CHAPTER V

DISCUSSION

The results of diversity of phytophagous and predatory mite fauna obtained from different zones of Tamil Nadu during 2013 to 2017, population dynamics, biology, screening of rice accessions against rice leaf mite, *Oligonychus oryzae* Hirst and predominant tapioca accessions against two spotted spider mite, *Tetranychus urticae* Koch and management of rice and tapioca mites are discussed in this chapter.

5.1. Diversity of phytophagous and predatory mite fauna in Tamil Nadu

In Salem region, among the four taxa of phytophagous mites, *Ologonychus oryzae* (Hirst) (29.10%) and *Tetranychus urticae* Koch (27.61%) were relatively more abundant on rice and tapioca ecosystem. Among the two taxa of predatory mites, *Amblyseius* spp*.,* was relatively more abundant (2.99, 2.24, 2.24 and 1.49 per cent on tapioca, rice, papaya and cotton, respectively) followed by *Neoseiulus longispinosus* Evans on castor (1.49%) and mango (0.75%). In Namakkal region, *O. oryzae* was relatively more abundant on rice ecosystem (36.36%) followed by *T. urticae* on tapioca (12.12%) and *Tetranychus cinnabarinus* Boisd. on papaya (12.12%) and cotton (11.11%). The predatory mite *Amblyseius* sp. was relatively more abundant (3.03, 7.07, 3.03 and 2.02% on tapioca, rice, papaya and cotton, respectively) while *N. longispinosus* was on mango (3.03%) (Fig. 1).

In Erode region, among the five taxa of phytophagous mites, *O. oryzae* (13.47%) on rice, *T. cinnabarinus* (11.43%) on cotton and *T. urticae* (10.61 and 10.20%) on brinjal and grapes were relatively more abundant. The predatory mite *Amblyseius sp.* were relatively more abundant (2.04, 1.63, 1.22, 0.82, 0.82 and 0.82%) on rice, tapioca, brinjal, bhendi, jasmine and rose, respectively, followed by 1.22, 0.82, 0.41 and 1.22 per cent of *N. longispinosus* on mango, papaya, grapes and cotton. In Coimbatore region, the rice leaf mite, *O. oryzae* were relatively more abundant (20.80%) on rice ecosystem followed by erineum mite, *A. jasmini* (12.8%) on jasmine ecosystem. Among two taxa of predatory mites, *Amblyseius* sp. was relatively more abundant (2.4, 1.6, 1.2, 0.8 and 0.4 % on rice, brinjal, bhendi, jasmine and rose, respectively) followed by 1.2, 1.2, 0.8 and 0.8 per cent relative abundance of *N. longispinosus* on cotton, papaya, grapes and mango, respectively (Fig. 2).

In Trichy**,** the total relative abundance of phytophagous and predatory mites was 87.79 and 12.21 per cent, respectively. Phytophagous mites were relatively more abundant than predatory mites. It was 92.22 and 7.78 per cent in Thanjavur and Aduthurai (90.22 and 7.78), respectively (Fig. 3).

In Madurai, among the 6 taxa of phytophagous mites, *O. oryzae* (17.57%) on rice and *T. urticae* (12.84%) and *A. jasmini* recorded (12.16%) on jasmine relatively more abundant. Among the two taxa of predatory mites, *Amblyseius* spp. was relatively more abundant (3.38, 2.03, 1.35, 1.35, 0.68 and 0.68%) on rice, brinjal, maize, jasmine, sorghum and mango, respectively, followed by *N. longispinosus* (2.03, 1.35 and 0.68%), respectively on bhendi, grapes and chilli. In Tirunelveli, The two spotted spider mite, *T. urticae* was relatively more abundant (18.25 and 14.29%) on brinjal and bhendi ecosystem. Among the two taxa of predatory mites, *N. longispinosus* was relatively more abundant (3.17%) on bhendi followed by 2.38, 2.38, 2.38 and 0.79 per cent of *Amblyseius* sp. on brinjal, rice, jasmine and maize respectively. In Periyakulam, The rice leaf mite, *O. oryzae* were relatively more abundant (17.93%) on rice ecosystem followed by *T. urticae* (15.22%) on bhendi ecosystem. Jasmine erineum mite, *A. jasmini* (14.13%) on jasmine and *T. urticae* (13.04 and 13.04%) on grapes and bhendi were moderately abundant. Among two taxa of predatory mites, *Amblyseius sp.* was relatively more abundant (1.63, 1.63, 1.63 and 1.09%) on rice, brinjal, bhendi, jasmine and mango respectively, followed by 1.63 and 1.09 per cent relative abundance of *N. longispinosus* on bhendi and grapes, respectively (Fig. 4).

In Ooty, among the two taxa of phytophagous mites, *T. urticae* (61.05 %) was relatively more abundant followed by *P.latus* (28.34%) on tea ecosystem. In Kothagiri, *T. urticae* (64.83 %) was relatively more abundant followed by *P.latus* (24.56%). In Valparai, *T. urticae* (72.66 %) was relatively more abundant followed by *P.latus* (14.84%). In all regions, *Amblyseius sp.* was relatively more abundant among two taxa of predatory mites (Fig. 5).

Similar trends were observed by Kowsika and Ramaraju (2014), they carried out surveys from August 2012 to December 2013 to determine diversity of phytophagous mites (*Tetranychus* spp. and *Oligonychus* spp.) inhabiting different host plants from

Coimbatore district and nearby. *Tetranychus* spp. were collected from okra, brinjal and tomato, the major vegetables grown worldwide and also from other hosts such as cassava, jasmine, carnation, citrus, cardamom and *Bauhinia*. *Oligonychus* spp. were collected from rice, sorghum, tea, jamun and grapes. A total of six *Tetranyhus* species and five *Oligonychus* species were identified by them.

The results of the study were also in conformity with Yaseen and Bennett (1975) who carried out surveys on 1974 for cassava mites and their natural enemies in several areas in Central and South America and the Caribbean, and found several other tetranychids infesting cassava. *Mononychellus tanajoa* Bondar and other tetranychids on cassava were more abundant during the surveys.

A survey was conducted by Binisha and Haseena (2013) to explore phytophagous and predatory mites associated with six major vegetable crops namely, brinjal, bhendi, amaranthus, cowpea, chilli and bitter gourd in Thrissur district, Kerala during 2011-2012. A total of 19 species of mites belonging to eight families in two suborders namely Prostigmata and Mesostigmata were identified. The phytophagous mite families recorded were Tetranychidae, Tenuipalpidae and Tarsonemidae represented by the genera *Tetranychus*, *Eutetranychus*, *Brevipalpus* and *Polyphagotarsonemus. Tetranychus urticae* was found to be the dominant phytophagous mite species on brinjal, bhendi, amaranthus and cowpea, where as in chilli and bittergourd the tarsonemid mite, *Polyphagotarsonemus latus* (Banks) was the predominant one. The important phytoseiid predators recorded in the study include *Amblyseius paraaerialis* Muma, *Paraphytoseius orientalis* Narayanan, *N. longispinosus*, *Phytoseius* sp., *Euseius macrospatulatus* Gupta, *Typhlodromips* sp. and *Scapulaseius* sp.

Occurrence of *O. oryzae* was predominant in all three regions of Cauvery delta zone where rice occupies major cultivation area. Similar species were recorded earlier on rice cultivated locations of different regions by Karmakar and Soma Dey (2006), Nayak *et al*. (2007a), Beard (2008), Srimohanapriya *et al*. (2009), Kowsika and Ramaraju (2014) and Chitra *et al*. (2017). In cowpea, three phytophagous mites and three predatory mites were recorded by Binisha and Haseena (2013). The phytophagous mites included *Tetranychus* sp., *Eutetranychus* sp., and *P. latus*. Predatory mites recorded were *N. longispinosus*, *Typhlodromips* sp. and *Amblyseius* sp.

Oligonychus indicus was first reported from India, as a serious pest of sorghum in 1923 and documented by Stanley Hirst. *O. indicus* feeds mainly of Poaceae apart from Arecaceae, Leguminosae, Musaceae and Nelumbonaceae (Borrer *et al*., 1989).

Polyphagotarsonemus latus was the only phytophagous mite recorded from chilli. However, seven different species of predatory mites were collected during the study which included *Amblyseius paraaerialis* Muma, *Euseius* sp., and *Typhlodromips* sp. of the family Phytoseiidae, *Tydeus* sp. of the family Tydeidae, *Agistemus* sp. of Stigmaeidae, *Cunaxa* sp. belonging to Cunaxidae and *Bdella* sp. of Bdellidae.

The results are in accordance with Ramaraju (2005), who conducted a survey from different locations of Western Ghats of Tamil Nadu and in this study, thirty-four mite genera belonging to 16 families under 3 suborders were recorded. Maximum numbers of mites (1277) were collected from Mettupalayam forest area followed by Siruvani (1274), Maruthamalai (1060) and Mudumalai (742).

Tetranychus urticae has been reported from more than 120 host families such as Acanthaceae, Actinidiaceae, Aadoxaceae, Amaranthaceae, Annonaceae, Caryophyllaceae, Convolvulaceae, Cucurbitaceae, Euphorbiaceae, Hydrangeaceae, Leguminosae, Liliaceae, Malvaceae, Moraceae, Musaceae, Myrtaceae, Oleaceae, Pedaliaceae, Poaceae, Rosaceae, Rubiaceae, Rutaceae, Solanaceae and Zingiberaceae total around 1059 hosts (http:// www1.montpellier.inra.fr/).

From India the important contribution (on the diversity and distribution of species) made were Ghosh and Gupta (2003) Gupta (2005, 2012) Gupta *et al*., (2005), Lahiri *et al.,* (2004), Roy *et al.,* (2006, 2007, 2008, 2008a, 2009) and Roy & Saha, (2010). However many of the species indicated earlier were not reported by them and many of the host plants on which the mites reported in the present communication were earlier unrecorded.

5.2. Seasonal incidence and population dynamics of *O. oryzae* on rice

The results revealed that, during March 2017 (9^{th} standard week) to Jun 2017 (24^{th} standard week) there was a gradual increase in mite population and reached to the peak and the population ranged from 29.92 to 81.4 mites/ 10 cm leaf length, after which there was decline in mite population from 80.5 to 1.6 mites/ 10 cm leaf length during 26^{th} to 38^{th} standard week. Correlation studies between the rice leaf mite population and weather factors revealed that, there was significant positive correlation with maximum temperature (0.299) and negative correlation with evening relative humidity (-0.346) and rainfall (-0.498) respectively. Regression coefficients revealed that for every unit increase in maximum temperature, there was an increase of 2.49 mites, whereas for every unit increase in evening relative humidity and rainfall, mite population decreased by 1.03 and 0.76, respectively (Fig. 6).

Similar result has been reported by Karmakar and Soma Dey (2006) who noticed severe occurrence of *O. oryzae* on banana and observed that the mite persisted in the field throughout the year. During January- February the mite populations were recorded very low. Considerably high populations were found during 2nd fortnight of March (10 no./10 sq cm area) to 1st fortnight of June (16.6/10 sq cm area) reaching the peak during 1st fortnight of May (26.67/10 sq cm area). The high temperature coupled with low humidity was observed very congenial for rapid multiplication of the mite species and thereafter, their population declined with increase of atmospheric relative humidity on the onset of monsoon.

Sankar rao (2011) conducted a study on the seasonal occurrence of the rice leaf mite, *Oligonychus oryzae* in Chittoor district during July 2010 to June 2011 indicated the absence of mite from second fortnight of November to first fortnight of March due to fall in maximum temperatures and minimum temperatures. The rice leaf mite, *O. oryzae* reached its peak activity from first fortnight of May to second fortnight of July recording 11.33 mites/cm^2 leaf area during second fortnight of July. Thereafter the mite population decreased due to low temperatures and attained the low level peak during first fortnight of November.

The present results are in accordance with the earlier reports of Rahman and Sapra (1940) and Maragal (1977), Gupta *et al*. (1974), Rai *et al*. (1977), Dutta (1980), Swamiappan (1986),Veluswamy *et al*. (1987) and Karmakar and Dey (2006) who had reported that the high temperature and fairly low relative humidity was highly favourable for the high population of mite whereas less mite population was reported at low temperature and high humidity and peak activity during rainy season. Contrary to this, Kandibane *et al*. (2009) reported that the incidence of rice leaf mite, *Oligonychus oryzae* during later part of December and reached peak activity during April - May (summer) and August - September (Pre North East Monsoon). These variations may be due to different climatic conditions prevailing in the respective localities and the varietal characters of the paddy cultivated.

The maximum temperature, minimum temperature, relative humidity and rainfall prevailed during the peak activity of rice leaf mite, *Oligonychus oryzae* were 40.65 ^{0}C, 28.04 ^{0}C, 55.70 per cent and 3.594 mm in Chittoor district and in Nellore district those were 39.73 ^{0}C, 31.30 ^{0}C, 60.90 per cent and 7.42 mm, respectively.

Chitra *et al*. (2017) also recorded the increased range during the months of September and October (7.36 to 8.57 mites/1x10 cm leaf length) after which there was a decrease in mite population (0.76 to 3.57 mites/1x10 cm leaf length) during November 2015 (44th MSW) to February 2016 (5th MSW). Thereafter, a gradual increase in mite population was observed and reached to the peak of 16.49 mites/1x10 cm leaf length during April (17th MSW) and concluded that, there was significant positive correlation with maximum temperature (0.8449), negative correlation with morning relative humidity (-0.8522) and evening relative humidity (-0.8789).

5.3. Seasonal incidence and population dynamics of *T. urticae* on tapioca

The present studies on seasonal incidence and population dynamics revealed that, during February 2014 (5th MSW) to April 2014 (14th MSW) there was a gradual increase in mite population and the population ranged from 14.2 to 46.8 mites/cm^2 leaf area, after which there was decrease in mite population to 0.6 mites/ cm^2 leaf area during in November 2014 (45th MSW).

Correlation studies between the tapioca mite population and weather factors revealed that there was significant positive correlation with maximum temperature (0.084) and morning relative humidity (0.419), negative correlation with minimum temperature (-0.548), evening relative humidity (-0.360) and rainfall (-0.312), respectively. Regression coefficients revealed that for every unit increase in maximum temperature and morning relative humidity, there was an increase of 0.64 and 0.99 mites, respectively. Whereas every unit increase in minimum temperature, evening relative humidity and rainfall, there was a decrease of 3.95, 0.50 and 0.93 mites, respectively. (Fig. 7).

The results are closely related with the findings of Nukenine *et al*. (2002), who reported that, with the onset of warmer weather and the virtual disappearance of rain in January, 1994, there was an approximate logarithmic increase in numbers of *M. tanajoa*, reaching a peak on April, 1994 in Nigeria. This last peak in second dry season was smaller than the two peaks of January and March of 1993. *Mononychellus tanajoa* population was higher in 1993/94 (second) dry season than that of 1993 wet season, and lower than in 1992/93 (first) dry season. Skovgard *et al*., (1993) reported that, the mite population peaked at the onset of the long dry season with 1,100 mites/leaf, declined sharply to a level of about 300 individuals/leaf, not to increase again until the next rainy season commenced. An indigenous phytoseiid predator, *Iphiseius degenerans* Berlese was abundant during the dry spell with a maximum about 9 predators/leaf.

The seasonal changes in weather and host plant quality have been considered major factors for the population growth of *M. tanajoa* (Nyiira, 1977; Akinlosotu, 1982; Markham *et al*., 1987). However, there have been few attempts to demonstrate the real importance of these factors. Yaninek *et al*. (1989ab) demonstrated that during the wet seasons, rain had a dominating effect by suppressing the density of *M. tanajoa* whereas declining host quality in the dry season limited further increase of the mite population. Gutierrez *et al*. (1988) used a simulation model to show that leaf nitrogen content and intensity of rain could be important factors affecting the density of *M. tanajoa* populations.

Edison *et al*. (2006) reported that, heavy rainfall accompanied by wind is harmful to mites, while a fall in relative humidity and an increase in temperature are highly conducive for their rapid multiplication. An outbreak can be expected during dry summers when the temperature is above 32^{o}C and the relative humidity below 75%. In periods of heavy infestation the population density ranges from 200-1000/leaf in almost all leaves.

5.4. Screening of rice varieties against rice leaf mite, *O. oryzae*

Among the thirty one varieties screened from glass house cum field condition, ADT 41, ASD 18, TKM 9, CO 41, CO (R) 50 and Paiyur 1 were categorized as resistance sources with mean damage grade ranging from 1 to 4. The entries PTB 33 and CO 48 were categorized as moderately resistant with mean damage grade ranging from >4 to 6. The varieties, ADT 42, ADT 47, ADT 48, ADT 49, CR 1009, White ponni, TKM 13, CO (R) 51, BPT 5209 and CO RH 4 were rated as moderately susceptible with mean damage grade ranging from >6 to 8. The varieties ADT 36, ADT37, ADT 38, ADT 39, ADT 40, ADT 43, ADT 44, ADT 45, ADT 46, ADT 50, CO 49, TN 1 and CO 43 exhibited grade >8 and were categorized as susceptible to leaf mite.

The results are in accordance with Balasubramani *et al*. (2000), who screened forty-nine rice varieties, based on 0-9 scale and rated ADT 41, ASD 8, IR 50, Improved White Ponni, AD 95319, ADT 94016, ASD 19, CO 43, Red Ponni, Bhavani, Paiyur 1, TPS 2 and TPS 3 as resistant varieties; ADT 36, ADT 37, ADT 42, AD 95010, AD 95078, AD 95104, AD 95106, ADTRH 1, DRRH 1, Pro Agro 6201, PHB 71, ASD 16, ASD 17, ASD 18, IR 36, IR 64, IR 72, TKM 9, MDU 5, ADT 38, ADT 39, ADT 40, AD 90072, AD 92215, CO 45, CO 46, MDU 2, MDU 3, MDU 4, IR 20 and PY 1 as moderately resistant varieties; ADT 43, ASD 20, IR 66, AD 94010 and TRY 1 as moderately susceptible entries. Radhakrishnan and Ramaraju (2009) also found that ASD 16, ADTRH1 and CO47 were moderately resistant to rice leaf mite ADT 45, TN1, IR 50 and ADT 36 were moderately susceptible and ADT 43 was found to be the most susceptible variety.

Thilagam and Jalaludin (2018) evaluated the rice varieties and landraces against paddy leaf mite. Out of 40 rice varieties tested, predominantly short duration variety, Paiyur 1 showed resistantance and no variety was found to be susceptible against *O.oryzae*. Another predominantly cultivated variety, ADT 39 during *rabi* season was found to be moderately resistant. Most of the varieties tested showed resistance which might be due to the presence of trichomes on the leaves to reduce the activity of the mites.

The result is closely related with the findings of Chitra *et al*. (2017), who screened eighty seven entries of rice against rice leaf mite under field cum glass house condition. In field screening, Overall seventy entries *viz.,* AD 09367, ADT 50, AD 08142, AD 09493, AD 10003, AS 13364, AS 12050, TNRH 281, TM 12456, EC 725224, CB 12588, AD 12132, AS 12066, TP 12005, Pusa Basmati 1, TP 09055, TP 08053, CB 11107, CB MAS 14065, VG 09006, TKM 13, CB 12186, Jeeragasamba, CO(R) 50, CB (Bio) 12015, TM 12721, AS 12079, AD 11150, AD 12033, AD 13116, TR 09027, TR 11085, TM 12202, Improved White Ponni, ACM 7001, CB 12702, TM 12061, CB 13805, TM 12039, MDU 6, TM 12057, TKM (R) 12, PM 12009, TRY 2, Ptb 33 and IR 50, AD 09219, AS 12104, CB 12581, ACK 12001, TNT(RH) 55, CB 12132, TNT(RH) 61, AD 12069, AD 11024, TR 10024, Improved White Ponni *Saltol*, Anna (R) 4, ADT 39, ADT (RH) 45, CR1009, CO 51, ADT 49, AD 09225, CB 12532, AD 12180, CO(RH) 4, CO 39, PY 1 and CO(RH) 3 were categorized as resistant. Fourteen entries, ADT 36, TRY 3, TPS 5, CB 13804, IR 64, ADT 45, ADT R 46, TP 09156, ASD 16, CB

12662, CB 12570, ACK 13005, ASRH 12001 and CB MAS 14142 were categorized as moderately resistant. Three entries ADT 43, TN 1 and BPT 5204 were categorized as moderately susceptible. However, a low leaf mite population was observed under natural conditions in field screening. In glass house condition, twenty three varieties were screened and concluded that, Ptb 33, MDU 6, ADT 39, IR 50 and TRY 2 were categorized as resistant. The entries CR 1009, ADT 50, ADT 49, CoRH 3, CoRH 4, IR 64, PY 1, ADT RH 45, TPS 5 and ASD 16 were categorized as moderately resistant, Co 51, ADT 43, ADT 45, Co 39, TRY 3, TN 1 and ADT 36 were rated as moderately susceptible and BPT 5204 was categorized as susceptible to leaf mite.

5.5. Screening of tapioca varieties against two spotted spider mite

Among the thirty varieties evaluated from glass house cum field condition, Rasi 20, Thailand, Sri Sahiya and Sri Athulya were exhibiting grade 0 – 1 and categorised as resistant, CO (DB) 4, Mulluvadi 1, Burma, H 226, Kerala rose, Sri Visagam, Sri Jeya, Sri Prabha, Sri Apoorva, Sri Swarna and Harswa (grade 2 – 3) categorised as moderately resistant, Yethapur 1, Kungumarose, H 165, Sri Prakash, Sri Pavithra, M (4) and Vellayani were categorised as moderately susceptible with the grade of 3 – 4, and CO 2, CO 3, CO (DB) 5, H 97, Sri Harza, Sri Vijaya, Sri Reka and Sri Bathmanaba were categorised as susceptible with the grade of >5.

The result is in accordance with the findings of Akparobi *et al*. (1998) who evaluated twelve cassava genotypes in Nigeria for their reaction to cassava mosaic disease (CMD), cassava bacterial blight (CBB) and cassava green mite (CGM), using visual injury scores as the index for resistance. The highest injury scores for CMD, CBB and CGM were recorded 9 months after planting (MAP). TMS 30001 and TME1 showed resistance to CMD while TMS 30001, TMS 30572 and TMS 91934 were resistant to CBB. TME1, TMS 91934, TMS 30572 and TMS 50395 were moderately resistant to CGM.

Nukenine *et al*., (2002) conducted an experiments at Ibadan, Nigeria to assess the effect of leaf trichome characteristics (pubescence intensity index, length, and orientation) on field resistance of cassava to the green spider mite, *M. tanajoa*. A significant ($P < 0.01$) negative correlation was obtained between trichome orientation and mite density. The results suggest that, high pubescence intensity significantly reduces leaf damage by *M. tanajoa* through mechanical disturbance to movement and feeding. Trichome length is more important than trichome orientation in cassava resistance to *M. tanajoa.*

Molo *et al*. (2016) evaluated nine cassava *(Manihot esculenta* Crantz) varieties in Kenya based on cassava green mite (CGM) abundance and HCN of leaves for their ability to sustain low CGM populations to enhance biocontrol of *Typhlodramulus aripo* De Leon. In the screening study of CGM abundance and HCN content of leaves, the lowest cumulative CGM population densities (<1200 mites/leaf) were recorded on MM97/3567, Tajirika and MM96/9308, with the lowest cyanide content of leaves (8.5 ± 4.9, 12.5 ± 3.2 and 12.3 ± 2.5 mg/ kg, respectively). Cassava varieties with hairy and non-hairy tips sustained *T. aripo* with highest densities (0.96 actives per tip) on hairy TME14. High *T. aripo* population densities corresponded to high densities of hairs on cassava tips. There were significant inverse linear relationships between CGM densities and *T. aripo* on TME14 at moderate CGM population densities (CGM damage level 2).

5.6. Biology

5.6.1. Developmental duration of rice leaf mite, *O. oryzae* on different rice entries

Detailed investigation made on the biology of *O. oryzae* on the selected four test entries of rice, the trends on fecundity, oviposition period, per cent egg hatchability, egg period, larval period, nymphal period, total developmental period and adult longevity are discussed here under.

5.6.1.1. Fecundity

Number of eggs laid was significantly less on the resistant CO (R) 50 (39.2 eggs/female) compared to the susceptible ADT 50 (71.2 eggs/female). The moderately susceptible entry CO (R) 50 registered 65.6 eggs/ female, while the moderately resistant PTB 33 registered 52.8 eggs/ female. The results indicated that the mites laid more number of eggs on the susceptible entries than on resistant entries. Total number of eggs laid by an individual female varied from 25 - 38 eggs with an average of 32.05 ± 3.88 eggs which were in accordance with Kumar and Nadarajan (2007) and Hegde *et al*. (2008) who have reported that the fecundity per female was 30.70 ± 9.26 eggs.

5.6.1.2. Oviposition period

The shortest oviposition period was 4.4 ± 1.14 days on resistant CO (R) 50, while the longest period was recorded on susceptible ADT 50 (6.0 ± 1.00 days). The moderately resistant PTB 33 and moderately susceptible CO (R) 51 entries recorded a oviposition period of 4.8 ± 0.84 and 5.2 ± 0.84 days, respectively. The pre-oviposition, oviposition and post-oviposition periods reported by Hegde *et al*. (2008) were 0.95 - 2.0 days, 8.0 - 16.0 days and 1.0 - 3.0 days, respectively. Thus, the results are in the accordance with the above report. The slight variations may be due to difference in rearing conditions.

5.6.1.3. Egg period

The egg period was more in resistant CO (R) 50 variety 5.6 ± 0.89 days, while it was less in CO (R) 51 (2.8 ± 0.45) and ADT 50 (3.4 ± 0.55). Nayak *et al.* (2008) and Srimohanapriya *et al.* (2009) have observed the incubation period to vary from 3.5 to 7 and 3 to 5 days in rice crop, respectively.

5.6.1.4. Protonymphal period

The protonymph period lasted for 1.2 – 2.2 days. The development time of protonymph was less in ADT 50 (1.2 ± 0.45), while it was the highest (2.2 ± 0.45 days) in CO (R) 50. The observations are similar to studies made by Radhakrishnan and Ramaraju (2009) and Shukla and Radadia (2015) who reported the protonymphal period of rice leaf mite as 1.6 to 2.70 days and 1.20 to 1.90 days, respectively.

5.6.1.5. Deutonymphal period

In CO (R) 51, this stage lasted only for 1.8 ± 0.45 days followed by 2.2 ± 0.45 days in ADT 50 which, whereas in the case of resistant CO (R) 50 the mite took 3.8 ± 1.84 days to complete this stage. In moderately resistant PTB 33 the deutonymphal period lasted for 2.4 ± 0.55 days. The result coincides with the Nayak *et al.,* (2008) and Srimohanapriya *et al.* (2009) who reported that the deutonymphal period varied from 1.65 to 2.63 and 1 to 2 days, respectively to rice leaf mite.

5.6.1.6. Total development period

The total development period from egg to adult was significantly different among the resistant and susceptible sources. The variety CO (R) 50 influencing comparatively more number of days for completion of total life cycle (14.8 ± 1.64 days), whereas ADT

50 recorded the shortest period of 9.0 ± 0.71 days and these findings are in close agreement with Radhakrishnan and Ramaraju (2009) wherein the developmental period was 8.33 to 16.1 days at laboratory condition. Shukla and Radadia (2015) studied the biology of rice leaf mite under laboratory conditions on two different varieties Jaya and Gurjari. They found that males took 15.15 days on Jaya and 17.27 days on Gurjari to complete the life cycle, whereas mated female took 35.73 days on Jaya and 41.60 days on Gurjari.

5.6.1.7. Adult longevity

The adult females lived for minimum 9.0 to maximum 13.2 days. The male longevity ranged from 5.8 ± 0.84 days in ADT 50 to 9.0 ± 0.71 days in CO (R) 50. Similar observations were made by Radhakrishnan and Ramaraju (2009) who reported that female longevity varied from 8.66 to 13.15 days and male longevity varied from 5.74 to 9.53 days, respectively. The sex ratio (female/ male) was higher on susceptible BPT 5204 (2.60) and lower in the resistant Ptb 33 (1.83) varieties. The tendency of higher sex ratio in susceptible entry might have been caused by higher nitrogen content of the susceptible entry. Similar results have been stated by Sheeba (2010) and Yadav Myakala (2014) on bhendi two spotted mite, chilli yellow mite, respectively.

Similar observations were also recorded by Hegde *et al.*(2008) who reported that the males and females lived for about 7.0 - 10.0 days and 10.0 - 16.0 days. Kandibane *et al*. (2009) also reported that the longevity of male ranged from 5 - 6 days and female's longevity period varied for 7.0 - 13.0 days. Hence the present findings corroborate the results reported by earlier researchers.

Sankar rao (2011) conducted a study on biology on the leaves of rice (BPT-5204) variety under laboratory conditions and he concluded that, an average, the total number of eggs laid by a single female was 32.05 ± 3.88. The oviposition lasted for an average period of 8.03 ± 0.65 days, average egg period was 2.94 ± 0.26 days, larval stage lasted for an average period of 1.63 ± 0.256 days, protonymphal stage lasted for an average period of 1.51 ± 0.30 days, deutonymphal stage lasted for an average period of 1.63 ± 0.37 days, total life cycle in both male and female lasted for an average period of 6.91 ± 0.73 days and 9.09 ± 0.61 days, respectively and adult male longevity lasted for an average period of 6.13 ± 0.77 days and female longevity lasted for an average period of 9.54 ± 0.417 days.

Nayak *et al*. (2008) studied the biology of rice leaf mite under laboratory condition and inferred that the egg, larval, protonymphal and deutonymphal periods were 4.70 ± 1.09, 1.89 ± 0.30, 1.89 ± 0.18 and 2.09 ± 0.24 for male and 5.90 ± 1.12, 2.23 ± 0.36, 2.27 ± 0.26 and 2.42 ± 0.28 days for female, respectively.

5.6.2. Developmental duration of tapioca mite, *T. urticae* on different tapioca entries

Investigation was carried out on the biology of *T. urticae* on the selected four test entries of tapioca. The trends on fecundity, oviposition period, per cent egg hatchability, egg period, larval period, nymphal period, total developmental period and adult longevity are discussed hereunder.

5.6.2.1. Fecundity

Number of eggs laid was significantly less on the resistant Thailand (11.6 eggs/female) compared to the susceptible Sri Reka (28.6 eggs/female), while the moderately susceptible entry Yethapur 1 registered 22.8 eggs/ female. The moderately resistant CO (DB) 4 registered 17.2 eggs/female. Reduced fecundity of *T. urticae* on resistant host varieties has been observed by Kumaraswami (1977) on okra, Palanisamy (1984) and Vinothkumar (2009) on brinjal, Saeidi *et al*. (2007) and Saiedi and Mallik (2006) on tomato and Sederatian *et al*. (2009) on soybean.

5.6.2.2. Oviposition period

The shortest oviposition period was 2.0 ± 0.71 days on Thailand, while the longest period was recorded on Sri Reka (3.8 ± 0.84 days), while other moderately resistant CO (DB) 4 and moderately susceptible Yethapur 1 entries recorded a oviposition period of 2.2 ± 0.45 and 3.0 ± 1.0 days, respectively.

5.6.2.3. Egg hatchability

The highest percentage of hatchability was recorded on the susceptible entry Sri Reka (75.8 %), while the resistant Thailand recorded the lowest egg hatchability (48.2 %). The moderately susceptible entry Yethapur 1 recorded 68.0 per cent followed by moderately resistant CO (DB) 4 (64.4%). Reduced hatchability of the eggs on the resistant accessions may be the reason for the reduced population of build up of mites on the resistant entry. Temperature and relative humidity in the vicinity of the eggs have been considered as important factors in influencing the hatchability of eggs (Hazan *et al*., 1974). The hatchability of eggs may be influenced by the diet of the adult mite, especially amino acid and sucrose content of the leaves. Wilson (1994) suggests the importance of nitrogen content of the leaves for the egg laying by adult mites, thus, the nutritional, mineral and physiological factors would have contributed to the lower oviposition and egg hatchability of mites on the resistant entry.

5.6.2.4. Egg period

The egg period was more in resistant Thailand variety 2.2 ± 0.45, while it was less in Yethapur 1 (2.2 ± 0.45) and Sri Reka (1.2 ± 0.45). Similar result have been stated by Leuschner (1975) for *T. telarius* on cassava. The life duration varied from 7 to 12 days; 2-6 eggs are laid per day with a total of 70 eggs per female.

5.6.2.5. Larval period

There was no significant difference in larval developmental times. Among four different varieties, the highest larval period (2.6 ± 0.55 days) was observed on Thailand, whereas minimum of 1.2 ± 0.45 days was recorded on Sri Reka. The result has close relation with the findings of Yaseen and Bennett (1975), who recorded the larval period of *M. tanajoa* (1-2 days) on Tapioca.

5.6.2.6. Protonymphal period

The duration of the protonymphal period was on par in the moderately susceptible and susceptible (1.2 ± 0.45 - 1.2 ± 0.45 days) entries. The longest duration (2.2 ± 0.45 days) of the protonymphal period was recorded on the resistant (Thailand) entry followed by 1.4 ± 0.55 days on moderately resistant variety (CO (DB) 4).

5.6.2.7. Deutonymphal period

The duration of this stage was 2.6 ± 0.55 days in resistant type and 1.2 ± 0.45 days in the moderately susceptible entry Yethapur 1. The total developmental days on susceptible entry was lesser than the resistant entries.

5.6.2.8. Total development period

The total development period was significantly higher in resistant Thailand variety (9.6 ± 0.55 days) than the susceptible Sri Reka (5.4 ± 1.52 days). Whereas, Sakunwarin *et al*. (2003) observed that, the development time of cassava mite, *Tetranychus truncatus* Ehara. from egg to adult varied from 6.30 to 14.89 days.

5.6.2.9. Adult longevity

The female mites lived for longer periods on the resistant Thailand (7.8 ± 0.84 days) than on the susceptible Sri Reka (4.4 ± 0.55 days) while the females survived for 6.6 ± 0.55 and 6.4 ± 0.55 days, respectively on moderately resistant entry CO (DB) 4 and moderately susceptible entry Yethapur 1. Females lived longer than the male mites generally. The male mites on resistant Thailand survived for 5.4 ± 0.55 days when compared to the susceptible host Sri Reka (3.4 ± 0.55 days).

Yaninek *et al*., (1989a) report that at 27°C, with relative humidity of 70% and a photoperiod of 12 hours light and 12 hours dark, the developmental times of egg, larva, protonymph and deutonymph on leaves of cassava (variety TMS 30572) were 5.4, 3.0, 1.1 and 2.8 days, respectively. At this temperature, typical of most areas in sub-Saharan Africa, the adult female mite lives for 11.6 days and lays an average of 62.8 eggs over a period of 9.8 days. The net reproduction rate reached a maximum of 43.2 progeny. Egg to adult developmental periods were estimated to be 21.3, 15.5, 12.3, 7.7 and 6.9 days at 20, 24, 27, 31 and 34°C, respectively.

5.7 Biochemical basis of rice entries

5.7.1 Moisture content

The highest percentage of moisture content was recorded on the healthy leaves of susceptible ADT 50 (82.62), while the lowest moisture content of 69.72 per cent was recorded on resistant CO (R) 50. The moderately resistant CO (R) 51 recorded 78.49 per cent followed by 75.44 per cent on PTB 33. Decrease in moisture content due to mite infestation was the highest (20.60 %) in ADT 50 and the lowest (12.86 %) in CO (R) 50. High infestation by mites on the susceptible entry might have resulted in greater depletion of moisture content. Peters and Berry (1980) have been reported that, development of immature stages of the mite have adverse effect on the latter stage by the influence of moisture content. Therefore mites prefer the high moisture containing varieties compared to the lower ones. Similar findings have been reported by Kamruzzaman *et al.* (2013) in jute infested with yellow mite.

These results were also in conformity with Chitra (2017), who reported that, The water loss due to mite injury was found to be maximum in susceptible rice variety BPT 5204 (21.12%) and it was minimum in resistant Ptb 33 (3.30 %), whereas in other entries the per cent reduction ranged from 4.38 to 17.32 per cent.

5.7.2. Chlorophyll

The chlorophyll contents namely 'a', 'b' and total chlorophyll were analysed in the selected entries of rice, both in the healthy and mite infested plants and presented in the Fig. 13.

5.7.2.1. Chlorophyll 'a'

The per cent reduction of chlorophyll 'a' over healthy leaves was high (53.10%) in susceptible ADT 50 followed by CO (R) 51 (34.65%), whereas CO (R) 50 and PTB 33 recorded per cent increase over healthy leaves (8.86 and 0.71%), respectively.

5.7.2.2. Chlorophyll 'b'

The per cent reduction of chlorophyll 'b' content over healthy leaves was high (44.07%) in resistant CO (R) 50 followed by PTB 33 (28.16%). Whereas, the moderately susceptible CO (R) 50 and susceptible ADT 50 recorded per cent increase over healthy leaves (41.03 and 25.76%, respectively).

5.7.2.3. Total chlorophyll

With high level of mite infestation the total chlorophyll content in the susceptible ADT 50 was found to reduce by 43.02 per cent, whereas the reduction was only 14.50 per cent in the resistant CO (R) 50. The other entries belonging to the moderately resistant and moderately susceptible category recorded 8.39 and 36.43 per cent, respectively. Reduction in chlorophyll may be due to the dessaping of water and depletion of nitrogenous compounds essential for the assimilation of chlorophyll. The susceptible accessions might have attracted more number of mites due to higher chlorophyll content resulting in healthy attractive bushy green colour. The results are in accordance with the studies by Samsone *et al*. (2012) on *Prunus padus* damaged by *Eriophyes padi*, wherein, decrease in the chlorophyll content was associated with decreased photochemical efficiency. Chitra (2017) also found that, the reduction in total chlorophyll of mite infested plants was highest in susceptible BPT 5204 of about 52.16 per cent whereas it was lowest in the resistant Ptb 33 of around 10.46 per cent over its healthy plants.

5.7.3. Total carbohydrates

In healthy leaves, there was a difference in total carbohydrates among the entries tested. The total carbohydrate content of healthy leaves varied from 13.06 mg/g in CO (R) 50 to 21.64 mg/g in ADT 50. The per cent reduction of total carbohydrates due to mite infestation was more to the extent of 21.44 per cent in susceptible ADT 50 and less to an extent of 3.22 per cent in resistant CO (R) 50. The present findings agree with Palanisamy (1979) and Yadav myakala (2014), who reported the resistant varieties contained higher amounts of carbohydrates than the susceptible varieties in bhendi and chilli crop for two spotted spider mite and yellow mite, respectively. Sanjib Ghoshal (2013) also observed reduction in total carbohydrate content in tulsi leaves due to two spotted mite feeding to an extent of 24.32 per cent. Chitra (2017) also found that, the reduction of total carbohydrates in rice leaf mite infested plants ranged from 9.81 per cent in resistant Ptb 33, whereas 23.97 per cent in susceptible BPT 5204.

5.7.4. Reducing sugars

Among the healthy entries, the maximum amount of reducing sugar was found in the susceptible ADT 50 (7.61 mg/g), while in the resistant CO (R) 50, it was 2.56 mg/g. The minimum per cent increase of 4.88 was observed in the resistant entry ADT 50, while in other entries moderate increase was noticed and it varied from 16.07 to 22.43 per cent (Fig. 14). The results are in conformity with Palanisamy (1984) on brinjal infested by two spotted mite, who found that the more amount of reducing sugars leads to more susceptibility.

5.7.5. Crude protein content

In healthy leaves, the highest amount of protein was observed in the susceptible ADT 50 (7.84 mg/g) and CO (R) 51 (7.00 mg/g), whereas it was 6.55 and 6.95 mg/g, respectively in PTB 33 and CO (R) 50. The per cent reduction in crude protein content due to mite infestation was 44.77 in susceptible ADT 50 and 18.10 in CO (R) 50 (Fig. 14). Chitra (2017) confound that, the rice leaf mite infested plants recorded a lower amount of protein than the mite free plants. The highest amount of protein was observed in the susceptible BPT 5204 (11.69 mg/g). The resistant Ptb 33 leaves recorded 4.07 per cent reduction from its healthy plants, while BPT 5204 showed 21.93 per cent reduction. It is evident that high nutritive food will encourage the build up of mite pest. Similar results were noticed by Nangia *et al.* (1999) and Sanjib Ghoshal (2013), who reported the depletion of protein in tulsi and mulberry leaves, due to feeding of *Tetranychus neocaledonicus* and *Eotetranychus suginamensis*, respectively. Punithavalli *et al.* (2013) have also noticed significant reduction in total protein content due to leaf folder infestation in rice.

5.7.6. Total free amino acid

The minimum amount of total free amino acid was recorded in the healthy leaves of resistant CO (R) 50 (4.65mg/g) and the maximum amount in susceptible ADT 50 (8.02 mg/g) and with the mite infestation, the same plants had 4.88 and 9.66mg/g of total free amino acid, respectively (Table 26). PTB 33 and CO (R) 51showed 7.24 and 7.68mg/g on healthy leaves, respectively. The per cent increase over healthy leaves was more in ADT 50 (16.98%) than CO (R) 50 (4.71%). A positive relationship was observed between total free amino acid and degree of infestation in the present investigation. Similar trends were observed by Chitra (2017), who reported that, amino acids are known to have a greater role in insect nutrition and reproduction. The total free amino acid was more in the susceptible BPT 5204 (1.92 mg/g) compared to the resistant Ptb 33 (1.43 mg/g) of rice accessions against rice leaf mite. The other entries recorded 1.44 – 1.66 mg/g of total free amino acid. Bharathi (1989), reported low free amino acid and reducing sugar content in varieties resistant to brown plant hopper when compared to susceptible rice varieties. Hosamani (2007) also stated the mite resistant chilli accession DAC- 40 had lower quantity of amino acid (6 – 25 mg /g).

5.7.7. Total phenols

The healthy leaves of resistant CO (R) 50 had higher amount of phenols (4.70 mg/g), while the susceptible ADT 50 had lower amount (2.50 mg/g). There was increase in phenol content to the tune of 9.62 per cent in resistant CO (R) 50 and it was less in susceptible ADT 50 with 1.96 per cent due to mite infestation. This explains that phenols played a vital role in imparting resistance against mite infestation. The results were in conformity with Chitra (2017), who found that, highest phenol content was recorded in both healthy (9.83 mg/g) and infested (12.48 mg/g) leaves of resistant Ptb 33. On contrary, the susceptible BPT 5204 possessed the lowest total phenol content in both healthy (3.24 mg/g) and mite infested (3.65 mg/g) leaves.

5.7.8. Tannin

The quantity of tannin in the healthy and infested leaves of resistant plant (CO (R) 50) increased from 1.40 to 1.64 mg/g with the per cent increase of 14.63. On the contrary, the tannin concentration (0.83 and 0.90 mg/g) in the susceptible check showed the lowest increase (7.78%) after mite feeding. The present study is in line with Sanjib Ghoshal (2013) and Kharbangar *et al.* (2015) who observed increase in phenolic compounds in tulsi and rice due to *T. neocaledonicus* and thrips infestation, respectively. The results are in agreement with Sharma and Lopez (1990) who found that tannin content in some midge resistant lines of sorghum were higher than in susceptible ones.

5.7.9. Nitrogen

The present study revealed that there was reduction in the nitrogen content due to mite infestation. The highest per cent reduction in nitrogen content over healthy leaves was observed on ADT 50 (16.01%) followed by CO (R) 51 (14.16%), respectively. Whereas, the lowest reduction was observed on resistant CO (R) 50 (4.40%). These results are in accordance with Kumaraswami (1977) who reviewed the overall effects of deficiency in nitrogen and concluded that limitation of nitrogen supply decreased the rate and extent of protein synthesis followed by that of carbohydrate synthesis. The present findings agrees with Yadav Myakala (2014) who observed that there was reduction in nitrogen content due to chilli mite infestation and it exhibited positive correlation with mite population. Chitra (2017) also reported that, the nitrogen reduction ranged from 4.07 per cent in resistant to 21.93 per cent in the susceptible accession of rice against *O. oryzae*.

5.7.10. Phosphorous

Phosphorus plays a key role in various enzymatic reactions in carbohydrate metabolism including inter-conversion of carbohydrates and providing respiratory energy. There was marginal increase of phosphorus in infested leaves over the healthy in all the entries tested. Increase of 77.20 per cent was noticed in susceptible ADT 50, whereas it was 63.87 per cent in moderately susceptible CO (R) 51, 61.68 per cent in moderately resistant PTB 33 and the least in resistant CO (R) 50 (35.63%). Such an association of low phosphorus content with resistance of plants to insects and mites has been reported earlier by Palanisamy (1984) and Uthamasamy *et al*. (1971).

5.7.11. Potassium

Potassium was negatively correlated with the mite population on the test accessions. The percentage reduction in potassium due to mite feeding was low in CO (R) 50 (5.47%) followed by 12.12, 16.50 and 43.75 per cent in PTB 33, CO (R) 51 and ADT 50, respectively (Fig. 16). These result were in accordance with Chitra (2017), who reported that, the least potassium content was observed in susceptible BPT 5204 (1.20 %) which harboured high mite population. Inversely, the resistant Ptb 33 possessed highest potassium content (1.93 %) with lowest mite population. Similar results were also obtained by Sheeba (2010) in bhendi infested by two spotted mite and chilli yellow mite infestation (Yadav Myakala, 2014).

5.7.12. Calcium

The maximum calcium content of 0.84 per cent was recorded in the healthy leaves of resistant CO (R) 50 and the minimum of 0.68 per cent in susceptible ADT 50. The mite injury caused a reduction in the calcium content by an extent of 6.67 to 21.47 per cent.

5.7.13. Magnesium

Among the tested entries CO (R) 50 registered the highest magnesium content both in the healthy and infested plants (0.46 and 0.44 %), while susceptible ADT 50 registered the lowest content (0.33 and 0.25 %, respectively).

5.7.14. Iron

The healthy plants contained 283 to 485 ppm of iron in their leaves. But, the infested leaves exhibited differences among the entries. The percentage reduction was minimum in CO (R) 50 (4.54%) followed by PTB 33 (5.65 %) and CO (R) 51 (7.24 %) where as it was maximum (12.47%) in susceptible ADT 50.

The result is closely related with the findings of Rodriguez (1951), who found a positive correlation between magnesium level and *T. urticae* population, but with *T. kanzawai*, Osakabe (1967) found a negative correlation. In cucumber, while calcium had a negative effect, magnesium and sulphur showed a favorable effect on *T. telarius* (Le Roux, 1959). No significant association was found between mite damage and manganese, magnesium, copper, zinc or iron levels in the leaves of peanut lines, but calcium showed a negative correlation (Johnson and Campbell, 1982).

5.7.15. Enzymes activity

5.7.15.1. Peroxidase (PO) activity

The entries responded differently in their peroxidase activity against the mite infestation and mite free plants. The highest peroxidase activity was noticed on resistant CO (R) 50 (9.64 changes in OD value (ΔA) /min/g of fresh leaf tissue) followed by PTB 33 (7.44 ΔA/min/g of fresh leaf tissue) in the infested plants. The resistant entries had a higher rate of peroxidase activity even under uninfested condition. The susceptible ADT

50 under both healthy and infested condition recorded the lowest mean peroxidase activity 5.37 and 5.85 ΔA/min/g of fresh leaf tissue, respectively. Changes in host-physiology due to herbivory are invariably associated with changes in the enzymatic activities of host plants. Antioxidant enzymes such as catalase, superoxide dismutase and peroxidase are known to be correlated with induced defenses to herbivory and mite attack (Grinberg *et al.,* 2005; Nachappa *et al.,* 2013). Spence *et al*. (2007) also found that the incidence of *T. urticae* and flower thrips *Frankliniella occidentalis* (Pergande) on cotton increased the activity of peroxidase.

5.7.15.2. Polyphenol oxidase (PPO)

The polyphenol oxidase activity also exhibited significant differences among the test entries in healthy and infested plants and it was the maximum on the resistant CO (R) 50 with 0.79 and 0.82 ΔA/min/g of fresh leaf tissue in healthy and infested leaves respectively. The lowest activity was observed on ADT 50 with 0.62 and 0.45 ΔA/min/g of healthy and infested leaves, respectively. The general trend in the healthy plants of the test entries was similar to that of infested plant. The results in accordance with Chitra (2017), who reported that, in the rice leaves, *O. oryzae* infestation has led to increase in the peroxidase (PO) and polyphenol oxidase (PPO) activity, compared to the healthy mite free plants. Alagar (2005) and Vanitha (2008) also reported that, rice varieties resistant to brown plant hopper recorded highest peroxidase and polyphenol oxidase compared to the susceptible varieties. Similar trend was observed by Chandrasekar (2012) in rice varieties resistant to white backed plant hopper.

5.7.15.3. Phenylalanine ammonia lyase (PAL)

Phenylalanine ammonia lyase activity was more in panicle initiation stage and less activity was observed on active tillering and flowering stage. The maximum activity of PAL (4.51 ΔA/ min/g of fresh leaf tissue) was recorded in the mite infested resistant entry CO (R) 50 during panicle initiation stage. Whereas, the moderately resistant entry PTB 33 recorded a higher activity (3.96 ΔA/ min/g of fresh leaf tissue) of PAL next to resistant entry, while the activity was least in susceptible ADT 50 (3.04 ΔA/ min/g of fresh leaf tissue) in infested plants. Phenylalanine ammonia lyase is the key enzyme of phenylpropanoid metabolism in higher plants which catalyzes the conversion of phenylalanine to trans-cinnamic acid which supplies the precursors for flavanoids, lignins and phytoalexins (Hahlbrock and Scheel, 1989). Several studies indicated that the activation of phenylalanine ammonia lyase and subsequent increase in phenolic content in plants are a general response associated with disease resistance (Velazhahan and Vidhyasekaran, 1994).

5.8. Biochemical basis of tapioca entries

5.8.1. Moisture content

The highest percentage of moisture content was recorded on the healthy leaves of susceptible Sri Reka (81.64), while the lowest of 61.48 per cent on resistant Thailand. The moderately resistant CO (DB) 4 recorded 68.28 per cent followed by 77.61 per cent on Yethapur 1. Per cent reduction of moisture content due to mite infestation was the highest in Sri Reka (17.94 %) and the lowest in Thailand (8.36%). Similar results were also obtained by Sheeba (2010), who observed the differences in the moisture content between the susceptible and resistant accessions of bhendi against *T. urticae*, indicated the possible involvement of this factor in mite resistance. Reduction in carbohydrate synthesis, accumulation of free amino acids and sugars are some of the physiological disorders associated with water stress caused by mite feeding (De Angelis *et al*., 1982 and 1983; Jager and Mayer, 1977).

5.8.2. Chlorophyll

The chlorophyll contents namely a, b and total chlorophyll were analysed in the selected entries of tapioca both in the healthy and mite infested plants and presented here under.

5.8.2.1. Chlorophyll 'a'

The healthy leaves of susceptible variety Sri Reka recorded the highest chlorophyll 'a' content (1.29 mg/g) whereas it was low in Thailand (0.95 mg/g). In the infested leaves of the test entries, the chlorophyll 'a' content ranged from the least of 0.59 mg/g in Thailand to maximum of 0.73 mg/g in Sri Reka.

5.8.2.2. Chlorophyll 'b'

The chlorophyll 'b' content in the resistant CO (DB) 4 was the least (0.52 mg/g) than other entries. Sri Reka recorded the maximum amount of 0.94 mg/g followed by moderately susceptible Yethapur 1 (0.82 mg/g). In the infested leaves of the test entries, the chlorophyll ‘b’ content was found to be maximum of 0.42 mg/g in the susceptible Sri Reka and it was the least of 0.34 mg/g in CO (DB) 4. The per cent reduction of chlorophyll ‘b’ was more in susceptible Sri Reka (55.78%) than resistant Thailand (28.07%).

5.8.2.3. Total chlorophyll

The healthy leaves of susceptible Sri Reka had more amount of total chlorophyll (2.23 mg/g) than the other entries. With high level of mite infestation, the total chlorophyll content in the susceptible Sri Reka was found to be reduced by 48.81 per cent, whereas, the reduction was only 34.38 per cent in the resistant Thailand. The other entries belonging to the moderately resistant and moderately susceptible category recorded 37.35 to 45.76 per cent reduction in total chlorophyll due to mite infestation. The results are in accordance with Palanisamy (1984), Campbell and Marini (1990) and Labanowskur and Labanowska (1996) on black current. Bondada *et al.* (1995), Iatrou *et al.* (1995) and Park and Lee (2002 and 2005) also noticed reduction in total chlorophyll and net photosynthetic rate of leaves due to the feeding of two spotted spider mite.

These results were also in conformity with the findings of Sheeba (2010), who reported that, the chlorophyll 'a' content in the healthy leaves of different accessions of bhendi showed less difference (1.212-1.439). But the mite injured leaves showed wide variation in the chlorophyll a, b and total chlorophyll, especially between the susceptible (0.614, 0.337 and 0.867) and resistant accessions(1.026, 0.273 and 1.097). The chlorophyll 'a' was high in uninfested susceptible Mahyco 10 (1.439), while it was low in resistant Kasturi bhendi (1.212).

De Angelis *et al.* (1983) reported that depletion of chlorophyll in peppermint leaves due to *T. urticae* feeding resulted in reduced leaf conductance to gas exchange leading to reduced photosynthetic activity. Similar results of reduction in total chlorophyll to a tune of 78.5 per cent in whiteflies infested plants was reported by Mariamma Ninan and Kavitha Kirubavathy (1998). Gimenez-Ferrer *et al.* (1993) also noticed necrosis in mite infested plants of strawberry. The loss of chlorophyll differed with cultivars differing in levels of resistance and the leaves exhibited cultivar-specific pattern of colour change as they became necrotic while the susceptible cultivar showed marked bronzing of leaf tissues. Campbell *et al.* (1990) proved that the total chlorophyll content was reduced by 16 per cent in the mite infested leaves of apples in Green house condition. Sances *et al.* (1982) measured 10 per cent reduction in photosynthesis of winter green straw berry plants infested by two spotted spider mite. The reason for the loss of chlorophyll may be attributed to the ultra structural disruption of the chloroplast cells due to the stylet penetration by mites. The protoplast coagulated and pressed tightly to the intercellular sides of the cell wall leading to poor function of the cell organelles.

5.8.3. Total carbohydrates

In healthy leaves, there are differences in total carbohydrates among the entries tested. The total carbohydrate content varied from 11.98 mg/g in resistant Thailand to 19.62 mg/g in susceptible Sri Reka, whereas in infested leaves, it decreased. The per cent reduction of total carbohydrates due to mite infestation was more to the extent of 6.34 per cent in resistant Thailand and less to an extent of 19.16 per cent in susceptible Sri Reka. The photosynthesis process would have not been efficient without the pigment to harvest the light and O_2 to transport the electrons which directly resulted in reduced carbohydrate synthesis in the infested plants. Similar observations were made by Palanisamy *et al*. (1977) on okra varieties infested by two spotted mite. A faster breakdown of compound to serve as substrate for the increased respiration or conversion of carbohydrates into organic acids would have lead to the synthesis of amino acid and phenols.

Ghoshal *et al*. (2011a and b) reported decrease in carbohydrates in guava leaves due to *T.pernicis* and in mango leaves due to *O. mangiferus* (Rahaman and Sapra) when compared to uninfested leaves. Mohd Yaqoob *et al*. (2011) reported decrease in the carbohydrate content in mite infested mulberry leaves in contrast to the uninfested leaves.

5.8.4. Reducing sugars

The reducing sugars in the entries indicated that the lower the reducing sugar, lesser is their susceptibility to the mite infestation. Among the healthy leaves, the minimum amount (3.78 mg/g) of reducing sugar was found in the resistant Thailand, while in the susceptible Sri Reka, it was 8.34 mg/g. The reducing sugar content in the infested leaves was found to be higher than that of uninfested plants. Similar trend were recorded by Sheeba (2010) in bhendi leaves against *T. urticae*, the findings showed that, in healthy entries, the maximum amount of reducing sugar (5.33 mg/g) was found in the susceptible entry Mahyco 10, while the resistant entry Kasturi bhendi, a wild type had only 2.07 mg/g of reducing sugar in their healthy leaves.

The reducing sugar, which is considered to be an essential component in insect nutrition and plays a vital role in host selection by phytophagous insects. As they are imperative for the normal growth and development of insects, their concentration in host plants is positively correlated with feeding behavior of insects. The fecundity of mites increased with increased sugar concentrations. Direct availability of reducing sugar such as glucose for metabolism ensures a steady growth environment and hence, the higher reducing sugar levels attracted more mites.

Kashyap *et al*. (1988) reported that, reducing sugar showed positive correlation with mean multiplication of *Myzus persicae*. Bharpoda *et al*. (2007) also found a positive relationship between reducing sugar and gall maker incidence in susceptible Amla varieties.

5.8.5. Crude protein content

Infested plants recorded a lower amount of protein than the mite free plants. In healthy leaves the highest amount of protein was observed in the susceptible Sri Reka (9.88 mg/g), which was followed by Yethapur 1 (9.37 mg/g), whereas, in infested leaves of Sri Reka and Thailand it was 6.34 and 7.01 mg/g, respectively. The protein content in healthy and mite infested leaves of resistant Thailand was 7.52 and 7.01 mg/g, respectively. The per cent reduction in crude protein content due to mite infestation was 35.83 in susceptible Sri Reka, but it was 6.78 per cent in resistant Thailand. Similar results were noticed by Mollema and Cole (1996) who found that low amount of total leaf proteins were correlated with a reduction in damage by the insect. They concluded that higher concentrations of aromatic amino acids in plant proteins are important for successful pest development.

5.8.6. Total free amino acid

The maximum amount of total free amino acid was recorded in the healthy leaves of susceptible Sri Reka (8.86 mg/g) and the minimum amount in Thailand (5.28 mg/g) and with the mite infestation, the same plants had 11.62 and 5.46 mg/g, respectively. The healthy leaves of CO (DB) 4 and Yethapur 1 showed 6.46 and 7.84 mg/g of total free amino acids, respectively. However, there were 8.76 and 11.71 per cent increase in CO (DB) 4 and Yethapur 1due to mite infestation. Amino acids are known to have a greater role in insect nutrition and reproduction. Many reports point out that low concentration and less number of amino acids occurred in resistant varieties (Uthamasamy, 1971; Palanisamy, 1971; Kumaraswami, 1977). Balasubramanian and Subbiah (1981) also found that reduced amino acid suppressed the thrips and aphids population in chillies.

According to Mellors and Propts (1983), the total dry weight of infested plants was significantly lower than those for the corresponding uninfested plants.

5.8.7. Total phenols

The healthy leaves of resistant Thailand had higher amount of phenols (5.05 mg/g), while the susceptible Sri Reka had lower amount (2.85 mg/g). There was increase in phenol content to the tune of 15.49 per cent in resistant Thailand and it was less in susceptible Sri Reka with 2.90 per cent due to mite infestation. The finding is in accordance with Larson and Berry (1984) who reported that phenolic compounds are associated with resistance against *T. urticae* in peppermint and found that mite resistance is positively correlated with foliar phenolics. Plant phenols have been implicated in resistance against two spotted spider mite in strawberry (Kielkiewiez and van de Vrie, 1982; Inove *et al*., 1985; Alimukhamedov and Shrestova, 1988; Luczynski *et al*., 1990a), against *Heliothis zea* (Boddie) (Taneja *et al*., 1988) in cotton (Guerra *et al*., 1990), against brown plant hopper in rice (Kavitha, 2008) and stem borer *Sesamia nonagrioides* (Lefebvee) in maize (Santiago *et al*., 2005).

Phenols are known to reduce the digestibility and antinutritive in nature. Owing to reduction in digestibility, the insects may have lost feeding incitation and hence, leading to poor growth and development of mites. Stout *et al*. (1996a), Wilkens *et al*. (1996) and English-Loeb *et al*. (1997) reported that level of phenols in tomato foliage was influenced by nitrogen fertilization, water stress and light intensity and were inducible. The low phenolic content in the susceptible entries might be due to its high nitrogen context.

Chlorogenic acid, caffeine acid and other related ortho-dihydroxy phenolics are present in the leaf lamina and glandular tips (Isman and Duffey, 1982 a and b). When an insect disturbs the trichome tip, the contents are mixed and the ensuing reaction results in oxidation of the phenolic substrate to quinine which are known specifically for their ability to form rapid and stable bends with protein (Herrel *et al*., 1982) and leading to the inhibition of enzymatic activity and reduction of dietary availability of proteins (Van Seemere e*t al*., 1975) while the product of browning reaction entangles appendages and mouth parts of small arthropods and mites (Duffey and Isman, 1981; Duffey, 1986 and Gregory *et al*., 1986). The entrapment and immobilization by the exudates of glandular trichomes was associated with reduced survival of *T. urticae* in *Lycopersicon* and

Solanum spp. (Ramsy, 1985) and in strawberry (Larson and Berry, 1984). This explains the reduced mite population on the resistant entry.

5.8.8. Tannin

The tannin quantity examined in four tapioca entries showed a notable difference in the healthy as well as mites infested plants. The quantity of tannin in the healthy and infested resistant plant (Thailand) showed an increase from 1.82 to 2.45 mg/g with the per cent increase of 25.71. On the contrary, the tannin concentration in the susceptible check showed the lowest increase (4.76%) after mite feeding. The present result is in accordance with the findings of Singh (1988) and Singh and Agarwal (1988) who reported the leaf hopper resistant varieties of okra had higher amounts of tannins in the leaves. Lane and Schuster (1981) found that size of *T. urticae* mite population in primitive cotton races was related to concentration of condensed tannin.

Mansour *et al*. (1997) found that higher concentration of tannins conferred resistance to aphids, white flies and hoppers on cotton. Post absorptive inhibition is the primary factor responsible for poor insect growth caused by dietary tannins. Bell (1986) found association of high levels of condensed tannin with resistance in cotton cultivars to spider mites *T. urticae.* Maheshwari *et al*. (2006), Emmanuel *et al*. (2002) and Kavitha (2008) suggested that the white backed plant hopper and BPH resistant and tolerant rice cultivar had the highest content of phenol and tannin than the susceptible cultivars.

The increased amount of secondary metabolites namely phenol and tannin in the resistant entries as revealed in the present study is in conformity with Kamakshi *et al*. (2008) who found that several biochemical constituents namely, phenols, tannins, fibre and silica were comparatively higher in resistant varieties of *Lab lab purpureus* L.

5.8.9. Nitrogen

In healthy plants, the per cent nitrogen content varied from 3.75 in Thailand to 4.42 in Sri Reka, whereas in mite infested leaves, there was decrease in nitrogen content to an extent of 29.79 per cent in Sri Reka and it was the least in Thailand of 9.12 per cent only. With mite infestation, reduction in nitrogen content was observed as 10.26 and 21.77 per cent in CO (DB) 4 and Yethapur 1, respectively. Peng *et al*. (1995) reported a strong linear relationship between chlorophyll content and nitrogen content of the plant. The chlorophyll content increased in proportion to the amount of nitrogen present in plant. Hence, the bushy green growth of the susceptible accession might have resulted in more on them and more over nitrogen and essential component of amino acids and proteins would have supported the faster growth, development and reproduction of mites on the susceptible test entry.

Nitrogen is an important, and often limiting, nutrient for herbivores (Mc Neill and Southwood, 1978; Mattson, 1980). In comparing plant species as a host for mites, it was found that nitrogen levels in leaf tissue are positively correlated with rates of mite development and fecundity (Hanna *et al.,* 1982). It is probably not just the total nitrogen content, but rather the concentration of protein-bound essential amino acids that determines the nutritional value of leaf tissue for mites (Tulisalo, 1971). Hoffland *et al.* (2000) showed that the protein concentration in leaves is negatively correlated with CN and positively with nitrogen availability. The protein content of leaf tissue might therefore also contribute to the mites' preference for leaves of plants grown at high nitrogen availability.

5.8.10. Phosphorous

There was marginal increase of phosphorus in infested plants over the healthy plants in all the entries tested. Increase of 11.49 per cent was noticed in susceptible Sri Reka followed by 9.24 per cent in moderately susceptible Yethapur 1, and 6.06 per cent in moderately resistant CO (DB) 4. The least per cent increase was noticed on resistant Thailand (3.68%). Phosphorus as a nutrient is rated next only to nitrogen and has been found essential for egg production in *T. urticae* (Rodriguez, 1954). Under phosphorus deficient conditions, reduction in fecundity has been reported in various mites (Rodriguez, 1951; Osakabe, 1967; Palanisamy, 1991), while Hanneberry (1963) found a negative correlation between fecundity and quantity of phosphorus in the leaves. Hanna *et al*. (1982) observed no detectable effect on the fecundity of mites.

5.8.11. Potassium

Potassium is known to be positively involved in the photosynthetic phosphorylation and potassium concentration is essential in the opening and closure of stomata which is involved in respiration. Further, calcium, magnesium and boron are known to induce resistance to mites and influence the synthesis of various enzymes and amino acid and thereby enhancing the plant vigour. The present study revealed that, the potassium content ranged from 1.82 per cent in Sri Reka to 2.44 per cent in Thailand in healthy leaves as against 1.11 and 2.15 per cent in mite infested entries, respectively. The percentage reduction in potassium due to mite feeding was the lowest in Thailand (11.89%) followed by 16.22, 22.62 and 38.88 per cent in CO (DB) 4, Yethapur 1and Sri Reka, respectively.

Ramaraju *et al*. (2003) explained that phosphorus deficiency leads to inhibition of protein metabolism and auxin production. Unlike nitrogen, higher levels of potassium exert a negative influence on mite populations. Moore *et al*. (1991) studied the relationship between *Aceria guerreronis* Keifer eriophyid mite damage and nutrient levels and found that increase in foliar nitrogen increased the mite damage, while there was a negative relationship between the damage and potassium level. The mite populations tended to be lower, when potassium was applied double the normal dose per coconut palm (David *et al*., 2000).

The results are in accordance with Ramaraju *et al*. (2007) who reported that application of higher amount of muriate of potash to coconut increased the resistance to eriophyid mite and reduced the build up mite population and Moore *et al*. (1991) confirmed that the coconut mite damage increased with increased levels of nitrogen, while potash reduced the population of mite. Rajaram and Ramamurthy (2001) reported that potash had significant effect on reducing broad mite on chilli.

5.8.12. Calcium

The resistant entries had more calcium than the susceptible check both under healthy and infested conditions. The mite injury caused a reduction in the calcium content by an extent of 4.69 to 29.17 per cent. The maximum calcium content being 1.92 per cent was recorded in the healthy Thailand and the minimum being 1.19 per cent in the mite infested susceptible Sri Reka. The maximum per cent reduction over healthy leaves was observed on susceptible Sri Reka (29.17%) and it was minimum in resistant Thailand (4.96%). Calcium is a cell wall constituent present in the middle lamella of cell wall and the decrease in calcium content therefore has an important bearing on the strength of tissue. Therefore, the high calcium concentration found in the cell walls of the resistant accessions might have rendered the cells less penetrable by chelicerae of the mites. Higher calcium content was found to be associated with *T.cinnabarinus* resistance in okra (Kumaraswami, 1977) and brinjal (Palanisamy, 1984) and *T. urticae* resistance in peanut (Johnson and Campbell, 1982). Moreover, higher concentration of this inorganic salt in the resistant entries is bound to increase the osmotic concentration of cell sap, which would directly affect the feeding capacity of the mites.

5.8.13. Magnesium

The healthy entries recorded increased level of magnesium than the infested plants. Among the tested entries, Thailand registered the highest magnesium content both in the healthy and infested plants (0.67 and 0.65 % respectively), while susceptible Sri Reka registered the lowest per cent (0.41 and 0.32 %, respectively). Magnesium content declined due to mite feeding in all entries irrespective of their degree of resistance. The highest reduction was noticed on susceptible Sri Reka (23.06%) whereas, the least was on Thailand (2.98%). Magnesium is a constituent of chlorophyll and an activator of numerous enzymes affecting phosphate transfers. Deficiency of this element affects every facet of metabolism of plant and low quantity of magnesium might be one of the reasons for its high susceptibility. Terriene and Rajadhyaksha (1964) reported that the higher magnesium content might be responsible for the reduced fecundity on the resistant accessions against *T. urticae*.

5.8.14. Iron

The healthy plants contained 300 - 498 ppm of iron in their leaves. But, the infested leaves exhibited differences among the entries. The resistant and moderately resistant varieties showed 498 and 400 ppm iron in healthy leaves. The percentage decline of iron due to mite infestation was minimum in Thailand 9.04, moderate in CO (DB) 4 (14.50 %) and maximum (28.00%) in susceptible Sri Reka and the reason for the reduction might be due to the requirement of iron for the fecundity and reproduction of mites. The values of iron in the infested leaves of the test entries ranged from 216 to 453 ppm.

5.8.15. Enzymes activity

5.8.15.1. Peroxidase (PO)

The highest peroxidase activity was noticed on resistant Thailand (10.28 ΔA/min/g of fresh leaf tissue) followed by CO (DB) 4 (8.34 ΔA/min/g of fresh leaf tissue) in the healthy plants. The resistant entries had a higher rate of peroxidase activity even under infested condition. The susceptible Sri Reka under both infested and healthy condition recorded the lowest mean peroxidase activity 3.21 and 6.88 ΔA/min/g of fresh leaf tissue, respectively. Peroxidase reacts with several acematic compounds to generate reactive oxidative species (ROS) that are known to play a role in herbivore resistance (Bi *et al*., 1997b; Kawano, 2003).

5.8.15.2. Polyphenol oxidase (PPO)

The maximum activity of polyphenol oxidase was recorded on the resistant Thailand with 2.43 and 3.54 ΔA/ min/g of fresh leaf tissue in healthy and infested leaves, respectively whereas the lowest activity was observed on Sri Reka with 1.24 and 2.48 ΔA/ min/g of fresh leaf tissue, respectively. The moderately susceptible variety Yethapur 1 recorded 1.28 and 2.84 ΔA/ min/g of fresh leaf tissue in healthy and infested leaves. The general trend in the healthy plants of the test entries was similar to that of infested plant. Polyphenols function as phenol oxidase in higher plants and the PPO oxidized compounds have been associated with antifeedant and antioxidant property. Anh-Thu *et al*. (2004) recorded peak activity of PPO in okra plants during summer corresponding to periods of high solar irradiance and herbivorous insect population, and PPO has been demonstrated to be effective against both these stresses. Moreover, PPO was found to be more active in the post-flowering stage in all the seasons as compared to the young pre-flowering stage (Sen and Mukerji, 2009), thus supporting the results of increased activity of PPO after 150 days after planting.

The findings from the current study support a number of previous reports that have demonstrated that oxidative enzymes like peroxidase, catalase and polyphenol oxidase in plants play an important role in responding to biotic and abiotic stresses (Zhang and Kurkham, 1994; Hildebrand *et al*., 1986, 1989; Felton *et al*., 1994a and b). The oxidative enzymes have been implicated as key enzymes in plant cell wall – building processes, such as peroxidase-mediated oxidation of hydroxyl cinnamyl alcohols into free radical intermediates (Cross, 1980; Duffey and Felton, 1991; Constabel, 1999), phenol oxidation (Schmid and Feucht, 1980), polysaccharide cross linking (Fry, 1986; Chitoor *et al*., 1999), cross linking of extension monomers suberization and lignification (Everdeen *et al*., 1988). The final product of such enzymatic activities would be anti-nutritive because they cannot be efficiently digested and assimilated by insects (Stout and Duffey, 1996; Constabel and Ryan, 1998).

5.8.15.3. Phenylalanine ammonia lyase (PAL)

The Phenylalanine ammonia lyase activity in the infested leaves was higher than the healthy leaves of the entries with varying in their levels of resistance. The maximum activity of PAL (9.62 ΔA/ min/g) was recorded in the mite infested resistant entry Thailand on 150 days after planting than other entries of tapioca. The moderately resistant entry CO (DB) 4 recorded moderately higher activity (6.84 ΔA/ min/g) of PAL enzyme next to resistant entry, while the activity was the least in susceptible Sri Reka (6.05) in infested plants.

Phenyl Alanine ammonia Lyase is inducible by wounding through herbivory, pathogens and abiotic stress. Increase in PAL activity was noticed after infestation of *Liriomyza trifoli* (Burgess) and *Bemisia tabaci* in *Pseudomonas fluorescens* treated plants (Murugan, 2003). Phenyl Alanine ammonia Lyase activity was found to increase in resistant varieties and hybrids of okra than the susceptible ones tested against Yellow Vein Mosaic (Nageswari, 2005). Vimala and Suriachandraselvam (2009) found pre inoculation spraying of salicylic acid in okra against powdery mildew pathogen showed increase in PAL activity from the time of treatment up to 7 days. An increased level of polyphenol oxidase and peroxidase was found in the resistant than in susceptible varieties infected with chilli mosaic leading to the formation of more quinine and other oxidative products (Singh *et al*., 2003; Jabeen *et al*., 2009).

The higher amounts of total phenols and ortho-dihydroxy phenols in the resistant wild type and hybrid were accompanied by increased activities of PPO and peroxidases, resulting in more oxidation of phenolic substances to form more toxic quinines and other oxidative products and these oxidative products might be the key to combat the mites in the resistant entry. On the other hand, lower amount of phenols and lower enzyme activities in the susceptible entry failed to produce toxic quinines and other oxidative product to that extent as found in resistant entries.

5.9. Evaluation of certain botanicals, entomopathogenic fungi (EPF), mineral oil and acaricides on rice leaf mite, *O. oryzae* on rice - Field experiment I

In first season, among the eight treatments, overall per cent reduction was high in fenazaquin (94.68%) followed by propargite (92.73%) and fenpyroximate (91.90%), the mineral oil was able to reduce the population by 81.36 per cent followed by neemazal, *B. bassiana* and *H. thompsonii* with reduced the population by 81.07, 80.84 and 80.27 per cent, respectively. The highest yield of 4.3 tonnes/ha was recorded in fenazaquin with 27.91 per cent increased yield over control. This was followed by propargite and fenpyroximate which recorded 22.89 and 19.69 per cent increase over control, respectively and the corresponding yield was 4.02 and 3.86 t/ha. Application of neemazal registered 14.36 per cent yield increase over the control followed by mineral oil (13.17

%). Fungal pathogens *viz., B. bassiana* and *H. thompsonii* recorded the lowest yield 4.91 and 3.13 per cent increase over control (Fig. 8).

In second season, among the eight treatments overall per cent reduction was high (94.81) in fenazaquin followed by propargite (93.65) and fenpyroximate (92.68). The *B. bassiana*, *H. Thompsonii* and mineral oil reduced the population by 87.80, 86.77 and 87.75 per cent, respectively. the highest yield of 4.82 tonnes/ha was recorded in fenazaquin followed by propargite and fenpyroximate which recorded 39.71 and 38.01 per cent increase over control and the corresponding yield was 4.76 and 4.63 t/ha (Table 42). Application of neemazal registered 27.16 per cent yield increase over control followed by mineral oil (20.28 %). Fungal pathogens *viz., B. bassiana* and *H. thompsonii* recorded the lowest yield 3.29 and 3.31 tonnes/ha, respectively (Fig. 9).

5.10. Effect of certain Botanicals, EPF, Mineral oil and Acaricides on two spotted spider mite, *T. urticae* on tapioca - Field experiment II

In first season, among the eight treatments overall per cent reduction was high (85.80%) in fenazaquin followed by propargite (83.44%) and fenpyroximate (80.98%). Neemazal reduced the population by 71.21 per cent, followed by fungal formulations 69.72 (*B. bassiana*) and 68.42 (*H. thompsonii*) per cent, respectively. The lowest per cent reduction was observed on mineral oil (67.73 %). The highest yield of 25.34 tonnes/ha was recorded in fenazaquin with 22.45 per cent increased yield over control. This was followed by fenpyroximate and propargite which recorded 21.05 and 19.99 per cent increase over control and the corresponding yield was 24.89 and 24.56 t/ha and they were on par with each other (Table 45). Application of neemazal registered 13.32 per cent yield increase over the control followed by mineral oil (12.63 %). Fungal pathogens *viz., B. bassiana* and *H. thompsonii* recorded lowest per cent increase of yield (6.78 - 8.56) over control (Fig. 10).

In second season, among the treatments overall per cent reduction was high (88.94%) in fenazaquin followed by propargite (87.88%) and fenpyroximate (85.55%). The mineral oil, neemazal, *H. thompsonii* and *B. bassiana* reduced the population by 74.76, 73.51, 70.58 and 71.22 per cent, respectively. The highest yield of 25.46 tonnes/ha was recorded in propargite with 21.21 per cent increased yield over control. This was followed by fenazaquin and fenpyroximate which recorded 19.98 and 18.72 per cent increase over control and the corresponding yield was 25.07 and 24.68 t/ha and are on par (Table 48). Application of neemazal registered 14.71 per cent yield increase followed by mineral oil (12.93 %) over the control. Fungal pathogens *viz., B. bassiana* and *H. thompsonii* recorded the lowest per cent increase on yield over control (6.39 and 9.11%) (Fig. 11).

Duchovskiene *et al*. (2008) conducted a study on the effect of two doses of biopesticide NeemAzal-T/S (a. i. 10 g/l *azadirachtin A*) on abundance of two-spotted spider mites (*Tetranychus urticae* Koch.) on ecologically grown carrot seed plants. The efficiency of NeemAzal-T/S 0.3 % was 25.29, 50.0 and 64.48 % – 3, 5 and 9 days respectively after application. The effect of NeemAzal-T/S 0.5 % was 36.78, 55.78 and 71.03 % – after 3, 5 and 9 days respectively.

Devi *et al*. (2008) conducted an experiment to study the efficacy of neem azal against red spider mite (RSM), *Oligonychus coffeae*, infesting tea in Manipur, India. The efficacy of neem azal against mites was 5.7 followed by 10.3 and 12.0 mites per leaf in sulfur and neem azal sprayed plots, respectively. The abundance of RSM was significantly low in all the chemical treated plots compared to the control. Neem azal at 5% was superior to that of sulfur and 3% neem azal.

Modern petroleum distilled spray oils (PDSOs) are highly refined, linear molecules with a range between 21 and 24 carbons, to combine good insecticidal efficacy with low phytoxicity. PDSOs have been found to be effective against numerous orchard pests including scales and mites (Beattie *et al.,* 1995; Beattie, 1990; Beattie and Smith, 1993), whiteflies (Larew and Locke, 1990; Liang and Liu, 2002), aphids (Najar-Rodríguez *et al.,* 2007), psylla (Zwick and Westigard, 1978; Weissling *et al.,* 1997), and fruit-feeding Lepidoptera (Davidson *et al.,* 1991; Al Dabel *et al.,* 2008).

Recent studies have also suggested new uses of PDSOs against a wider range of pests, such as the European corn borer, *Ostrinia nubilalis* Hubner (Lepidoptera: Pyralidae) in maize (Mensah *et al.,* 2005a, 2005b; Al Dabel *et al.,* 2008), *Helicoverpa spp*. in cotton (Mensah *et al.,* 2002, 2001), and the obliquebanded leafroller *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae) in orchards (Wins-Purdy *et al.,* 2009).

Nugroha and Ibrahim (2004) reported that, *B.bassiana* caused mortality up to 80 to 88 per cent at a dose 1 x 10^8 conidia per ml, while *M. anisopliae* and *P.fumosoroseus* caused 60 to 80 per cent mortality on *Polyphagotarsonemus latus* Bank, respectively. Wekesa *et al.* (2005) also found that, seventeen isolates of *M.anisopliae* and two isolates of *B.bassiana* were proved pathogenicity against the tobacco spider mite. *T.evansi* and caused mortality between 22.00 to 82.60 per cent.

Wei-Bing Shi *et al*. (2008) reported ten isolates of *B.bassiana, M.anisopliae, P. fumosoroseus* with different host insect origins were assayed for their biocontrol potential against the female adults of carmine spider mite *T.cinnabarinus* using a novel bioassay system, these three fungal concentrations resulted in the mite mortalities of 31.9 – 87.7% for *B.bassiana*, 24.2 – 80.3% for *M.anisopliae*, 19.4 – 77.7% for *P. fumosoroseus*, respectively.

In Surinam, Van Brussel (1975) found that the application of *H. thompsonii* prevented buildup and suppressed moderate populations of the citrus rust mite. In the field, *H. thompsonii* at the concentrations of a 0.025%, 0.05% and 0.1% spore mycelial suspension prevented the development of mite populations on citrus fruits during the dry season. Moreover, a spore-mycelial formulation at 0.05-0.1% could control citrus rust mites on fruit for at least 2 weeks in dry weather. Odongo et al. (1998) reported also that *H. thompsonii* applied at $1.2x10^{11}$ and $6.0x10^{10}$ conidia/ha induced mycosis and reduced field populations of the cassava mite, *Mononychellus tanajoa*.

Gerson *et al.* (1997) reported effect of *Hirsutella thompsonii* against *T. cinnabarinus* under various relative humidity conditions. The mortality was higher at 100 per cent RH and it decreased as the per cent RH decreases. The infection was also maximum at 100 per cent RH.

Aghajanzadeh *et al*. (2006) for studying the bioefficacy of six isolates of *Hirsutella thompsonii* Fisher a fungal pathogen of eriophyid mites collected from different agro-climatic regions of India, fungal suspension was sprayed on fruits and leaves infested with healthy citrus rust mite, *Phyllocoptruta oleivora* Ashmead and two spotted spider mite, *Tetranychus urticae* Koch. The results revealed that all isolates of *H. thompsonii* were effective against citrus rust mite. HtEMC isolate of *H. thompsonii* brought about maximum mortality of 48.05% ten days after treatment followed by HtCRMB (46.87%), HtCRMK (44.27%), HtCRMC (42.09%), HtPMG (39.82%) and HtPDBC (31.22%), however, this difference was not significant statistically. These isolates were also found to be effective against adult two spotted spider mite. HtEMC isolate of *H. thompsonii* brought about maximum mortality of 83.33% after eight days of treatment, followed by HtCRMB (70.85), HtCRMK (39.48), HtPMG (33.05), HtCRMC (31.86) and HtPDBC (19.64). The HtCRMB isolate of *H. thompsonii* was found to be effective against nymphal stage of the two spotted spider mite with 88.85% mortality six days after treatment.

The results were also in conformity with Sankar rao (2011), who conducted a field studies with acaricides against rice leaf mite revealed that, highest (97.57) per cent reduction in adult mite population was observed in the spiromesifen treatment which was followed by, propargite (92.91%) and fenzaquin (84.36%).

Kavitha *et al*. (2007a) reported that diafenthiuron 50 SC 450g ai/ ha was the most effective treatment which brought 96.08 mean per cent reduction in *T. urticae* population on bhendi and was on par with higher doses of fenazaquin and fenpyroximate which registered a mean per cent reduction of 93.43 and 92.72 per cent, respectively up to 15 days after second spray. Similar effect of fenpyroximate and fenazaquin was reported by Bhaskaran et al. (2007a and b) on bhendi and rose against *T. urticae*.

Studies of Jeyarani *et al*. (2007) revealed propargite (Indofil) 57 EC at 850 g ai/ha was the most effective acaricide against yellow mites in chillies which recorded a cumulative mean reduction of 72.19 per cent followed by propargite (Omite) 850 g ai/ha (70 %) and propargite 570 g ai/ha (65.78 %) after three rounds of spraying.

Vinoth Kumar *et al*. (2009) conducted a field trial on brinjal against two spotted spider mite and reported that, fenpyroximate 5 EC @ 0.8ml/lit and Propergite 57 EC @ 4ml/lit recorded a mean per cent reduction of 78.73 and 78.37, respectively.

Aswin (2015) conducted a field trial on rice against *O. oryzae* and reported that, fenazaquin recorded the highest reduction in mite counts of 97.10 per cent followed by spiromesifen (96.60), propargite (96.03), fenpyroximate (95.07), wettable sulphur (95.46) and standard check, dicofol (94.64). Among botanicals, highest reduction in mite population was recorded by azadirachtin (87.32 %) in comparison to neem oil (85.53%).