Vegetables constitute an important source of nutritive minerals, fibers, vitamins and anti-oxidants brimming with many other protective ingredients which are essential for body building and maintenance. The term ‘vegetable’ generally means the edible parts of plants. They provide more food within a short period from a limited area. During the present national emergency, vegetable growing has its own value both in general agricultural production and as kitchen gardening as these are short duration crops having the capacity to produce more food per unit area. A spectacular field of mite activity leading to depletion of plant quality is their potential to rise to the pest status. This extraordinary ability of the spider mites to colonise vegetable plants, replenish the available nutrients and cause serious injuries has raised the importance of these mites as pests in terms of the degree of damage. Therefore, this would obviously necessitate control programme augmenting regulation of these pests well below the problem level. In this context, introduction of biological control programmes seems to be quite promising. Implementation of a successful biocontrol method demands a concrete and reliable data on the biology of the mite in question as well as the temperature-relative humidity conditions favourable for their outbreak as a dreadful pest. Hence, a detailed investigation on the feeding and breeding biology and the influence of the temperature and relative humidity on the life cycle of 5 serious tetranychid pest mites has been focussed in greater detail.
Mites have emerged as a prominent faunal element on almost all the 40 species of vegetable plants surveyed, of which prostigmatids showed predominance in terms of species composition followed by mesostigmatids represented by predatory mites. Other groups including oribatids made a nominal representation. Taxonomic analysis of the prostigmatid fauna envisaged the presence of 3 superfamilies; Tetranychoidea, Tarsonemoidea and Eriophyoidea in almost all of the collection sites.

The recovery of rich and varied faunal complexities of spider mites from the vegetable crops affords adequate evidence to consider their potential of infestation under natural conditions. A total of 5 species of tetranychid mites belonging to 3 genera were selected for further biological studies within the limit of the objectives of the current study. A worth mentioning aspect of the study was that these spider mites were comparatively scanty in the case of plants sprayed with pesticides whereas the same plants without pesticides harboured quite a good number of them.

A comparison of the site wise incidence of the species of spider mites shared interesting trend in their distribution pattern. Occurrence of atleast 3 species from 19 out of 25 localities screened, well proved the potential of this group to infest vegetable crops. This would suggest the possible micro and macro habitats provided by the vegetable plants for the flourishing of spider mites. Most of the locality sampled were open vegetable fields. Probably the erect leaves and micro and macro habitats provided by the extensively grown vegetable plants favoured distribution of spider mites without any interspecific differences.
The current study also added knowledge on the host range of the spider mites studied. Each of the host plant examined during the study revealed the occurrence of more than one species of mite. However, analysis of the host range of each species within the limit of the study suggests 21, 20, 20, 9 and 5 species of host plants respectively for *T. ludeni*, *T. neocaledonicus*, *T. cinnabarinus*, *E. orientalis* and *O. biharensis*. However, infestation was observed to attain peak levels during the months of February to April/May for *T. neocaledonicus*, *T. cinnabarinus*, *E. orientalis* and *O. biharensis* (Lal and Mukharji, 1980; Dhooria and Butani, 1983; Gupta, 1985; Pande and Sharma, 1986) with an exception of *T. ludeni* which appeared at high levels from May to July (Puttaswamy and ChannaBasavanna, 1981a). This would probably suggest their tendency to avoid competition even though they occurred at moderate to scanty levels during the rest of the year.

During the monsoon season, the mites were scanty on the leaves of the various vegetable crops, though their abundance was noted in the lower vegetation like grasses and weeds. This comprised almost all species of mites including the soil mites. It leads to the conclusion that these mites were compelled to leave their normal niche in order to escape from the washing effect of heavy rain and had to take shelter in such protected niches. At the same time the increased population of the predators in these areas during the monsoon season may be due to the abundance of their prey species around the area. The occurrence of the former 4 species at similar seasons of the year may be attributed to their ability to co-exist despite similarity in their feeding trends.
A study of the relative abundance of the spider mites under study revealed the occurrence of *T. ludeni* in almost all the localities screened followed by *T. cinnabarinus, T. neocaledonicus, O. biharensis* and *E. orientalis*. The active nature of the former group depicted by the earlier workers (Moutia, 1958; Meyer and Rodriguez, 1966; ChannaBasavanna, 1971; Jeppson *et al.*, 1975; Puttaswamy and ChannaBasavanna, 1980a, b & c, 1981b; Manjunatha and Puttaswamy, 1989; Ghoshal *et al.*, 2006; Sangeetha and Ramani, 2007a, 2008a & 2009) would have been one of the factors that favoured them in dominating these habitats. The relative abundance of spider mite species was noted on the plants which were under modern cultural practices like frequent fertilizer application and irrigation than those species grown in comparatively barren land. This observation is in agreement with the suggestion of Sadana (1985) that the use of fertilizer and better crop management practise enhanced the power of increased reproductive potential of these mites. Sarkar and Somchoudhury (1981) and Puttaswamy and ChannaBasavanna (1982a) also reported the enhanced pest status of plant feeding mites on high yielding varieties of crops under improved cultural practices. The reason for the abundance of infestation may be related to the fact that the morden fertilizers increase the availability of rich food supply with high nutritive value to the mite pests from plants.

An interesting aspect that emerged from the study of relative abundance was the tendency of *T. ludeni* to compete with *T. neocaledonicus* for the host plant infested by both of them. Following initial infestation on a host plant both species spread gradually to all other leaves. A tendency of restricting itself to a small area
of the leaf and then gradually spreading to other areas as shown by \textit{T. neocaledonicus} appeared contrary to \textit{T. ludeni} which explored and spread all over the leaf area at a faster rate. The slow dispersal from the area of initial infestation appeared to explain the slow increase in numbers of \textit{T. neocaledonicus} cohabiting with \textit{T. ludeni} initially. This observation is in support of earlier findings concerning the reciprocal effects of cohabitation by these two mites by Puttaswamy and ChannaBasavanna (1980c) and many other pairs of spider mites (Newcomer and Yothers, 1929; Webster, 1948; Chapman and Lienk, 1950; Lienk and Chapman, 1951; Foott, 1962, 1963), suggesting the possibility of competition between them.

Results of field observation on distribution pattern revealed that the spider mites under study could infest almost all age groups of host leaves except the newly sprouted and very tender ones. The petiole and the tender stem of the plants remained unaffected. Inspite of such preference for leaves, the mites exhibited profound variation in their distribution pattern among the leaves. Accordingly, the middle aged leaves were found mostly favoured by all the species, as their population densities were high on these leaves. Probably the biochemical constituents of these leaves at this age provided the ideal nutritional components for the development of these mites. Leaves that were too old (Dhooria, 1985) or too young (Sobha and Haq, 1999) harboured comparatively lower population of adults eventhough eggs could be seen on younger leaves. This could be a preventive measure against loss of eggs due to leaf dehiscence. The particular absence of spider mites on younger leaves suggested their preference to the less turgid tissues of mature leaves. This observation is in accordance with that of Jeppson \textit{et al.}, (1975)
who also remarked *O. coffeae* as a less turgidity preferring species. The apical 1-3 tender leaves generally revealed a total absence of the mites. Total avoidance of most tender leaves may be attributed to the non availability of specific nutritional components required for the survival and population build up of these spider mites. On the leaf blade, the spider mites were often found occurring in the joining regions of leaf veins. The shallow concavity available in such regions appeared to provide some shelter for their oviposition as well as serve to prevent their direct exposure to sunlight. Moreover, the veins and veinlets enable to provide a firm grip to these mites during oviposition (Banu and ChannaBasavanna, 1972; Dhooria, 1982) preventing their dislodgement from the leaf surfaces. This indicated a high degree of thigmokinesis, thereby favouring the earlier findings of Jeppson *et al.*, (1975).

The spider mite species selected for study represented the category of leaf suckers. Feeding activities of these sucking forms enabled to produce conspicuous injury to the host plant, manifested through chlorosis of the leaves. This category was entirely represented by all the 5 species of tetranychids. It was observed that infestation by *T. ludeni* and *E. orientalis* initiated on the upper surface of the leaf. This appears to support the observations of Banu and ChannaBasavanna (1972), Lal (1977) and Dhooria (1985) who observed *E. orientalis* invariably on the upper leaf surface of different host plants. While *T. neocaledonicus* and *T. cinnabarinus*, in all stages preferred lower surface of the leaf blade (Sobha and Haq, 1999; Sangeetha and Ramani, 2007a). Probably, the dorsoventral disposition of the host leaves would have favoured feeding of these mites on one side of the leaf. On the contrary, *O. biharenensis* colonised both the leaf surfaces simultaneously. Difference in feeding
trends in these spider mites could be a mechanism to avoid competition especially when more than one species occur together on the same host plant. However, infestation by the former 4 species readily spread to the other surface of the leaf or petiole when the feeding niches on preferred leaf surface were completely exhausted (Banu and ChannaBasavanna, 1972; Gupta, 1985; Sangeetha and Ramani, 2007a & b). This revealed intraspecific competition among the members of the colony. Also, the incidence of mites was more pronounced on the exposed upper layer of the canopy than the lower ones.

Webbing behaviour is a character recognised in some genera like Tetranychus, Oligonychus, Eotetranychus and Schizotetranychus (Hazan et al., 1974, 1975; Saito 1977a, 1977b and 1979b; Gerson, 1979; Saito, 1983; Duncan and Lindquist, 1989). The complicated nature of the webbing produced by the above genera seems to be identical with that of the present species. Webbing was found to serve as a protective device for the eggs and immatures as they remained totally confined within the canopy of the webbing. Webs were proved to safeguard the viability of eggs also, as removal from the web, often resulted in reduced hatchability (Hazan et al., 1974). Apart from this, webbing was also found acting as a means of transport for the individuals within or between the host plants. In addition, webbing was reported to serve as carrier of sex pheromone and increase the potential of the species to compete with other non-spinning phytophagous mites. The webs served as a place for excretion (Saito, 1983; Oku, 2008) and also enhanced the accumulation of dust particles on the leaves, impairing the fast movement of the predatory mites. This might have resulted in the avoidance of the
host plants by the latter. This finding substantiated the reports of Griffiths and Fischer (1950) who reported the favourable effect of inert dusts on spider mite population and the adverse effects on the population of their natural enemies. Plants with the web laden debris were seen to be paler in colour than their relatives without the dusts. This suggests that in addition to the direct disservices, the spider mites can even affect the metabolism of the host indirectly by reducing the quantum of light reaching the surface of the leaves thereby reducing the photosynthetic activity. This inference supports the view of Sadana (1985) who remarked that dust entangling the spider mite webs impaired photosynthesis by preventing the sunlight reaching the leaf surfaces.

Spider mites produce large quantities of black coloured faecal pellets which normally appear to be a reflection of their feeding tendency. However, *T. neocaledonicus* produced violet faecal pellets on *A. tricolor*, which could be attributed to the colour of the host leaves on which the mite was feeding. A special feature observed in the current study was the production of two types of faecal pellets by all the life stages of *T. ludeni* suggesting the lack of influence of age on the type of faecal pellet produced. The excreta of this species constituted black and white pellets with a central core of oval granules glued together and covered by a transparent membrane. Analysis of the reason behind the production of two types of faecal pellets, its nature and origin needs further indepth studies. *T. kanzawai* was reported to produce two types *viz.*, black and yellow faecal pellets (Oku, 2008) where the viscous yellow pellets (Wiesmann, 1968) reduced chances of egg predation by predatory mites by preventing the foraging activity of the latter. The
black pellets are excreta and the yellow pellets could be considered to deter predators, as they are suggested to be secreted not excreted for actively deterring predators (Oku, 2008).

Egg deposition as a common feature, has been observed during the process of feeding and webbing and the deposited eggs were often found entangled in the web along with the faecal pellets. Egg cases and moulting skins of the various developing stages were also found attached to the webs which facilitated accumulation of dust particles and formation of a thick layer over the leaf surface. The above observations seem to support the earlier findings in several tetranychid representatives (Sumangala and Haq, 2000; Reddall et al., 2004; Sangeetha and Ramani, 2007b).

Spider mites are known to induce various types of damages ranging from simple mechanical injury of the cells to complex physiological alterations to their host plants. Some of the major mechanical injuries include flattened epidermal cells, collapse or reduction in cells of pallisade and spongy parenchyma, loss of cell contents, coagulation of proplasts, damage and loss of chloroplasts, alterations to stomatal apparatus and other visible contents in cells of mesophyll tissue (Geijskes, 1938; Blair, 1951; Avery and Briggs, 1968b; Jeppson et al., 1975; Tanigoshi and Davis, 1978; Mothes and Seitz, 1982; Tomczyk and Kropczynska, 1985, Bondada et al., 1995; Nachman and Zemek, 2002; Skaloudova et al., 2006). In addition, apparently unattacked cells were affected by the formation of chloroplasts with cup shaped thylakoids (Tanigoshi and Davis, 1978). Injuries at the physiological level
include reduction in photosynthesis and transpiration rates, vegetative growth and productivity (Sances et al., 1982; Royalty and Perring, 1989; Welter, 1989; Nihoul et al., 1992, Reddall et al., 2004). Biochemical studies of spider mite feeding injury (Boulanger, 1958; Leigh, 1963; Avery and Briggs, 1968a; Avery and Lacey, 1968; Storms, 1971) have led to the conclusion that fundamental metabolic pathways such as dissimilation, assimilation and water balance are disturbed before visible changes in the leaf occurs (Hall and Ferree, 1975; Reddall et al., 2004).

Feeding injury induced by *T. neocaledonicus* on their respective host leaves was invisible to naked eyes in the initial stage and marked by the appearance of white spots at the point of suction of sap from the plant cells. These spots could be distinguished from the feeding spots produced by *T. ludeni, T. cinnabarinus, E. orientalis* and *O. biharensis* which were respectively represented as pale etiolated spots, pale yellow spots, light yellowish brown spots and yellowish brown patches. The symptoms of injury produced by *T. ludeni* were more conspicuous even during the early stages of infestation. The attack by *O. biharensis* on *M. esculenta* was so severe that the whole plantation appeared to be crinkled. Various reasons may be attributed to this. There might have occurred a loss of considerable amount of water due to high rate of evaporation through the feeding punctures produced on the leaves. Loss in the chlorophyll content as well as nutrients and cell contents might have caused the initiation of development of bronzing, crinkling and ultimate drying up of the plants. Further, *T. neocaledonicus* and *T. cinnabarinus* feed on the underside of the leaves which are major sites of photosynthesis (Tomczyk and Kropczynska, 1985; Welter, 1989). The effects of mite feeding at the leaf level were
so severe that mite infestation increased leaf resistance to CO₂ uptake thereby decreasing the rate of photosynthesis (Brito et al., 1986).

The difference in the morphological responses of the 5 species may be attributed to variation in chemical constituents of the salivary secretion injected by these species during feeding. Prolonged and excessive feeding by T. neocaledonicus resulted in acute chlorosis and premature leaf abscission while the leaves infested by T. ludeni appeared to be bleached following chlorosis. Heavy infestation by T. cinnabarinus resulted in crumpling, curling or twisting of leaves. However, bronzing, depigmentation and drying of leaves were characteristic of E. orientalis infestation when leaves infested severely by O. biharensis encompassed crinkling, drying and defoliation. An overall assessment of the damage strategies of these 5 species enabled to reach a conclusion that the attack by these mites affected the growth and vigour of their host plants (Reddy and Baskaran, 2006). However, observations made by Candolfi et al. (1993) appeared to be contrary in that the authors failed to observe any negative effect on plant vigour and yield even at much higher infestation levels of P. ulmi on grapevine leaves.

Cytological alterations resulting from feeding of O. biharensis on M. esculenta using electron microscopy showed reduction in the number of cells and chloroplasts, alterations in cell structure, increase in space in the spongy layer, extensive disruption of the mesophyll cells and even reduction of chloroplasts in adjacent unpunctured cells. These findings were in agreement with the descriptions of Geijskes (1938), Blair and Groves (1952), Avery and Briggs (1968 a & b) on P.
ulmi, Tanigoshi and Davis (1978), Kielkiewicz (1985) and Park and Lee (2002). Cells punctured by the mite do not participate further in the metabolic processes of the plant. Further, reduction of photosynthetically active organelles in apparently unattacked cells resulted in a decrease in the rate of photosynthesis and metabolic activities, although the cells themselves were not injured by mechanical influence of the mite (Mothes and Seitz, 1982). The present study supports the cytological results of mite feeding on different plants (Tanigoshi and Davis, 1978). Because of the small size of O. biharensis, it seemed impossible to answer metabolic and energetic questions which arose from feeding injury on host plants. Subsequent investigations combining plant and mite reactions and their mutual effects are demanded.

Quantitative analysis of physiological injuries caused by the 5 species of spider mites were made through estimation of chlorophyll content of host leaves. Data on chlorophyll estimation of V. unguiculata leaves proved a notable loss in chlorophyll content (a & b) due to the feeding activity of T. neocaledonicus which accounted upto 47% and 48% respectively. The loss in chlorophyll a and b reached upto 35% and 43% in the case of T. ludeni on M. deeringiana, 41% and 51% in the case of T. cinnabarinus on D. lablab, 36% and 35% for E. orientalis on M. oleifera and 29% and 46% for O. biharensis on M. esculenta leaves respectively. The results proved significant at 1% or 5% levels on various hosts. A very high loss in chlorophyll content could be recorded by Haq (1997) on okra leaves infested by T. macfarlanei (55% to 68%), Sumangala and Haq (2000) on Eichhornia crassipes infested by T. ludeni (20% to 54%) and Park and Lee (2002) on cucumber leaves infested by T. urticae (55% to 80%). Results obtained by Iatrou et al. (1995),
Nachman and Zemek (2002) on *T. urticae* feeding on *Phaseolus vulgaris* leaves and Sangeetha and Ramani (2007b) on *M. oleifera* infested by *T. neocaledonicus* further substantiated the fact that leaf chlorophyll content decreased with increase in mite density and duration of feeding. But the observations of Sances *et al.*, (1979) who demonstrated that total chlorophyll content was not reduced significantly even at relatively high mite densities appeared to be contrary to the results of the present study. Despite this, the results of the present study helped to support the findings of Bounfour *et al.* (2002) who through measurements of chlorophyll fluorescence and chlorophyll contents of raspberry leaves injured by spider mites, concluded that spider mite feeding primarily injures the plastoquinone pool, which plays a major role in electron transport during photosynthesis. The chlorophyll content of the leaves is regarded as one of the parameters determining the photosynthetic efficiency of the plant (Maithra and Sen, 1988; Ekanayake *et al.*, 1996 & 1998; Oyetunji *et al.*, 1998; Lahai *et al.*, 2003). Moreover, these leaves were found glued with faecal pellets, egg cases and exuviae of various life stages in innumerable numbers. Such leaves along with the profuse webbing of the mites facilitated settling of dust particles, producing a separate coating over the leaf surface. This coating imparts a cumulative effect on the retardation of photosynthesis by preventing the absorption of light by the residual chlorophyll left unfed by the mites (Sumangala and Haq, 2000). In addition, feeding activity of the individuals induced heavy loss of water from the leaf tissue. The overall impact of the above processes had resulted in the total destruction of the photosynthetic machinery of the plant leading to its final collapse. These results have clearly established the potentiality of the leaf sucking
forms in damaging the host plants (Ekanayake et al., 1996 & 1998; Bounfour et al., 2002; Lahai et al., 2003; Reddall et al., 2004; Sangeetha and Ramani, 2007b).

Analysis of the feeding response of 2 species of mites viz., *T. neocaledonicus* and *O. biharensis* was extended to the estimation of total phenolics of their host leaves. Phenols, the aromatic compounds with hydroxyl groups are wide spread in plant kingdom, the role of which in the metabolism of the plant has not been adequately explained, though are believed to offer resistance to pests and diseases. Because certain phenolics have the ability to precipitate plant proteins and render them indigestible, they have been considered as defense compounds. A significant increase in phenol content was observed respectively on *V. unguiculata* and *M. esculenta* leaves following *T. neocaledonicus* and *O. biharensis* infestation suggesting the innate response of the plants against mite attack. Ananthakrishnan et al. (1992) recorded a similar increase in the production of phenolics in *M. esculenta*, castor and eucalyptus during pest attack and concluded that increase in total phenols induced resistance in hosts against herbivory. Such an increase in phenolic content due to spider mite feeding in ‘Conica’ leaves was reported earlier (Puchalska, 2006), estimating upto 50% reduction in photosynthesis rate after 3 weeks of heavy infestation by *O. ununguis*. Accumulation of phenolic compounds in plant tissues is reported to be one of the causes of photosynthesis suppression (Puchalska, 2006). Hence it is feasible to suggest that spider mites cause drastic reduction in photosynthesis by making mechanical damage aggravated by biochemical alterations.
Studies on the protein profile of *M. esculenta* leaves infested by *O. biharensis* in order to outline a basic understanding of the biochemical changes occurring in the host leaves revealed the occurrence of identical bands in the mite-infested as well as uninfested leaves. A slight decrease in the protein concentration in the mite infested leaves as observed in the current study suggests that apparently there occurred no qualitative change in the protein profile as a result of infestation. That is, neither de novo synthesis of proteins occurred nor was there a selective depletion of any protein. Contradicting the present observation, spider mite infestation was already known to induce drastic changes in host plants, leading to the production of volatile compounds (Takabayashi *et al.*, 1994; Bouwmeester *et al.*, 1999) to attract natural predators and thus to promote plant defence. In the present study, no additional bands could be visualised upon gel electrophoresis of extracts of infested leaves though the concentration of protein bands showed a decrease in intensity. Probably, endogenous degradation of existing proteins might have occurred, following mite infestation. The amino acid thus liberated might have been utilized for other metabolic needs or transported away from the leaf tissue. It is undoubtful that the infestation of *M. esculenta* leaves by *O. biharensis* imposes a severe stress on the host plant in as much as it depletes the protein content of the leaves. However, the studies undertaken were preliminary and therefore, in-depth studies on this aspect are inevitable to substantiate the results.

An overall assessment of the feeding strategies through qualitative and quantitative analysis of morphological, anatomical and biochemical aspects of infestation by 5 species of spider mites made during the present study helped to
supplement better results on the impact of their feeding on host plants. Comparison of the nature and extent of damage produced by these mites to the host plants has disclosed the supremacy of the above mites over the others. In addition, tetranychids are capable of altering the balance of growth regulators (Avery and Lacey, 1968; Storms, 1971) by injecting toxic materials into the host plants (Avery and Briggs, 1968 a & b). Such physiological hazards appeared to be more effective when compared to the mechanical injury induced by them.

Information gathered on the developmental aspects of the spider mites studied depicted a common pattern of developmental processes as in other tetranychid mite species. The development involved a larval and 2 nymphal instars before attaining the adult status. Each of the instar after the larval stage was proceeded by quiescent and moulting processes.

Mites in general, exhibit certain degree of site selection for oviposition. Majority of the tetranychid species were found depositing eggs adjacent to the midrib of the leaves of the host plant (Banu and ChannaBasavanna, 1972; Barrion and Corpuz-Raros, 1975; Sangeetha and Ramani, 2007). However, *T. neocaledonicus* and *T. cinnabarinus* were found depositing eggs in groups on the lower surface of the leaves. This habit of laying eggs on the underside and attached to the webbing would definitely ensure better chances of protection from desiccation as well as washing effects of rain (Sobha and Haq, 1999; Sangeetha and Ramani, 2007a). *T. ludeni* and *E. orientalis* showed no specific preference during oviposition. The eggs were laid in a very random fashion, all over the leaf lamina. The silken
web in *T. ludeni* (Puttaswamy and ChannaBasavanna, 1980b), waxy secretion and sparse webbing in *E. orientalis* (Banu and ChannaBasavanna, 1972) probably served adequate protection to the eggs and the subsequent instars, which may be the possible reason for the randomised deposition of eggs. Ovipositing females of *O. biharensis* preferred areas close to the mid rib and major veins of the leaf though they showed no preference for the leaf surface. Such habit of laying eggs in secluded habitat may offer better chances of protection of eggs.

Temperature as well as relative humidity (RH) are known to influence the development and reproduction of several species of tetranychid mites (Boudreaux, 1958; Das and Das, 1967; Lal, 1977; Puttaswamy and ChannaBasavanna, 1980a; Boyne and Hain, 1983; Congdon and Logan, 1983; Pande and Sharma, 1986; Bonato et al., 1990; Childers et al., 1991; Bonato et al., 1995b; Liu and Tsai, 1998; Bonato, 1999; Bounfour and Tanigoshi, 2001; Zhang et al., 2001 a & b; Fu, et al. 2002; Kasap, 2003; Badii et al., 2003; Sakunwarin et al. (2003); Gotoh et al., 2004; Kasap, 2004; Geraldo, et al., 2004; Sangita and Bhardwaj, 2004; Ji et al., 2005 a & b; Ghoshal et al., 2006; Sangeetha and Ramani, 2008b). The 5 species of spider mites considered in the present study showed variation in the durations of their development as influenced by temperature, relative humidity and host plants.

The pre-oviposition period of *T. neocaledonicus* was recorded to be around 2.57, 1.6 and 1.25 days on *A. tricolor* at 25°C & 80% RH, 30°C & 70% RH and 35°C & 60% RH respectively. While on *V. unguiculata*, the respective durations were 2.62, 1.8 and 1.42 days. The durations were found to decrease with increase in
temperature and decrease in RH. The maximum pre-oviposition period of 2.62 days was therefore noted for *T. neocaledonicus* when fed on *V. unguiculata*, followed by 2.57 days on *A. tricolor* and at 25°C & 80% RH. Differences in the duration at 1% significance level was noted by Puttaswamy and ChannaBasavanna (1982b) in *T. neocaledonicus* infesting tapioca, mulberry, castor and *Amaranthus*. Reports of other workers on pre-oviposition periods of *T. neocaledonicus* viz., 1.83 ± 0.19 days (Mallik and ChannaBasavanna, 1983), 2.5 ± 0.15 days (Ghoshal et al., 2006) and 1.5± 0.12 days (Sangeetha and Ramani, 2007a) were almost in agreement with the results of the present study. Also, the pre-oviposition periods of mated females were comparatively lower than that of virgin females, probably because the former got fertilised as soon as they emerged from the preceding quiescence. While the durations of pre-oviposition (0.5 day) and post-oviposition periods (0.5 day) of *T. ludeni* on *M. deeringiana* were recorded lowest and that of oviposition the highest (11.5 days) at 30°C & 70% RH. The observations on the respective durations made by Puttaswamy and ChannaBasavanna (1981b) on brinjal leaves were 0.98 day, 10.85 days and 2.3 days. However, at 19.3 °C - 28.4 °C and 53% - 88% RH, the pre-oviposition, oviposition and post-oviposition periods were 1.54 days, 12.75 days and 3.61 days respectively (Puttaswamy and ChannaBasavanna, 1980b).

Apart from the studies on the influence of temperature and relative humidity, influence of 2 species of host plants viz., *C. papaya* and *D. lablab* on the biology of *T. cinnabarinus* was considered in detail. However, the duration of pre-oviposition and post-oviposition periods of *T. cinnabarinus* did not show much variation (0.5 day) at 30°C & 70% RH and 35°C & 60% RH on both the host plants. At the same
time, Nandagopal and Gedia (1995) recorded 1.12 days and 1.22 days of pre-oviposition and post-oviposition respectively for the mite at 30°C & 80% RH. The pre-ovipositional and post-ovipositional characteristics of *E. orientalis* on *M. oleifera* were found to be high at very low temperature and high humidity conditions. The respective durations were 1.1 and 1.75 days for pre-oviposition and post-oviposition at 25°C & 80% RH. At higher temperatures, the durations were found to decrease to less than 1 day. Similar results were recorded for the mite by Dhooria (1985). The durations of pre-oviposition and post-oviposition of *O. biharensis* on *M. esculenta* showed a gradual decline with increase in temperature. Lowest durations for the respective periods were recorded at 35°C & 60% RH (0.5 day each) while extended durations were noted at 25°C & 80% RH (1.8 and 1.5 days).

The durations of oviposition period of *T. neocaledonicus* was reported to be 4.7 days on *R. mucronata* (Ghoshal *et al.*, 2006), 8.4 days on *M. oleifera* (Sangeetha and Ramani, 2007a), 8-10 days on lady’s finger (Ray and Rai, 1981) and 13-19 days on French bean (Manjunatha and Puttaswamy, 1989). On *A. tricolor* and *V. unguiculata*, it was found to range from 7.5-9 days and 7-9.7 days depending on temperature and relative humidity. Similar observations on the effect of temperature on the life history of *T. evansi* were recorded by Bonato (1999). Similarly, respective durations of post-oviposition ranged from 2.2-2.3 days on *A. tricolor* and 2.2-3 days on *V. unguiculata*. Contrary to these results, many authors reported comparatively lower duration for the post-oviposition period of this mite (Manjunatha and Puttaswamy, 1989; Ghoshal *et al.*, 2006 and Sangeetha and Ramani, 2007a). The results suggests that apart from temperature and humidity, host
Plants also exert a considerable influence on the biology of plant mites (Rasmy, 1978; Jesioter, 1980; Puttaswamy and ChannaBasavanna, 1981 b & c, 1982b; Dhooria, 1982; Sharma and Kushwaha, 1984; Dhooria, 1985; Tomczyk and Kropczynska, 1985; Manjunatha et al., 1991; Karmakar et al., 1994; Sarkar et al., 1998; Gotoh and Higo, 1997; Bonato et al., 2000; Kerguelen and Hoddle, 2000; Thongtab et al., 2002; Kasap, 2003; Kasap, 2004; Czajkowska and Puchalska, 2006; Vasquez et al., 2008). The oviposition period of *T. ludeni* was very low at 25°C & 80% RH (5.7 days) and high at 30-35°C & 55-70% RH (10.9-11.5 days). The above results have clearly indicated that high temperatures and low humidities were more favourable for *T. ludeni*.

The oviposition period of *T. cinnabarinus* seemed to be affected by prevailing temperature and relative humidity. A progressive increase in the duration was observed with decrease in temperature and increase in RH. The duration of oviposition was similar on *C. papaya* and *D. lablab* at all the temperature-humidity combinations studied. Similarly at 30°C, no differences occurred in the daily oviposition rates at 70% RH. The oviposition period was much reduced at 35°C and 60% RH. This resulted from greater mortality of adults at 35°C and 60% RH. The duration of egg laying period in the females of *E. orientalis* significantly decreased from 8.2 days to 7.7 days with increase in temperature and a corresponding decline in humidity conditions. This was higher than those recorded by Dhooria (1985) when Rasmy (1977) noted no much variation in the oviposition periods for the mite. Studies on the period of oviposition of *O. biharensis* on *M. esculenta* showed that the temperature-humidity combinations of 25°C & 80% RH promoted extension of
oviposition periods to 8.8 days, though rearing of mites at these conditions led to poorest fecundity. Shortest duration of oviposition with maximum fecundity was recorded at 35°C & 60% RH (7.7 days).

The number of eggs produced during the life time of a female tetranychid mite may vary greatly among species and also with hosts, temperature and relative humidity. It is not surprising to note that even individuals of the same species show variation in the number of eggs produced by them. Fecundity of *T. neocaledonicus* on *A. tricolor* and *V. unguiculata* was highest at 35°C & 60% RH (41.8 & 48.7) and lowest at 25°C & 80% RH (27.6 & 31.2). However, significantly higher fecundity of the mite was recorded by Puttaswamy and ChannaBasavanna (1981c) for *A. tricolor* (95.08) and *A. viridis* (147.42) at 23-26°C & 74-81% RH. The number of eggs laid by individual female mite on *V. unguiculata* was higher than on *A. tricolor*, though was much lower than that of earlier reports on other host plants (Gupta *et al.*, 1974; Ray and Rai, 1981; Manjunatha and Puttaswamy, 1989; Kasap, 2004). While on *M. oleifera*, the same mite was reported to lay 27-45 eggs which supported the results of the current study (Sangeetha and Ramani, 2007a & Sangeetha *et al.*, 2007). The number of eggs deposited by *T. ludeni* was affected by both temperature and relative humidity levels. The highest number of eggs (83.6 eggs/female/day) was laid at 30°C & 70% RH. The lowest number (28.3 eggs/female/day) was deposited at 25°C & 80% RH. Irrespective of temperature, the number of eggs laid by an individual was maximum at 70% relative humidity levels. The number of eggs laid per female per day was reduced at higher humidities (80% RH) since high humidities reduced egg production capacity of adults irrespective of temperature ranges. These results
are in agreement with the findings of several authors (Boudreaux, 1958; Puttaswamy and ChannaBasavanna, 1980a & b) on tetranychids.

Humidity though had little influence on the pre-oviposition and post-oviposition periods of *T. cinnabarinus*, higher humidity proved to have negative impact on the egg laying capacity as shown by adult females. A decrease in the fecundity was recorded at low temperatures and higher humidity. Rate of egg production on *C. papaya* was 23.5, 40.7 and 33.2/female/day respectively at 25°C & 80% RH, 30°C & 70% RH and 35°C & 60% RH. While on *D. lablab*, the respective fecundity was 25.2, 42.5 and 33.9/female/day. (Nandagopal and Gedia, 1995; Biswas et al., 2004; Sangeetha and Ramani, 2008b).

The number of eggs laid by *E. orientalis* varied from 27.1 to 33.9 at temperature-humidities ranging from 25°C & 80% to 35°C & 60% RH. Lowest fecundity was recorded at 25°C & 80% RH and 35°C & 60% RH due to high rate of adult female mortality which prevented the species from laying more eggs. Lal (1977) and Dhooria (1985) recorded fecundity of the mite to range from 10-36 and 2.58-29.87 respectively. A combination of 30°C & 70% RH proved to be the optimum conditions for high fecundity of *E. orientalis* in the present study. High mortality for the mite at 35°C was reported by Gupta (1985) and Banu and ChannaBasavanna (1972). However, Lal (1977) observed doubling in fecundity with increase in temperature from 23.61 °C to 28.64 °C. Data recorded on the fecundity of *O. biharensis* revealed that the average number of eggs laid per female at 35°C & 60% RH (47 eggs) was significantly higher as compared with that of the females
reared at 30°C & 70% RH (37.6 eggs). The lowest number of eggs was laid at 25°C & 80% RH (34.2 eggs). This was in support of the findings of Ji et al. (2005b) who reported highest fecundity of *O. biharensis* at 35°C (71.6 eggs/female). While on cultivars of litchi, *O. biharensis* deposited 34 - 68.8 eggs which were significantly much higher to that recorded in the present study (Chen et al., 2005).

Longevity of the mites was often found influenced by several factors, of which temperature, humidity, host plants and mating appear to be vital. Comparison of the life span of mated and virgin females of *T. neocaledonicus* has shown shorter duration on *A. tricolor* (10.9 days) and *V. unguiculata* (11.7 days) at 35°C & 60% RH. Durations recorded by several authors on different hosts at different temperatures and humidities fell in the range of 24-50 days in the case of mated and virgin individuals (Puttaswamy and Reddy, 1980, Puttaswamy and ChannaBasavanna, 1981c; Manjunatha and Puttaswamy, 1989; Ghoshal et al., 2006). This has established negative influence of mating and higher temperature on the longevity of these individuals. Similar observation on *T. neocaledonicus* was made by Ray and Rai (1981) on lady’s finger and Sangeetha and Ramani (2007a) on *M. oleifera*. Rate of daily egg production was yet another factor that influenced the longevity of these individuals. Probably, high frequency of oviposition reduced the life expectancy of the females as observed in the present study. Longevity of *T. ludeni* was observed to be highest (12.7 days) at 35°C & 60% RH and lowest (8 days) at 25°C & 80% RH on *M. deeringiana*. This appears to be the usual trend under field conditions where *T. ludeni* lived longer at higher temperatures and low relative humidities (Puttaswamy and ChannaBasavanna, 1980a).
The longevity of *T. cinnabarinus* was shorter on *D. lablab* (6.8 days) and *C. papaya* (6.2 days) at 35°C & 60% RH due to low survival rate of the adults. However, the conditions for longer life was observed at 25°C - 30°C & 70% - 80% RH. The overall trend was that the mite, *T. cinnabarinus* lived longer at low - moderate temperatures and humidities. The life span of females of *E. orientalis* on *M. oleifera* varied from 7.5 days to 11.1 days depending on the temperature and relative humidities provided. Longevity was highest (11.1 days) at 25°C & 80% RH, while 30°C & 70% RH recorded lowest (7.5 days) life span for the adults. Mean longevity of 2-5.8 days and 6-12 days for the mite was recorded by Dhooria (1985) and Gupta (1985) respectively. In the case of *O. biharensis* on *M. esculenta*, 35°C & 60% RH was the least suitable temperature and relative humidity in terms of lowest longevity (8.74 days) followed by 30°C & 70% RH (10.1 days) and 25°C & 80% RH (12.2 days). Similar trend was observed by Ji et al. (2005a), who recorded lowest longevity at 35°C (19 ± 3.11 days) and highest of 98.9 ± 20.77 days at 15°C.

The duration of development from egg to adult stage *T. neocaledonicus* was longer on *A. tricolor* (16.83 days) at 25°C & 80% RH. The same species completed its development at a comparatively shorter span of time (14.73 days) on *V. unguiculata*. Both the species however took lowest developmental time of 12.85 days and 10.25 days respectively at 35°C & 60% RH and 30°C & 70% RH. The durations as reported by earlier workers seem to coincide with the current duration. The statement of Praslicka and Huszar (2004) that higher the temperature, faster was the development of *T. urticae* on different hosts supported the current findings of *T. neocaledonicus*. Further, the authors recorded the optimum temperature as 35°C.
The results obtained on the preference of *T. neocaledonicus* on 2 hosts reflected *V. unguiculata* to be the more susceptible host for the mite than *A. tricolor* owing to shorter developmental time, higher fecundity, adult longevity and feeding responses. Also, the temperature-humidity combination of 35°C & 60% RH was found to be favourable for the production of maximum number of generations. While studies made on the effect of temperature by Gupta *et al.* (1972) indicated 30°C as the most favoured temperature for the mite. The mean egg to adult period of *T. ludeni* on *M. deeringiana* was recorded to be a maximum of 12.85 days at 25°C & 80% RH and minimum of 9.54 days at 30°C & 70% RH. This duration appeared to be on a higher side as compared to 222 hours (Mallik and ChannaBasavanna, 1983) and 10.16 days (Singh *et al.*, 1989) in *T. ludeni*.

Developmental duration of *T. cinnabarinus* was found to be affected mainly by temperature, with relative humidities playing a minor part. The optimum temperature for development as observed in the current study was 30°C & 70% RH on *D. lablab* (7.33 days) and *C. papaya* (7.95 days) for the mite. Similar results on *T. cinnabarinus* were recorded by Jeppson *et al.* (1975). At 35°C & 60% RH, *T. cinnabarinus* could survive only for a limited period of time. This resulted from greater mortality of pre-adults and lower survival of adults at 35°C & 60% RH. As per reports of Gupta *et al.* (1976), high temperature and high RH proved detrimental for mite population while moderate temperature and RH proved congenial for its multiplication. Population was positively correlated with RH and negatively correlated with temperature. According to Biswas *et al.* (2004) temperature reduced the developmental, reproductive period and longevity of *T. cinnabarinus* though
fecundity increased with increase in temperature. Significant differences in duration of development was not observed on both the hosts, but *T. cinnabarinus* performed better on *D. lablab* than on *C. papaya* in terms of net reproductive rates and adult survival rates.

Comparison of data regarding development of *E. orientalis* at 25°C & 80% RH, 30°C & 70% RH and 35°C & 60% RH revealed that the mean duration of development was shorter (8.27 days) while fecundity was higher when the species was reared at 30°C & 70% RH, followed by those reared at 35°C & 60% RH (9.48 days) and 25°C & 80% RH (12.37 days). To summarise the results, 25°C & 80% RH was least suited for the mite owing to lowest fecundity and longest developmental time. High temperature and low humidity were best preferred to by the mite (Lal and Mukharji, 1980). Contrary to these observations, Jeppson *et al.* (1975) suggested 21°C & 59-70% RH as the best suited conditions for *E. orientalis* beyond which the conditions were unfavourable for mite development. Among the different conditions, development of *O. biharensis* on *M. esculenta* was much faster at 35°C & 60% RH (6.83 days). But, 25°C & 80% RH was not found suitable as the mean duration of development of all life stages was comparatively higher on it. Highly significant and positive correlation was recorded among adult, immature stages and eggs with temperature. Further, higher temperature accelerated the developmental rates and reduced the durations of developmental stages. Temperature exerted a significant effect on all developmental stages of *O. coffeae* (Haque *et al.*, 2007). Accordingly, at higher temperatures, the development of *O. coffeae* occurred
rapidly. This seems to explain why this spider mite multiplies and attains pest status during the drier and hotter months of the year in Kerala.

In all the 5 species of spider mites, the number of females outnumbered males on all hosts and at various combinations of temperature and relative humidities. In the present study, a maximum of 10 females to 1 male was found in the population of spider mites reared on different host plants. Observation on the life cycle of the spider mites at temperatures above 40°C recorded high mortality of the life stages. Even though the spider mites were delicate and desicated after a short exposure to high temperature, the hatchability of their eggs was not considerably retarded and more than 70% eggs hatched into larvae. This may be due to the comparatively thick membranes of the egg whereas the larva and nymphs were found to be shrivelled out on subjecting to higher temperatures.

The hatching characteristics of the 5 species followed a more or less similar trend involving the formation of an equatorial slit on the egg case and culminating in the separation of the case into two halves. The entire process averaged 10 – 20 minutes in duration. Moulting of the quiescent individuals was initiated by the formation of a horizontal slit at the dorsal region of the propodosoma followed by the slow backward movement of the individual. This pattern of moulting was clearly followed by all 5 species of spider mites studied. These findings are in support with earlier reports on tetranychid mites (Siddig and Elbadry, 1971; Banu and ChannaBasavanna, 1972; Gupta, 1985; Sangeetha and Ramani, 2007a).
Mating marks the success of reproductive potential, which is crucial to the survival of a species. Mating, as a common feature was observed in all the tetranychid species studied during the current investigation. The phenomenon of sperm transfer was direct, achieved through copulation. The males emerged earlier than the females and found guarding the quiescent female deutonymphs and copulating with the female immediately after the emergence of the latter. These observations are in agreement with the behavioural activities observed in the case of *T. urticae* (Penman and Cone, 1972), *T. evansi* (Qureshi *et al.*, 1969), *P. citri* (Beavers and Hampton, 1971) and *E. orientalis* (Banu and ChannaBasavanna, 1972). Therefore the process appears to be common among different genera of tetranychid mites. Indepth studies on the mediation of the male attraction towards the female deutonymphs (Cone *et al.*, 1971a; Hazan *et al.*, 1973; Penman and Cone, 1974) have attributed the role of sex pheromones in the process. As the process appears to be similar in other species of mites studied, the production of sex pheromone by the females may be considered as a common feature among the members of the tetranychidae. Male preference for virgin and mated females of *T. kanzawai* was tested by Oku *et al.* (2005) who suggested the probability of the use of odours by males to discriminate the mating status of females. They added that the males preferred virgin females who were more gregarious and remained on the leaves for longer time than the mated ones so as to increase the mating opportunities. Generally, a single copulation was reported in the case of females, while males were known to copulate many times (Banu and ChannaBasavanna, 1972, Nandagopal and Gedia, 1995; Sangeetha and Ramani, 2007a).
A special type of reproductive behaviour in tetranychids called parthenogenesis has been reported by several authors. The instance of arrhenotoky in particular has been reported in several spider mite species by Nandagopal and Gedia (1995). During the present study, mated females of all the species were found to lay eggs which developed into both males and females. However, the eggs deposited by virgin females always developed into males only. This has clearly indicated the occurrence of normal sexual reproduction as well as parthenogenesis in all the 5 species studied. Probably, the occurrence of dual reproductive means may enhance the male population which is otherwise found low in field conditions.

An interesting observation emerged during the present study was the cannibalistic habit of the males of *T. cinnabarinus* on the females of the same species after their death immediately after egg laying. Predatory habit in tetranychid mites was already reported in species like *cinnabarinus*, the males of which devoured the females of *T. hypogea* (Nandagopal and Gedia, 1995). However, cannibalistic trend seems to be a new behavioural alteration so far unreported among phytophagous mites. This behaviour of switching of feeding trends of males from phytophagy to predation or even to cannibalism appears to be an interesting deviation from the general trend and therefore needs further studies for understanding its relevance.

The biological phenomenon of aggregation as observed in many groups of organisms, serving various life activities of the species in question, was a feature noted in *T. ludeni*. Repeated occurrence of the process at the time of each quiescent
period has indicated the significance of the phenomenon in the ontogeny of the species. Hence, further studies on the aggregation behaviour of this species particularly, of the larval and nymphal instars are warranted. More studies on the mediation of pheromones in this behaviour will help in unveiling the exact nature of the relationship among the members of the species.

A progressive decrease in duration of the active periods of life stages was a common feature observed in all the 5 species of these mites at different temperature-humidity combinations and different host plants. However, quiescent periods showed not much significant change in duration. But conditions of extremely high relative humidity (80% RH) caused all life stages of *T. cinnabarinus* to extend their period of quiescence. Similar observations were made by Jeppson *et al.*, (1975). The total duration of sexual development was found shortest in the case of *T. cinnabarinus* on *D. lablab* at 35°C and 60% RH which was 6.4 days and highest in the case of *T. neocaledonicus* on *A. tricolor* which was 17.2 days. Again the total duration of parthenogenetic development was found shortest in the case of *T. cinnabarinus* on *D. lablab* at 35°C and 60% RH which was 5.7 days and highest in the case of *T. neocaledonicus* on *A. tricolor* at 25°C and 80% RH which was 15.8 days. This would suggest that among the 5 species, *T. cinnabarinus* possesses maximum number of generations in the field at 35°C and 60% RH. The maximum number of generations of *T. neocaledonicus* was observed at 35°C and 60% RH on *V. unguiculata*, *T. ludeni* at 30°C and 70% RH on *M. deeringiana*, *T. cinnabarinus* on *D. lablab* at 35°C and 60% RH, *E. orientalis* on *M. oleifera* at 30°C and 70% RH and *O. biharensis* on *M. esculenta* at 35°C and 60% RH. Such variations in the
number of generations were observed at different temperature-humidity conditions as evidenced by the studies on same or other species of tetranychids.

Results of the morphological studies on the developmental stages enabled to distinguish the immatures of the above 5 tetranychid mite species. Further, the life stages of the genus *Eutetranychus* could be easily differentiated on the basis of the nature of their dorsal setae. They were short barbed and set on distinct tubercles, while that of genus *Tetranychus* were long, pointed, smooth and without tubercles. Further, the presence of empodium and claw set the members belonging to genus *Oligonychus* well apart from the other 2 genera. The number and position of hysterosomal setae showed variation in the different life stages of the species studied. This supports the importance of chaetotaxy in the recognition of species even in the larval and nymphal stages.

A progressive increase in body size and number of body setae from larva to deutonymph was noted in all the 5 species studied. The progressive change in the ventral setal complements of the individuals of all the species appeared to be identical. In all the species, the larvae possessed only 2 pairs of medioventral setae and lacked the pre-genital and post-genital setae. Development of the genital area and setae alone was attained at this stage. However, full setal compliment of 13 setae was observed at the larval stage itself in *E. orientalis*. In the rest, the complete dorsal setal compliment was attained only at the deutonymphal stage. These points have indicated a progressive trend in the morphological changes of the mite species studied.
Of all the different temperature - humidity conditions provided, the temperature-humidity combinations of 30°C & 70% RH and 35°C & 60% RH were found to be best suited for the successful survival and development of all the spider mite species studied on different hosts. This combination is almost in agreement with the temperature and humidity conditions prevalent during summer months when the population density of each mite has attained the peak level in the field. This clearly suggests that temperature and relative humidity exerts a direct influence on the developmental process of the spider mites. Thus, the study elucidates the fact that warmer temperature and low relative humidity available during the summer months in our state would ensure ideal conditions for the rapid population build up of these mites. Vegetable plants, being the most valuable crops of our nutritional concern, this has to be considered seriously, as these major mite pests would become a great threat to our vegetable crops.

Further, an interesting and cognitive aspect that emerged from the study was the incidence of *E. orientalis* on *M. oleifera* and *T. ludeni* on *M. deeringiana*, both of which are new records of host plants, so far unreported from India. The above results clearly indicate the possibility of new host arenas yet to be explored thereby necessitating further attention to be focussed on this aspect.