation was observed in sex ratio with female proportion to male was almost at par with each other (64.47 percent and 61.43 percent during summer and autumn seasons, respectively). There was a slight variation in female percentage with respect to prey stage and was highest (66.74%) when fed on *T. turkestani* immatures and shortest (59.84%) on *P. ulmi* females. Current observations are in line with that of Nguyen and Shih (2010) who observed egg hatching of *Neoseiulus womersleyi* (Schicha) and *E. ovalis* on different food sources and found that food sources of females affect hatchability of *N. womersleyi* but, not in *E. ovalis*. When *N. womersleyi* fed on *O. mangiferus*, the hatchability rate (89.33%) was significantly lower than those fed on *T. urticae* (97.33%) and *T. kanzawai* (96.00%).
Post developmental periods viz., pre-oviposition, oviposition and post-oviposition periods were influenced by the weather parameters and were longest in duration during autumn and shortest during summer. With respect to prey stage consumed significant differences were observed in all the aforementioned post developmental periods. Present findings are in line with that of Raza et al. (2005) who reported in *E. septicus*, a maximum pre-oviposition duration (3.8 days) at 20 °C which followed by 1.8 days and 1.6 days at 25 °C and 30 °C, respectively when fed with two spotted spider mite (*T. urticae*). The oviposition period followed the same trend observed in case of pre-oviposition period. Bounfour and McMurtry (1987) reported the oviposition period of *E. scutalis* decreasing with the increase in temperature except at 25 °C, at which the oviposition period was longest. Abou-Setta *et al.* (1997) found that *T. urticae* prolonged the oviposition period of the phytoseiid predatory mite, *P. rotondus* over any other kind of food source, leading to a conclusion that prolongation in oviposition period of predatory mite may give a higher rate of egg production. Similar results were observed by Nguyen and Shih (2010), who noticed that food source influence the pre-oviposition period of *E. ovalis* females and were shorter on *O. mangiferus*, loofah pollen and maize pollen. Bounfour and McMurtry (1987) reported that, for *E. scutalis* females (Marrakech strains) feeding on pollen of *M. crocea*, the pre-oviposition periods were 3.0, 2.2, 2.2, 0.6 and 0.9 days at 15, 20, 25, 30 and 35 °C, respectively. Oviposition and post-oviposition periods at these temperatures were 23.4, 23.4, 32.2, 19.4, 13.3 days and 10.5, 5.0, 3.5, 2.4, 2.5 days, respectively (Bounfour and McMurtry, 1987). These facts support our findings as temperature increased the oviposition and post oviposition period decreased, which was same in current studies as summer season with average temperature (26.22±2.23 °C) showed lower oviposition and post oviposition periods than autumn season with average temperature of (16.06±3.95 °C), but the fecundity was more during summer.

Eggs and immatures of *T. turkestani* relatively stimulated more predator fecundity than females of *P. ulmi*. Fecundity rate increased with increase in temperature (as found highest during summer) and decreased with decrease in temperature (as found during autumn). Maximum fecundity was observed (40.75
egg/female) during summer while it was minimum (35.32 eggs/day) during autumn, irrespective of prey stage. Bounfour and McMurtry (1987) reported that, when *Euseius scutalis* fed on pollen of *M. crocea*, daily and total fecundity were 0.69, 1.26, 1.98, 2.9 and 2.46 eggs/day and 15.3, 28.5, 64.8, 55.9 and 34.6 eggs/day at 15, 20, 25, 30 and 35 °C temperatures, respectively supporting the current study. Fecundity varied with the type of food and was highest when fed on *T. turkestani* immatures (44.90 eggs/female) and lowest (32.50 eggs/female) when fed on *P. ulmi* males. Daily fecundity fell in same line with that of total fecundity and was highest and lowest during summer and autumn, respectively. Variation in daily fecundity per female under the influence of prey stage/source was evident and was highest (3.97 eggs/♀/day) when fed on *T. turkestani* immatures and lowest (1.85 eggs/♀/day) on *P. ulmi* females. Current studies are comparable with that of Meyerdirk and Coudriet (1986) who have reported that daily egg production of *E. scutalis* fed on pollen of *M. crocea* was 1.0 eggs/day for the Jordan strain and 2.2/day for the Marocco strain. Similar results were found by Abou-Elella et al. (2013) where in egg production of *E. scutalis* was significantly highest (37.06 eggs/female) when females fed on pollen, while it was lowest (8.19 eggs/female) when they consumed *Insulaspis pallidula* eggs. Raza et al. (2005) reported significantly maximum daily fecundity (2.5/day) of *E. septicus* was observed at 30 °C than at 20 °C and 25 °C which was statistically low and at par.

Difference in total prey consumption of larva, protonymph, deutonymph, adult male and female of *Euseius* sp. was significantly influenced by stage of the provisioned preys. Quantitative analysis on the feeding potential of *Euseius* sp. showed that even though the individual stages of the predator showed considerable variation in feeding potential, all stages of the predator could feed on all stages of *T. turkestani* and *P. ulmi*. Results of the present study revealed the preference of life stages of *Euseius* sp. to the immature stages of the both prey species. A single larva consumed on an average 2.10 *T. turkestani* eggs per day and 1.37 *P. ulmi* eggs, which were significantly highest, than *T. turkestani* (1.02) and *P. ulmi* (0.63) females per day. Average number of preys consumed by larval stage was significantly highest (1.64) per day during summer and was shortest (0.79) per day during autumn. The
average preys of each stage consumed by female and male larvae of *Euseius* sp. irrespective of seasons clearly depicted that *Euseius* sp. female larvae had significantly highest feeding potential than male larvae. Protonymph and deutonymph stages devoured higher number of preys when provided with eggs of *T. turkestani* (2.40 and 2.61) than any other prey stages tested. The total consumption rate of female protonymph and deutonymph were highest than male protonymph and deutonymph which varied with type of prey stage used as food. Average number of preys consumed by a protonymph and deutonymph were significantly highest (1.84 and 2.29/day) during summer and was least (1.03 and 1.13/day) during autumn. Similar results were obtained by Mostafa (2012) who investigated that *Euseius metwallyi* protonymphal and deutonymphal stages devoured higher number of preys when fed on larvae of *T. urticae* (7.4 and 10.6) than any other prey stages tested. Badii *et al.* (1999) found that protonymphs and deutonymphs of *Phytoseiulus longipes* consumed a mean minimum of 3.15 and 3.56 eggs of *T. urticae*, respectively to complete their development at prey density of 20 eggs per leaf arena. Average spider mites consumed by *Euseius finlaudicus* (Oudemans) during immature stages were 9.18 for males and 11.85 for females (Abdallah *et al.*, 2001). Sheeja and Ramani (2009) revealed the preference of life stages of *Lasioseius* sp. to the immature stages of red palm mite, *Raoiella indica* (Hirst) but the predator was found feeding on all stages. The mean number of different stages of *R. indica* viz., egg, larva, protonymph, deutonymph and adult consumed by a single larva were 7.95, 3.55, 2.45, 0.088 and 0.05, respectively.

During summer season a single adult predator female of *Euseius* sp. consumed on an average of 71.9 eggs, 55.3 immature stages, 44.6 females and 46.2 males of *T. turkestani* and 52.2 eggs, 43.9 immature stages, 38.3 females and 39.7 males of *P. ulmi*. The total consumption rate of male predator was comparatively lower than that of female and was 46.9 eggs, 43.2 immatures, 36.8 female and 41.5 males of *T. turkestani* and 37.9 eggs, 37.9 immatures, 33.2 female and 36.6 males of *P. ulmi*. Whereas during autumn season the feeding potential on all stages was lower. Current results borrow support from that of Mostafa (2012) who observed that *Euseius metwallyi* female consumed 36.40 eggs, 43.60 larvae, 26.80 nymph, 23.00 male and
20.80 female of *T. urticae* during ten days after mating and deposited 8.00, 14.00, 13.00, 9.80 and 10.80 eggs, respectively on above mentioned prey stages. Average prey consumption per day varied between sexes (males and females) during both seasons (summer and autumn), which clearly depicted that both male and female of *Euseius* sp. had higher feeding potential during summer than during autumn season and females are more voracious feeders than males during both seasons. Comparison in feeding efficiency of *Euseius* sp. during summer and autumn seasons of Kashmir valley on different prey stages of *T. turkestani* and *P. ulmi* showed that summer season was most favourable season for its feeding and *T. turkestani* eggs are the most favoured prey stage. Abdallah *et al.* (2001) reported that adult *E. finlandicus* females consumed an average almost three fold of spider mite protonymphs (166.38) during adult stage compared to male (66.55). Present investigations also borrow support from that of Badii *et al.* (2004) who pointed out that *Euseius hibisci* (Chant) consumed significantly more *T. urticae* eggs than other prey stages. Shih and Ji (2001) showed that among all the tested prey stages, female *T. urticae* gave the highest reproductive values but the lowest predation rates of *Amblyseius ovalis* (Evans).

Present results clearly indicate that the predatory mite, *Euseius* sp. may be considered as a potential bio-control candidate against the phytophagous mites *viz.*, *T. turkestani* and *P. ulmi* infesting mulberry plants besides many other agriculturally/economically important plants in Kashmir valley and elsewhere.

### 5.5. Life history of *Agistemus industani* on eggs and immatures of *T. turkestani* and *P. ulmi*:

It is a well known fact that members of Stigmaeidae family show considerable variation in their feeding habits and diets that include pollen, scale insects, moth eggs and phytophagous mites (Abou-ElGhar *et al.*, 1969; El-Badry *et al.*, 1969, El-Bagoury *et al.*, 1989; El-Sawi and Momen, 2006 and Abou-Awad *et al.*, 2010). These species dependence on animal food in the form of phytophagous mites varies considerably by species, mostly because of their innate characteristics but possibly also because of relative availability of different food sources in the environment. Therefore food traits
are excellent predictors of the direct mutualism between the diets and natural enemies of plant consumers (McMurtry and Croft, 1997).

During the course of investigations it was noticed that duration of different life stages viz., egg, larva, protonymph and deutonymph were of shortest duration in summer and longest during autumn season. Egg incubation period varied with prey stage too and was shortest when fed with P. ulmi eggs and longest when fed with T. turkestani eggs. The shortest period of protonymph and deutonymph was observed when A. industani was fed with T. turkestani eggs. On contrary longest protonymph and deutonymph durations were observed when fed on P. ulmi immatures. In general larval and nymphal duration of A. industani were shorter when fed with eggs of T. turkestani and longest when fed with immatures P. ulmi. Present investigations borrow support from the findings of Khan and Afzal (2005) who witnessed lowest developmental durations of immatures of Agistemus buntex on Tetranychus urticae as compared to Panonychus citri and Eutetranychus orientalis. Hafez et al. (1983) studied the effect of two tetranychid mite species on the life stages of stigmaeid mite, Agistemus exsertus and witnessed that feeding on T. urticae favoured faster development as compared to feeding on T. cucurbitaceum. The total developmental periods were significantly shorter (17.12 days) when A. industani fed with eggs of T. turkestani and was longest (21.93) when fed with immatures of P. ulmi. Developmental period was more rapid for males than females during both the seasons. Both male and female developmental periods were completed in shorter durations during summer than in autumn season. Current results borrows support from that of Nassar et al. (2005) who recorded that male immatures had a shorter life cycle and they reached to adulthood before females. Momen (2001), SiQin et al. (2001), Ferla and Moreas (2003) and Goldarazena et al. (2004) had also witnessed the similar results as that Nassar et al. (2005). It has been observed that temperature accelerates the development of A. exsertus immature stages thus lending support to our study where it was observed that during summer season, when temperature was higher A. industani takes shorter time in completion of immature stages but, duration was higher during autumn (16.06 ± 3.95 °C) and very shorter than summer season (26.22 ± 2.23 °C).
When the adult parameters are considered, males lived for shorter duration than females. Male lived for 14.54; 16.76; 14.14 and 16.30 days on *T. turkestanii* eggs, *T. turkestanii* immatures, *P. ulmi* eggs and *P. ulmi* immatures, respectively. Whereas, adult female life span averaged 30.16; 34.90; 32.58 and 37.54 days, respectively on the aforementioned prey stages. Both longevity and total life span were significantly longer for *A. industani* during autumn and shortest during summer for both the sexes. Present observations are in close conformity with that of Nassar *et al.* (2005) who have reported that both adult longevity and life span of *A. exsertus* were shorter in males than females. They also observed that both adult longevity and life span increased in duration with the temperature decrease. Similar observation were recorded by Rai and Singh (1999) who experienced that longevity of adult female of *A. industani* was 23 to 46 days and that of male was 23-48 days when fed with *Tetranychus ludeni* on mulberry. Yue and Childers (1994) found that for *A. exsertus* mean generation time decreased as the temperature increased from 15 to 35 °C, when fed with *P. citri* eggs.

It was noticed that there was significant differences in the hatching of *A. industani* eggs, with highest hatchability (89.26%) during summer and least during autumn (73.63%). Hatchability too varied with the type of prey stage consumed but the differences are not significant. Abou-Awad *et al.* (2010) found that in *A. olive* the hatchability percentage averaged 99.00% at 30 °C and was lesser 79.00% at 20 °C, thus lending support to current findings where, *A. industani* registered higher hatchability during summer than during autumn season. Survival rate of immatures fell in the same line with that of hatchability and was 68.01 percent during summer and 50.63 percent during autumn, irrespective of prey. Irrespective of seasons, prey stage too influenced the survival rate with highest survival on *T. turkestanii* (67.92%) and lowest survival on *P. ulmi* immatures (52.22%). Proportion of females to male was almost at par with each other during both the seasons. It remained unaltered during seasons, but showed little variation with respect to prey stage as food. Rai and Singh (1999) observed that fertilized females of *A. industani* produce female and male progeny in a ratio of 3:1 when fed with *T. turkestanii*. Many studies have clearly showed that *Agistemus exsertus* Gonzalez develop, survive and reproduce on
tetranychids and various insects successfully (Zaher and El-Badry, 1961; Afifi et al., 1969; Soliman et al., 1976; Hanna et al., 1980; Oamen, 1982; Yousef et al., 1982; Hafez et al., 1983; Santos and Laing, 1985; El-Bagoury et al., 1989; Abou-Awad and El-Sawi, 1993 and Momen, 2001).

Post developmental periods viz., pre-oviposition, oviposition and post-oviposition periods were influenced by the weather parameters and were longest in duration during autumn and shortest during summer. With respect to prey stage consumed significant differences were observed in all the aforementioned post developmental periods. Saber (2012) observed that pre-oviposition and oviposition periods as well as longevity of A. exsertus significantly shortened as nymph densities of T. urticae increased. Developmental time, oviposition rate and longevity determine the intrinsic rate of increase \((r_m)\), which is high in A. exsertus feeding on T. urticae eggs (Abou-Awad and El-Sawi, 1993) and P. citri eggs (Yue and Childers, 1994). At low prey densities, A. exsertus was effective in controlling tetranychid mites because of its high oviposition relative to predation on P. citri (Yue and Childers, 1994), high preference for P. citri eggs (Yue and Tsai, 1995) and its ability to consume conspecific eggs (Rasmy and Saber, 2012) as shown on Z. mali predating P. ulmi (Clements and Harmsen, 1992). Kahan and Afzal (2005) witnessed a shorter pre-oviposition period in A. buntex when fed with P. citri as compared to T. urticae and E. orientalis. Current findings borrow support from the findings of Nassar et al. (2005) who found that pre-oviposition, oviposition and post – oviposition periods were longer (7.53, 30.00 and 8.00 days, respectively) at 20 °C and become shorter (1.13, 13.67 and 4.40 days) at 30 °C. Momen (2012) witnessed variation in oviposition period in A. olive on the basis of food source and confirmed that it was longer (24.33 days) when fed on Aculus fockeui (Nalepa and Trouessart) than on Aceria mangiferae (Sayed) (20.70 days) and Aculopus lycopersici (Massee) (20.26 days).

Eggs of T. turkestani relatively influenced the predator with more fecundity than immatures of the P. ulmi. Fecundity rate increased with increase in temperature (as found highest during summer) and decreased with decrease in temperature (as found during autumn). Maximum fecundity was observed (46.22 egg/female) during
summer where as a minimum fecundity (30.25 eggs/day) was recorded during autumn, irrespective of prey stage consumed. Fecundity varied with the type of food and was highest when fed with *T. turkestani* eggs (45.60 eggs/female) and lowest (31.83 eggs/female) when fed with *P. ulmi* immatures. Daily fecundity followed the same trend of that of total fecundity and was highest and lowest during summer and autumn, respectively. Daily fecundity varied with type of food consumed being highest (3.55 eggs/♀/day) when fed on *T. turkestani* eggs and was lowest (1.90 eggs/♀/day) on *P. ulmi* immatures. Present findings borrow support from that of Al-Shammary (2011) who found that the differences between the effect of tested temperatures on the fecundity and egg production of *A. exsertus* were significant. Present findings are in agreement with those of Khan and Afzal (2005) who obtained an average of 40 eggs/female from *A. buntex* when fed on *T. turkestani* as compared to 24.33 and 27.67 eggs/female, respectively when fed on *P. citri* and *E. orientalis*. Yue and Childers (1994) found that a female of *A. exsertus* produced an average of 66.0, 69.0, 46.5, 25.5 and 18.8 eggs when it was kept at 15, 20, 25, 30 and 35 ºC, respectively. El-Laithy (1998) found that *A. exsertus* had a fecundity rate of 66.6 eggs/female during an oviposition period of 18.58 days. Present findings are comparable to those of Yousef *et al.* (1982) who studied the effect of prey species on biology and fecundity of two stigmaeid mites, *Agistemus gossipi* and *A. exsertus* and showed that fecundity was higher when mites were fed on *T. urticae* as compared to *T. granati*.

Feeding potential of *A. industani* revealed its efficiency as a predator of eggs and immatures for both *T. turkestani* and *P. ulmi*. A quantitative analysis on the feeding potential of *A. industani* showed that even though the predator is not able to prey upon adults of *T. turkestani* and *P. ulmi* but could feed voraciously on eggs and immatures of *T. turkestani* and *P. ulmi*. Studies revealed the preference of life stages of *A. industani* to the eggs and immatures stages of the both prey species studied. A single larva consumed on an average 1.68 *T. turkestani* eggs per day, which was significantly highest than (0.54) *P. ulmi* immatures per day. Average numbers of preys consumed by larval stage were significantly highest (1.31) per day during summer and were least (0.70) per day during autumn. Female *A. industani* larva
consumed highest number of *T. turkestani* eggs (1.78/day) and least number of *P. ulmi* immatures (0.58/day), where as male larvae consumed significantly highest number of *T. turkestani* eggs (1.58/day) and least number of *P. ulmi* immatures (0.50/day) during summer season. Average prey consumption per day of predatory larva, irrespective of prey stage during summer (1.29 male; 1.33 female) was significantly higher than during autumn (0.69/day by male and 0.70/day by female). Current results are in close conformity with that of Nassar *et al.* (2005) who observed that larvae of *A. exsertus* consumed on an average of 5.0, 9.2 and 7.0 prey (eggs) at 20, 25 and 30 °C and 70% RH, respectively. Abou-Awad *et al.* (2010) also observed that the larva of *A. olivi* female and male devoured 3.71, 8.27, 5.63 and 2.81, 4.0, 4.81 individuals/day at 20, 25, 30 °C.

Protonymph of *A. industani* consumed on an average 2.19 eggs and 1.24 immatures of *T. turkestani*, 1.46 eggs and 0.76 immatures of *P. ulmi* per day which differed significantly from each other. The total number of prey of each stage consumed throughout lifetime by female protonymph was highest than that of male protonymph. Consumption varied with prey stage provided during both seasons. Average number of preys consumed by protonymph was significantly highest (1.81/day) during summer and was shortest (1.02/day) during autumn. The *A. industani* female protonymph consumed highest number of *T. turkestani* eggs (2.47/day) and least number of *P. ulmi* immatures (0.90/day), similarly, male protonymph also consumed significantly highest number of *T. turkestani* eggs (1.90/day) and least number of *P. ulmi* immatures (0.62/day). Feeding potential of *A. industani* deutonymph was significantly highest during summer (2.81 preys/day) and least (1.56 preys/day) during autumn season. Feeding rates of the deutonymph per day varied significantly with respect to feeding stage and was 3.30 *T. turkestani* eggs, 1.85 *T. turkestani* immatures, 2.35 *P. ulmi* eggs and 1.24 *P. ulmi* immatures. *Agistemus industani* female deutonymph consumed 2.51 preys per day which was significantly lesser (1.85 prey/day) by a male deutonymph. In this context, Abou-Awad *et al.* (2010), reported that in deutonymphal period of *A. olivi* female consumed 19.29, 18.64, 23.45 and 6.39, 15.0, 15.45 individuals/day at 20, 25 and 30 °C. Similar results were obtained by Nassar *et al.* (2005) where in protonymphal stage of
A. exsertus devoured 12.4, 13.46 and 12.33 T. urticae eggs and deutonymph devoured 21.53, 24.53 and 17.66 eggs, when they were kept at 20, 25 and 30 °C, respectively. Al-Shammary (2011) found that developmental stages of A. exsertus consumed about 11.7, 12.15, 9.32 and 9.25% from the total prey individuals of T. urticae during life span when developmental stages were kept at 20, 25, 30 and 35 °C, respectively.

Present investigations revealed that a single adult predator female of A. industani consumed an average of 92.00 eggs and 62.93 immature stages of T. turkestani, 82.00 eggs and 49.20 immature stages of P. ulmi. Whereas male predator has comparatively lower feeding potential than that of female and was 56.47 T. turkestani eggs, 46.93 T. turkestani immatures, 50.40 P. ulmi eggs and 43.13 P. ulmi immatures. Average prey consumption per day varied between male (3.87 preys/day) and female (4.50 preys/day) during summer and 2.17 preys per day by male; 2.35 preys per day by female during autumn seasons. Average feeding potential, irrespective of sex was significantly higher during both summer (4.18/day) and autumn (2.26/day). The feeding stage preference of A. industani adult irrespective of sex and season was highest (4.43/day) for T. turkestani eggs and least (2.44/day) for P. ulmi immatures. Current results borrow support from that of Osman and Zaki (1986) who found that the daily consumption of adult female of A. exsertus was about 60.3 eggs. While Nawar (1992) stated that A. exsertus female preyed on T. urticae eggs where the number of consumed eggs increased with increasing prey offered. Also, he found that predator female consumed 5.8 preys and laid an average of 2.3 eggs day. Present studies are in line with that of Rai and Singh (1999) who found that the feeding rate of A. industani female was three times higher than that of male and on an average deposits three eggs per day after the consumption of fifteen eggs per day. Rasmey et al. (1996) reported that rearing of stigmaeid mite, A. exsertus on the eggs of prey speed up development and causes a higher rate of oviposition than when fed on prey larvae and nymphs. Yue and Childers (1994) who reared A. exsertus on citrus spider mite, P. ulmi in florida at 15, 20, 25, 30 and 35 °C, obtained the best results with regard prey consumption and egg production at 25 °C. Also, Goldarazena et al. (2004) found that 25 °C was the most suitable temperature to rear three species of Agistemus, Agistemus cyprius Gonzalez, Agistemus floridanus Gonzalez and
A. industani. Abou-Awad and Elsawi (1993) noticed that T. urticae is the most preferred diet over Eutetranychus orientalis Klein, Brevipalpus pulcher (Canestrini and Fanzago) and whitefly, Bemisia tabaci (Genn) when it was reared at 25 °C.

5.6. Host range of mulberry mites in mulberry Ecosystem

Weeds in mulberry garden pose a serious problem for mulberry plantation in the production and quality of leaf. Weeds impact the growth of plant by competing for the soil nutrients, which reduce the yield and quality of mulberry leaf (Muniyppa and Shivakumar, 2000; Sikandar et al., 1981, Srinivasan et al., 1987). During current study some of the weeds had been found acting as collateral host for T. turkestani and helping it in population build-up which in turn causes mulberry leaf damage.

Monthly observations on host range of mites in mulberry ecosystem in the current study revealed that, among the two phytophagous species of mites found on mulberry foliage; only T. turkestani was found inhabiting six species of weed plants during 2012 and 2013. These plants were O. acetosella, R. acetosa, Conyza canadensis, Convolvulus arvensis, Amaranthus viridis and Lactuca varosa. These observations get endorsement from many reports that T. turkestani is a polyphagous mite in nature and feed on more than 200 plant species. Carpinera (2001) reported that, T. turkestani has vegetable hosts and occur on low growing plants; overwintering may occur on forage legumes and in greenhouses in cold winter areas and weeds and senescent crops can be important sources of mite infestation. Record of T. turkestani on weeds of Amaranthaceae family viz., Amaranthus albus, A. patulus, A. retroflexus, Atriplex australasica and A. canescens from central Asia (Ugarov and Nikolskii, 1937) supports the current findings. Tetranychus turkestani has been reported by various authors on large number of species of family Asteraceae like Ambrosia artemisiifoia and A. confertiflora (Tuttle and Baker, 1964); A. dumosa (Tuttle and Baker, 1968); A. trifida and A. lappa (Ugarov and Nikolskii, 1937); Calendula officinalis (Tuttle and Baker (1968); Carthamus tinctorius (Tuttle and Baker, 1968); Chrysanthemum sp., Cichorium intybus, Cirsium arvense, Erigeron annuus, Galinsoga ciliata and Helianthus annuus (McGregor, 1950; Bailly et al., 2004); Heterotheca subaxillaris (Tuttle and Baker, 1964); Lactuca canadensis, Lactuca
sativa (Tuttle and Baker, 1968); Senecio vulgaris (Aucejo et al., 2003); Sonchus arvensis, Tagetes erecta, Taraxacum officinale, Xanthium saccharatum (Tuttle, 1976). It was also reported from plants of convolvulaceae family, Convolvulus arvensis (Ugarov & Nikol., 1937; Tuttle and Baker, 1964; Bailly et al., 2004); Convolvulus sp. (Aucejo et al., 2003); Cressa cretica, Ipomoea hederacea, Ipomoea purpurea, Ipomoea sp.(Ugarov and Nikolskii, 1937) and was also present on some plants of Polygonaceae viz., Polygonum argyrocoleon (Tuttle and Baker, 1964); P. aviculare; P. hydropiper; P. nodosum; P. orientale; Rumex crispus and in Oxalidaceae family like Oxalis europaea; Oxalis sp. (Bolland, 2001).

Bali and Pandit (2014) recorded the weed flora of the mulberry gardens in Jammu and Kashmir which comprises of 123 species in 103 genera and 35 families. Among them 100 species are dicots and rest are monocots. During current studies weeds found inhabited with T. turkestani were dicot annual herbs except Convolvulus arvensis and Rumex actosa which are perennial herbs.

Future line of work

1. Life table studies of predatory mites on prey species during different seasons
2. Exploration of botanicals against strawberry spider mite and European red mite in laboratory and confirmation in field.
5. Standardization of field release protocols and dosage.