A review of the development of pesticide resistance on two-spotted spider mites -*Tetranychus Urticae*

Renuka Subramaniam[1,✦], Nadachi Kumarasami[1,✦], Jeyajothi Kalimuthu[2],Vinothkumar Natarajan[1,*]
[1]Department of Chemical Engineering, Mahendra Engineering College, Namakkal – 637503, India.

[2]Department of Petrochemical Engineering, Mahendra Institute of Engineering and Technology, Mallasamudram, Namakkal, Tamil Nadu – 637503, India.

✦These authors contributed equally to this work.

*Corresponding Author: Vinothkumar Natarajan

ABSTRACT

Developing effective solutions for controlling agro pests is a major challenge due to the severe destruction of various crops. The present review is focused on two-spotted spider mites, frequently referred as *Tetranychus urticae* affecting more than 1,100 plant species globally. Since *Tetranychus urticae* can able to grow in harsh climate conditions and able to feed various hosts lead to reduced photosynthesis area through a strong web development. Creation of formulations to control pests is more complex due to the rapid development of pesticide resistance and undesirable effects on various other species. Therefore, finding promising approach to develop highly efficient natural based formulations is required in the pest management. Hence, this review provides the challenges of pest management strategies to bridge the gap between pesticide resistance and unlocking the potential of various controlling methods.

Keywords: Two-spotted spider mites, Resistance development ability, Life cycle, Mortality, Fertility.

1. INTRODUCTION

Food is a cardinal source for the survival of living species which is an intricate system that directly influences the diet and fitness of a human being. Globally, the transformation of food is essential to clinch the delivery of fresh and nutritious foods in a reliable way [1]. The lack of healthy uptake of food leading to the nutrition deficiency and causes several deficiency-related diseases. According to a latter survey by Food and Agricultural Organization (FAO), around 13% of people face difficulties due to malnutrition. An adult human being requires at least an average of 2900 kcal/day to work efficiently. In many developed countries, the daily average consumption of food provides is about 3500 kcal, while in poor countries, people may not obtain even 2000 kcal/day, which is the major cause of undernourishment among them. A recent survey highlighted that 800 million people throughout the globe victim to health deficiency diseases [2]. Further, the survey stated that food production needs to be improved as double by 2050 to meet the increasing demand to the population growth [1,2].The path of agriculture plays a deliberate role in enhancing food availability and also paves the way to accomplish food security [3]. Due to the intensification in agriculture, it has also gradually caused an increase in the number of environmental issues related with excessive usage of fertilizers, pesticides, water etc [4]. Even though various pesticides are useful in controlling the pest it also has many major drawbacks that could cause serious issues in the society. Pests can be controlled using pesticides in the environment, but they also act upon other species which might cause serious side effects on non-target species. Pesticide residues may also contaminate water, soil and remain in the agricultural crops which will be later ingested by humans causing them health issues [5].

Agricultural pests are the major factor that restricts worldwide food production as they feed on plants and fruits which leads to the destruction of crops. Pests can be classified based on their level of destruction as stand reducers (damping-off pathogens), photosynthetic rate reducers (fungi, viruses, bacteria), leaf senescence accelerators (pathogens), light stealers (weeds, pathogens), assimilate sappers (nematodes, pathogens, sucking arthropods), and tissue consumers (chewing animals, necrotrophic pathogens) [5].

An increase in pest resistance is an emerging problem. Pests have demolished approximately 8-15% of wheat, rice, potato, soybean, and cotton production [6,7]. Another example is the devastation of rice fields in South Asia, by the brown plant hopper [8]. According to German authorities, pests and fungal pathogens each lead to a 10% production decrease in cereal yield. In potatoes, the pests have reduced the production rate by 5% whereas, in sugar beet, production was reduced by 10% [9].

In India, the effects and destruction of insect pests in agriculture have been evaluated periodically [10,11]. Several surveys conducted in the early 1960s reveal that fruits, cotton, and sugarcane have faced a production loss of 25%, 18%, and 10% respectively [12]. As the years passed on, during the early 2000s, there was a drastic increase in production loss due to the escalation in agriculture. The highest losses were identified in cotton (50%), followed by sorghum and millet (30%) [13]. Various studies have proved that early infestations of this pest resulted in high damage and yield loss in crops [14]. The losses of major crops due to pests are higher compared to other circumstances. During 2007-2008, pests have caused a loss of about US$ 21.5 billion in agricultural crops [13]. The two spotted spider mite for which the scientific name is known as *Tetranychus urticae* Koch, a member of the family *Tetranychidae,* is a common and an emerging pest as they attack several economically major crops such as cotton *(Gossypium hirsutum L.),* soybean (*Glycine* *max L.*), common beans (*Phaseolus vulgaris L.*), fruit trees and ornamental plants [15,16]. It has been discovered in all climate zones in Europe, Asia, and North and South America [17]. Its life span and population depends on a number of factors such as temperature, the type of plant host on which it occurs and the plants health [18,19]. However, under favorable conditions, its life span is said to be lower than 10 days [20,21]. On the other hand, the population of *Tetranychus urticae* is influenced by both biotic and abiotic factors likes temperature, humidity, etc.

The two spotted spider mite can affect more than 1100 plant species and approximately 140 distinct plant families [22, 23]. It can destroy mature green and breaker stages, and this causes massive losses in both the host plant and the economy [24]. The plant cells fluids are suck out and as the sharp mouth contain parts they can easily pierce the leaves of their host crops. They remove cellular contents from cells, which results in overall leaf discoloration which further causes the degradation of plant tissues if mites are not controlled [25, 26].

Smith et al., 2013 [27] investigated 8 dicotyledonous and 3 monocotyledonous species was henbit. The species Italian ryegrass, *Lolium perenne (L.) spp. Multiflorum (lam.),* found to be an irrelevant to be a host for *Tetranychus urticae*. It is one of the most well-known pests which quickly develop resistance to several pesticides of about 96 active ingredients due to its short developing time and high reproducing potential [28]. Hence, suitable alternatives are required to control this pest without increasing their ability to develop resistance.

This review is mainly focused to provide an overview of the factors that facilitate the rapid development of pesticide resistance, pest's life cycle, reproductive potential, and genetic adaptability. First, we discussed the biochemical and physiological mechanisms with descriptions of underlying resistance of mites, including target site modifications, metabolic detoxification, and cross-resistance phenomena. Second, we summarized the current pest management strategies, encompassing biological controls such as predatory mites, chemical controls with modern acaricides, and alternative approaches like botanical formulations and ovicidal activities. To focus on the main scope of the review, we discuss in detail the pesticide resistance in *Tetranychus urticae* to progress the implementation of materials in pest control management.

2. Life cycle of two-spotted spider mites

Approximately 7500 species were found together with the *Tetranychidae,* which is a giant family with 1300 species and creates health issues in humans by a survey as shown in Fig.1 [28, 29]. These belong to the family of spider mites and they can produce silk webs. A scenario of agricultural pests and their target crops are summarized in Table 1.The length of spider mites is 1mm and the existence cycle includes 5 developmental stages, such as egg, larva, protonymph, Deutonymph, and adult. Two-spotted spider mites are tinier (0.25 to 0.5 mm long) eight-legged arachnids with two massive spots on both sides of the body and the major crops losses due to mites is shown in Table 2. Mites are usually spotted on the lower sides of leaves however may additionally colonize complete flora at some point of outbreaks. Silk webbing on the bottom of leaves, and bronzing, stippling, and burning of leaves are characteristic signs of spider mites [29]. The life cycle of female mites in mint fields begins with overwintering in the soil and plant particles. During the spring, as temperatures rise, the females become active and start laying eggs on the undersides of leaves. The eggs usually emerge from their shells in around 4 to 5 days. Total loss in crop and livestock production, during 2008 –2018, at some regions is plotted in Fig.2. The complete life cycle, spanning from egg to adulthood, exhibits varying durations and can extend from 1 to 3 weeks, influenced by temperature conditions. This cycle highlights the seasonal and temperature-dependent nature of the mites' reproductive and developmental processes in mint fields. Infestations of mites may additionally manifest as early as March during hot weather. During the summer time, mite populations can extend very quickly, especially in hot, dry weather, during periods of water stress, and even in response to insecticide applications. Therefore, fields ought to be inspected at least weekly to detect the buildup of negative populations [29, 30]. Among various species (*Lamium amplexicaule L*. as the relevant host for mites as shown in Fig.3.

The life cycle of *Tetranychus urticae* consist of the egg, larvae, quiescent larva, protonymph, quiescent protonymph, deutonymph, quiescent deutonymph, and sexually mature individuals: males and females, it’s feeding and damages are depicted in Fig.4. The lifespan of these mites is relatively short, lasting about 8–12 days when the temperature is around 30 °C and approximately 17 days at a cooler temperature of 20 °C as shown in Fig.5a. Despite the brief individual life span, the mites are highly prolific, with the potential for over 20 generations to develop annually. However, it's important to note that external conditions may limit the actual number of population cycles that occur, as certain environmental factors could impact the mites' ability to reproduce and complete their life cycle as given in Fig.5b [31]. Overwintering may occur on many hosts in warm-winter climates, and in bloodless winter areas forage legumes and greenhouses often have these pests, however, adult two-spotted spider mite females also pass the winter beneath the leaves or different natural particles in a state of diapauses. The development time of the immature stages is 4–5 days at 30–32 °C but is prolonged to about 16–17 days when the temperature is 15°C at night time and 28 °C during the day [30]. The effects of *T. urticae* on crops in various states of India are listed in Table 3.

2.1 Eggs

The eggs are in orbicular shape and transparent (Food and Agriculture Organization, 2020).They measure about 0.10–0.15 mm in diameter. They are frequently deposited on the decreased floor of foliage, however the upper, and the leaf surfaces are shielded with a filament of silk. Females lay 5–6 eggs per day, for a complete of 60–120 eggs. The duration of the egg stage is about 3 days at 30°C and 6–7 days at 20 °C [31].

2.2 Larvae

The larvae are diminished and inexperienced in coloration and have six legs (Food and Agriculture Organization, 2020).

2.3 Nymph

There are two nymphal instars the protonymph and the deutonymph. These levels are effortlessly separated from the larva due to the fact they bear four pairs of legs. They tend to be green or red. As in the larval stage, the terminal portion of each nymphal length is a non-feeding duration called the deutochrysalis and teliochrysalis, respectively. The duration of each instar is 1–2 days at 30°C and about three days at 20 °C [31].

2.4 Adults

The eight-legged grownup stage is greenish with darker pigmentation laterally. Banks grass mite Is pretty similar to the two-spotted spider mite in appearance, but it has dark pigmentation basically in the anterior half of the body whereas, in *O. pratensis* the pigmentation extends back to the posterior tip of the body. Banks grass mite is slightly smaller and its physique is more flattened than the two-spotted spider mite. Banks grass mite measure about 0.4 mm long, with the females averaging larger, while the males are smaller. The abdomen tapers to a factor in males whereas, in females, it is bluntly rounded. Overwintering types are orangish or pinkish. Adults Live for about 7-23 days under warm conditions, and up to 48 days under cool conditions. The pre-ovation length is only 1-2 days, with the top ovipositor at about the sixth day and a regular decrease after that. Females produce 7-14 eggs per day, with a total fecundity of 75 to hundred and fifty eggs [32].

3. RESISTANCE DEVELOPMENT IN *TETRANYCHUS URTICAE*

An organism can develop resistance to pesticides by modifying the target site or by reducing the dose of pesticide in the target site. The binding of pesticide to its target protein can be reduced directly by target site modification; over 90% of resistant developing cases are caused by target site resistance and metabolic resistance [33-35]. Other than the two resistances cross-resistance also occurs when an organism with resistance to a single acaricide shows resistance to other acaricides without major contact [33].

It has the ability to develop resistance to chemicals in a very short span of time [33, 36,37]. The development of resistance is highly associated with its short life cycle, high reproduction rate, and arrhenotokous reproduction [38]. This factor increases the resistance development in it, especially in warmer condition [39]. It develops strong resistance to many acaricides within 1-4 years of use and it also develops a high degree of cross-resistance and a high mutation rate [40,41]. The development of organo-phosphate resistance by *Tetranychus urticae* was initially found in early 1948 at rose greenhouses in the Eastern United States and in 1991 it has been recorded that it exists in over 40 countries in both the fields and greenhouse crops [42,43]. Two-spotted spider mites also develop resistance to milbemycin [44] and a close analog of avermectins[45].

It has extremely high resistance to old pesticides like abamectin and has low to moderate levels of resistance to newly formulated pesticides namely chlorfenapyr, cyenopyrafen, spinetoram, bifenazate, B-alemiteacrylic [46]. The above result shows that, it *has* developed more resistance to old pesticides than newly formulated ones. An experiment conducted by H.R. Smissaert shows that the op's resistance is developed due to the decrease in the sensitivity to organophosphate at cholinesterase in the strain of two spotted spider mites [47]. The experiment results showed that they find eight single nucleotide polymorphisms (SNP'S) which are all related to mono crotophos resistance, in which a moderate level of resistance is conferred by A391T mutation and a high level of resistance is conferred by G228S and F439W mutations [48-50].

4. Various methods to control spider mites

Several investigations on the control of two spotted spider mites revealed that the growth of pest resistance through generations. For example, it has been dominated the cotton plantations in Australia during 1976-1995 [50-53]. The chemical demeton-S-methyl was used to control the pests in Australia and Dicofol was also used which was later observed that it was less effective than demeton-S-methyl and was not recommended after 1970. *Beauveria bassiana (Hypocreales: Cordycipitaceae),* has been used as a pathogen for various mites species that helps to reduce the populations [54-57]. In this review, some of the methods available to decrease the abnormal increase in the resistance of two-spotted spider mites against pesticides and summarized what further approaches are required to overcome this crisis.

4.1 Biological Control

The use of chemical pesticides to combat two spotted spider infestations is widespread, yet it poses several challenges. Apart from developing the tendency to resist against the targeted pest they also cause significance risk towards the environment and human health. Regulatory bodies, such as the Food Quality Protection Act (FQPA) of 1996, have been established to address these concerns [57-60]. Consequently, there is a growing demand for alternative pest control methods, with biological control emerging as a promising solution. Among biological control agents, the predatory mite *Phytoseiulus persimilis* has demonstrated remarkable efficacy against two spotted spider mites across various crops [60-62]. However, *P. persimilis* is highly susceptible to commonly used acaricides and fungicides and struggles to survive in temperate climates [63, 64]. In contrast, *Neoseiulus californicus* (McGregor) has proven to be more resilient in temperate Mediterranean climates compared to *P. persimilis*. Consequently, its use as a biological control agent is gaining popularity, particularly in the southeastern United States [65-67].

The *Phytoseiidae* family of mites has been the subject of considerable research over the past four decades due to their potential as natural enemies of *phytophagous* mites. These predatory mites have garnered attention for their ability to control populations of spider mites, which belong to the *Tetranychidae* family. Despite extensive study, there has been ongoing debate regarding the effectiveness of these predators in managing spider mite populations [68-70].The study found that P. *macropilis* tends to remain in crops even when the population of two-spotted spider mites is low, whereas *N. californicus* stays active for longer periods under similar conditions. This behavior suggests potential variations in their effectiveness as biological control agents under different environmental circumstances [71, 72].

The two predators of two spotted spider mites namely P. macropilis and N. californicus in the same host plant shows that the death rate of P. macropilis protonymphs as 62% on the third day in the absence of food and the amount of N. californicusprotonymphs still live after fourth day as 67% this is due their alternative food source [73]. So, it is much more resistant than P. macropilisthis experiment shows that P. macropilis and N. californicus do not avoid each other when introduced in same host plant of T. urticae[73-75]. An experiment conducted by Yvonne M. van Houten, Hans Hoogerbrugge & Karel Bolckmans using commercially available phytoseiid mite species with different life-styles namely Phytoseiulus persimilis, Neoseiuluscalifornicus, Amblyseius swirskii and Amblyseius andersoni shown that N. californicus can be regarded as a promising candidate for spider mite control throughout the season: it also showed good reproduction capacities, even at 15°C and was not hampered by the webbing [76].

Many fruit, vegetables and leafy vegetables are consumed without peeling and cooking [77], hence the occurrence and distribution of chemical pesticides in such a type of plant can cause many health risks for consumers who intake those vegetables [78]. Chemical pesticides can cause metabolic disease, infertility, cancer and also, they affect immune system and neurodevelopment [79, 80]. Hence synthetic or chemical pesticides can be replaced by Botanical pesticides due to the lower risk for humans and animals. Botanical pesticides are chemical derivatives that act as repellents, growth inhibitors and also as antifeedants, these derivatives occur naturally from plants [81, 82].

4.2 Chemical Control

The predominant approach to managing spider mites in Brazilian strawberry crops involves chemical control. The effects of azadirachtin on two spotted spider mites *(Acari: Tetranychidae*) and its compatibility with predatory mites (Acari: *Phytoseiidae*) on strawberry concluded that the conservation of biological control mainly relay on the usage of azadirachtin especially in the preservation of existing natural enemies, which is essential for the control of *T. urticae* in the strawberry crop [80, 84]. This would minimize insecticide/ acaricide applications and consequently, the selection of resistant spider mite populations and fruit contamination. However, the intensive use of acaricides has been compromising the effectiveness of the chemicals, in particular through the development of resistance in several countries [85-89].

4.3 Ovicidal Activity of T. urticae

Many studies have shown that certain plant species exhibit the potential to be used to control two-spotted spider mites. For example, the extract of *S. meifolia* showed highest egg mortality of 45.84% followed by *A. orientale* leaves of 41 .40% and *T. elliptica* with 40.11% whereas the least egg mortality was observed with the leaves of *D. viscose* [90-92]. However, further researches are required to test the efficacy of these extracts in order to control insect pests and mites.

A combination of thymol and menthol has shown a higher potential in the management of *Tetranychus urticae* [93]. On the other hand, Yanar et al., 2011 conducted experiments with several plant extracts as shown in Fig.6, in which the greatest egg mortality was observed in river red gum *E. camaldulensis* leaf extract of 63.26% at 10% concentration and among different extracts of flowers and leaves of *L. perenne* recorded the least mortality rate of 24.40% [94]. Similarly, the leaves of French marigold from which its extracts had both ovicidal and repellent effects against two-spotted spider mites and the results after 24, 48, and 73 hrs were recorded [95-96].

4.4 Neem Formulation

Azadirachtin is the major active ingredient of neem, it causes many harmful effects on arthropods, they reduce fertility, oviposition and increase mortality to the insects [97-99]. Low toxicity to humans and low persistence due to photodegradation makes the neem-based products to be used against pest [100-102]. Its population in parsley plants can be controlled by neem-based products with slight phytotoxic symptoms [103-105]. Neem-based products cause behavior and physiological effects on arthropods, thus the exposition of individuals to sub-lethal concentrations over time is expected to show negative toxicological effects that are not detectable in short time lethal toxicity assays [106-108]. An experiment conducted to control two spotted sider mites using two commercial neem formulations namely Neemros and Neemroc and two experimental formulations such as alcoholic extract (1 % *azadirachtin*) and Neemroc Combi, an *azadirachtin*-enriched oil formulation (0.5 % *azadirachtin*) showing that, it can be controlled by neem formulation on tomato [109-111]. Especially the formulation with higher neem oil (Neemroc EC) content shows more potential to *T. urticae* than all other pure formulations [112]. An Experiment conducted by Dimetry et.al.,1993 [113] also showed that the increase in the concentration of three neem-based products namely *Azamax*, *Neemseto* and Organic neem decrease the instantaneous rate of population growth of two spotted spider mites was linearly. Major neem-based products used as pesticide are Azal-S and Margosan-0 likewise an experiment conducted by (Dimetry et al., 1993) can be concluded that both *Neem azal-S* and *Margosan-0* are effective in decreasing the population of mites but still, *Neem azal-S* is more efficient than margosan-0 as it exhibited greater toxicity, decreased the egg production of the females and decreased the fertility of the eggs.

Various plant-based extracts, in addition to neem, have demonstrated significant acaricidal properties against *Tetranychus urticae.* Among these, the hydroethanolic extract of *Matricaria chamomilla L*. (commonly known as chamomile) and the aqueous extract of *Pimpinella anisum L*. (anise) have been found to exhibit potent effects on *T. urticae* females, achieving mortality rates exceeding 83%(114). Another effective extract is the hydroethanolic formulation of *Origanum vulgare L.* (oregano), which causes at least 75% mortality, showcasing its potential as a natural acaricide (115). Further research has highlighted the efficacy of other plant extracts such as *Chenopodium album* (lamb's quarters), *Conium maculatum* (hemlock), *Anthemis vulgaris* (wild chamomile), and *Lolium perenne* (perennial ryegrass), all of which have demonstrated over 90% mortality within 24 hours of application (116). Additionally, crude tomato leaf extracts have also been utilized to manage spider mite populations effectively (117). These findings underscore the diverse array of botanical alternatives that can be employed to control *T. urticae* while mitigating the environmental and health risks associated with synthetic acaricides. Further studies are needed to optimize the formulations and application methods of these extracts to enhance their practicality and efficiency in integrated pest management systems.

5. CONCLUSION

The short life cycle, high reproductive rate, and arrhenotokous reproduction of two spotted spite mites are strongly associated with the development of control resistance. The most effective method for controlling is ovicidal activity since it not only reduces egg mortality but also stops the growth of the resistance. However, the applicability of this approach is quite expensive owing to the need for various specialized pesticides and associated equipments. Further research on lowering the cost of this method (ovicidal activity) may increase usage in the agricultural field among farmers. Even though the other mentioned methods listed have a variety of applications, but they also carry several disadvantages to health and environment. For example, Chemical based control has several drawbacks because it can lead to infertility, cancer, diarrhea, etc., when it is consumed. An alternative method that can be used to decrease the fertility of this pest is exposure to heat waves. Some studies have proved that exposing two spotted spider mites to extremely high temperatures significantly reduce their chances of fertilization that can be a very useful method since exceptionally high temperatures avoid the development of resistance in the next generation of species. Further research on this method could reveal a potential solution to the resistance development in *Tetranychus urticae*.

Funding

There is no funding agency to report for this study.

Conflict of Interest

The authors declare that they do not have any conflicts of interest.

Authors contribution

Renuka Subramaniam (Assistant Professor) and Nadachi Kumarsami (Assistant Professor) contributed equally to the manuscript conceptualization, preparation and wrote the manuscript. Jeyajothi Kalimuthu revised the manuscript. Vinothkumar Natarajan (Associate Professor) revised, edited, corrected and conceptualized the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Tilman, D., Balzer, C., Hill, J., Befort, B. L. 2011. Global Food Demand and the Sustainable Intensification of Agriculture. Proceedings of the National Academy of Sciences of the United States of America, 108, 20260–20264.
2. Foley,J. A. 2011. Solutions for a cultivated planet. Nature, 478, 337–342.

3. Smutka, L., Steininger, M., Miffek, O. 2009. World agricultural production and consumption. AGRIS on-line Papers in Economics and Informatics, 1, 3–12.

4. Bockstaller, C., Laurence, G., Olivier, K., Philippe, G., Marie-Beatrice, G., Gerard, G. 2009. Comparison of methods to assess the sustainability of agricultural systems. A review. Agronomy for Sustainable Development, 29, 223–235.

5. Boote, K. J., Batchelor, W. D., Jones, J. W., Pinnschmidt, H., Bourgeois, G. 1993.In Systems Approaches for Agricultural Development.277-296.

6. Oerke, E. C. 2006. Crop losses to pests. Journal of Agricultural Science, 144 (1), 31–43.

7. Pimentel, D., Zuniga, R., Morrison, D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics, 52, 273–288.

8. Kenmore, P. E., Carino, F. O., Perez, C. A., Dyck, V. A., Gutierrez, A. P. 1984. Population regulation of the rice brown planthopper (NilaparvatalugensStal) within rice fields in the Philippines. Journal of Plant Protection in the Tropics, 1, 19–37.

9. Morstatt, H. 1929. Bibliography of plant protection literature for the year 1929. Berlin-Dahlem, 9, 433–477.

10. Singh, T. V. K., Satyanarayana, J.,Peshin, R. 2014. Integrated Pest Management. Pesticide Problems, 3, 227–243.

11. Koul, O., Dhaliwal, G. S., Cuperus, G. W. 2004. Integrated pest management: potential, constraints and challenges. CABI Publishing, 329.

12. Pradhan, S. 1964. Assessment of losses caused by insect pests of crops and estimation of insect population. Entomology in India, 17-58.

13. Dhaliwal, G., Jindal, V., Dhawan, A. 2010. Insect pest problems and crop losses: changing trends. Indian Journal of Ecology, 37(1), 1–7.

14. Reddall, A.,Sadras, V. O., Wilson,L. J.,Gregg, P. C. 2004. Physiological responses of cotton to two-spotted spider mite damage. Crop Science, 44, 835–846.

15. Milenovic, M., Wosula, E. N., Rapisarda, C., Legg, J. P. 2019. Impact of host plant species and whitefly species on feeding behavior of Bemisiatabaci. Frontiers in Plant Science, 10.

16. Iamba, K.,andDono, D. 2021. A Review on Brown Planthopper (NilaparvatalugensStål), a Major Pest of Rice in Asia and Pacific. Asian Journal of Research in Crop Science, 7–19.

17. Wehner, T. C.,andGuner, N. 2004. Growth stage, flowering pattern, yield, and harvest date prediction of four types of cucumber tested at 10 planting dates.International Society for HorticulturalScience, 637, 223–229.

18. Gupta, S., and Dikshit, A. K. 2010. Biopesticides: An ecofriendly approach for pest control. Journal of Biopesticides, 1, 186–188.

19. Peter, A. E. 2022. Field Crop Arthropod Pests of Economic Importance. Agriculture and biological science. Academic Press. 140-207.

20. Multani, J. S.,andSohi, A. S. 2001. Management of Helicoverpaarmigera (Hubner) on carnation (Dianthus caryophyllus Linn.). Pestology, 25, 44–45.

21. Chandra, B. K. N., and Rai, P. S. 1974. Two new ornamental host plants of Heliothisarmigera Huebner in India. Indian Journal of Horticulture, 31(2),198.

22. Gahukar, R. T. 2002. Population dynamics of Helicoverpaarmigera. Journal of Entomological Research 26(4), 265-276.

23. Lowe, A. D. 1969. A preliminary account of macrosiphum miscanthi takahashi on grasses and cereals in New Zealand. New Zealand Entomologist, 4, 33–35.

24. Gautam, M. P. 2018. Diamondback moth, Plutellaxylostella (Linnaeus) (Insecta: Lepidoptera: Plutellidae) a major insect of cabbage in India: A review. Journal of Entomology and Zoology Studies, 6, 1394–1399.

25. Liang, A. P. 1997. Sugarcane and rice leafhoppers of the genus Pyrilla STAAL in southern China (Insecta: Homoptera: Auchenorrhyncha: Lophopidae). Reichenbachia, 32(7):33-9.

26. Mardi, G., Pandey, A. C., Kumar, S. S. 2009. Occurrence and management of rice gall midge in transplanted rice (Orseoliaoryzae Wood Mason). Ecology, Environment and Conservation,15, 361–365.

27. Smith, J. F., Catchot, A. L., Musser, F. R., Gore, J. 2013. Survey of twospotted spider mite host plants in the Mississippi delta. Journal of Entomological Science, 48, 291–298.

28. Migeon, A., Nouguier, E., Dorkeld, F. 2010. Spider Mites Web: A comprehensive database for the Tetranychidae. Trends in Acarology, 557–560.

29. Hollingsworth, C. S.,and Berry, R. E. 1982. Regression Sampling Plan for Twospotted Spider Mite (Acari: Tetranychidae) in Oregon Peppermint. Journal of Economic Entomology,75, 497-500.

30. Capinera, J. L. 2020. Handbook of Vegetable Pests. 2nd Edition, Academic Press, 601–624.

31. Broughton, S. (2013). Mites in citrus. Agriculture and Food. Government of Western Australia: Department of Primary Industries and Regional Development. Available at: https://www.agric.wa.gov.au/citrus/mites-citrus?nopaging=1 (accessed on: 13.09.205).

32. Jeppson, L. R., Keifer, H. H.,Baker, E. W. 1975. Mites injurious to economic plants. Berkeley: University of California Press, 614.

33. Grbić, M., Cokus, S., Johnston, J. S., Stevenson, B. 2011. The genome of Tetranychus urticae reveals herbivorous pest adaptations. Nature, 479, 487-492.

34. Rioja, C., Zhurov, V., Bruinsma, K., Grbić, M., Grbić, V. 2017. Plant-herbivore interactions: A case of an extreme generalist, the two-spotted spider mite Tetranychus urticae. Molecular Plant-Microbe Interactions, 30, 935-945.

35. Duso, C., Kreiter, S., Tixier, M.-S., Pozzebon, A.,Malagnini, V.2010. Carpinusbetulus: Insights from host-switch experiments and molecular data. In Trends in Acarology pp. 399-407.

36. James, D. G., and Prischmann, D. 2010. Mites in Washington States vineyards and hop yards. In Trends in Acarology pp. 477-482.

37. Domingos, C. A., Melo, J. W. S., Oliveira, J. E. M., Gondim, M. G. C. (2014). Mites on grape-vines in northeast Brazil: Occurrence, population dynamics, and within-plant distribution. International Journal of Acarology, 40, 145-151.

38. Rotem, K. A., and Agrawal, A. A. 2003. Density dependent population growth of the two-spotted spider mite, Tetranychus urticae, on the host plant Leonuruscardiaca. Oikos, 103, 559-565.

39. Yang, H., Yan-Chao, Z., Wen-Nan, Y., Shou-Ming, W., Xin, W., Cong-Fen, G. 2024. Increasing resistance of Tetranychus urticae to common acaricides in China and risk assessment to spiromesifen. Crop Protection, 176, 106519.

40. Kerns, D., Lorenz, G., Catchot, A. 2009. Spider mite biology and ecology. In Proceedings, Beltwide Cotton Conferences, 1532-1534.

41. Wybouw, N., Van Leeuwen, T., Vontas, J., Clark, S. 2012. A horizontally transferred cyanase gene in the spider mite Tetranychus urticae is involved in cyanate metabolism and is differentially expressed upon host plant change. Insect Biochemistry and Molecular Biology, 42, 881-889.

42. Murúa, G., Molina-Ochoa, J., Coviella, C. 2006. Population dynamics of the fall armyworm, Spodopterafrugiperda and its parasitoids in northwestern Argentina. Florida Entomologist, 89(2), 175-182.

43. Bensoussan, N., Migeon, A., R. A. 2016. Plant-herbivore interaction: Dissection of the cellular pattern of Tetranychus urticae feeding on the host plant. Frontiers in Plant Science, 7.

44. Fasulo, T. R., and Denmark, H. A. 2003. Twospotted Spider Mite,Red spider mite Koch (Arachnida: Acari: Tetranychidae) EENY150/IN307, 8/2000. EDIS, 15.

45. Shukla, A., Radadia, G. G., Hadiya, G. D. 2017. Estimation of loss due to two-spotted spider mite, Tetranychus urticae Koch infesting brinjal. International Journal of Current Microbiology and Applied Sciences, 6, 2145–2150.

46. Prakash, J., Bhaskar, H., Mathew, D., Vidya, C. V., Gowda, C.,Shylaja, M. R. 2022. Diversity of spider mites on ornamental plants in Central Kerala. Indian Journal of Entomology, 8, 82–87.

47. Singh, S. K., Verma, P., Kumar, A.,Gupta, S. 2018. Seasonal incidence and management of red spider mite, Tetranychus urticae Koch on okra, Abelmoschus esculentus (L.) Moench. Journal of Entomology and Zoology Studies, 6, 650-656.

48. Sangavi, R., Radadia, G. G., Shukla, A. 2020. Population dynamics of two-spotted spider mite, Tetranychus urticae (L.) on cowpea in relation to weather parameters. Journal of Entomology and Zoology Studies, 8(5), 554–558.

49. Isaac, M. K., and Kennedy, J. S. 2018. Assessment on the incidence of two-spotted mite of jasmine, Tetranychus urticae Koch, and its natural enemies in Tamil Nadu. International Journal of Acarology, 44, 162–170.

50. Borkar, A. N., Kolhe, A., Undirwade, D. 2020. Biology and life studies of Tetranychusmacfarlanei on okra. Journal of Entomology and Zoology Studies, 8, 2411–2415.

51. Gupta, S. K. 1991. Mites of agricultural importance in India and their management. All India Coordinated Research Project on Agricultural Acarology. Bulletin of the Indian Council of Agricultural Research, New Delhi.509-522.

52. Ghongade, D. S., and Sood, A. K. 2018. Diversity and seasonal abundance of tetranychid mites in polyhouses in Himachal Pradesh. Indian Journal of Entomology, 80(4), 1688–1695.

53. Sharma, A., and Pati, P. K. 2012. First record of the carmine spider mite, Tetranychus urticae, infesting Withania somnifera in India. Journal of Insect Science, 12(15), 1-4.

54. Whalon, M. E., Mota-Sanchez, D., Hollingworth, R. M. 2008. Global pesticide resistance in arthropods. Global Pesticide Resistance in Arthropods, 1–169.

55. Walgenbach, J. F. 2018. In Sustainable Management of Arthropod Pests of Tomato. Academic Press. 323–339.

56. Migeon, A., Nouguier, E., Dorkeld, F. 2010. Spider Mites Web: A comprehensive database for the Tetranychidae. Trends in Acarology, 557–560.

57. Jeppson, L. R., Keifer, H. H., Baker, E. W. 1975. Mites Injurious to Economic Plants. University of California Press, 614.

58. Ryosuke W., Yuki S., Satoshi K., Nobusuke I., Hitoshi I. 2024. Investigation to answer three key questions concerning plant pest identification and development of a practical identification framework,Computers and Electronics in Agriculture, 222, 109021.

59. Dittrich, V. 1975. Acaricide resistance in mites.The Journal of Applied Entomology, 78(1–4), 28–45.

60. David, A. K., Juan, A.M., Douglas, J. F., Amanda E. M. 2025. Invertebrate diversity is shaped by farm management, edge effects and landscape context in the Prairie Pothole Region of Canada. Agriculture, Ecosystems & Environment 377, 109194.

61. Knowles, C. O. 1997. Mechanisms of resistance to acaricides. In Sjut, V., Molecular Mechanisms of Resistance to Agrochemicals, Chemistry of Plant Protection, 13, 57–77.

62. Van Leeuwen, T., Vontas, J., Dermauw, W. 2008. Mitochondrial heteroplasmy and the evolution of insecticide resistance: Non-Mendelian inheritance in action. Proceedings of the National Academy of Sciences of the United States of America 105, 5980–5985.

63. David, G.J., and Deirde, P. 2010. The impact of sulfur on biological control of spider mites in Washington State vineyards and hop yards. Trends in Acarology, 477-482.

64.Domingos, C. A., Melo, J. W. S., Oliveira, J. E. M., Gondim, M. G. C. 2014. Mites on grape-vines northeast Brazil: Occurrence, population dynamics within-plant distribution. International Journal of Acarology, 40, 145-151.

65.Rotem, K. A., Agrawal, A. A. 2003. Density dependent population growth of the two-spotted spider mite, Tetranychus urticae, on the host plant Leonurus cardiaca. Oikos, 103, 559-565.

66.Fatemeh B., Seyed H. G., Mahmoud S. 2024. Evaluating dispersal ability of Venturia canescens Gravenhorst (Hymenoptera: Ichneumonidae) using natural abundance technique and geostatistics. Crop Protection, 176, 106499.

67.Kerns, D., Lorenz, G., Catchot, A. 2009. Spider mite biology and ecology. Proceedings, Beltwide Cotton Conferences,1532-1534.

68.Wybouw, N., Martel, V., Danchin, E. G. J., Schiffer, M., Geuverink, E., Grillenberger, B. K., Posthuma, L., Richard, M., Koelewijn, H. P., Koffmann, D., Smant, G., Bakker, F. T. 2012. A horizontally transferred cyanase gene the spider mite Tetranychus urticae is involved cyanate metabolism and is differentially expressed upon host plant change. Insect Biochemistry and Molecular Biology, 42, 881-889.

69.Murúa, G., Molina-Ochoa, J., Coviella, C. 2006. Population dynamics of the fall armyworm, Spodoptera frugiperda and its parasitoids northwestern Argentina. Florida Entomologist, 89(2), 175-182.

70. Santamaria, M.E., Arnaiz, A., Rosa-Diaz, I., González-Melendi, P., Romero-Hernandez, G.,Ojeda-Martinez, D.A., Garcia, A., Contreras, E., Martinez, M., Diaz, I. 2020. Plant Defenses Against Tetranychus urticae: Mind the Gaps. Plants 9, 464.

71.Vacante, V. 2016. The Handbook of Mites of Economic Plants: Identification, Bio-Ecology and Control; CABI International: Wallingford, UK.

72. Talent, N., Rémi, C., Regis, C., Marc, C., Joyful, T. R., Stanford, M., Aude, R. 2024. Do intercropping and mineral nitrogen fertilizer affect weed community structures in low-input maize-based cropping systems?. Crop Protection, 176, 106486.

73. Antonious, G.F., Snyder, J.C. 2015. Repellency and oviposition deterrence of wild tomato leaf extracts to spider mites, Tetranychus urticae Koch. Journal of Environmental Science and Health, Part B 50, 667–673.

74. Lucini, T., Faria, M.V., Rohde, C., Resende, J.T.V., Oliveira, J.R.F. 2015. Acylsugar and the role of trichomes in tomato genotypes resistance to Tetranychus urticae. Arthropod Plant Interactions. 9, 45–53.

75.Kielkiewicz, M., van de Vrie, M. 1990. Within-leaf differences in nutritive value and defense mechanism in chrysanthemum to the two spotted spider mite (Tetranychus urticae). Experimental and Applied Acarology 10, 33–43.

76. Stahl, E., Hilfiker, O., Reymond, P. 2018. Plant-arthropod interactions: Who is the winner? Plant Journal. 93, 703–728.

77.Easterbrook, M. A. 1992. The possibilities for control of two-spotted spider mite Tetranychus urticae on field-grown strawberries in the UK by predatory mites. Biocontrol Science and Technology, 2, 235–245.

78.Rhodes, E. M., and Liburd, O. E. 2019. Predatory mite, Neoseiuluscalifornicus . 78-79

79.Liburd, O. E., Seferina, G. G., Dinkins, D. A. 2003. Suppression of twospotted spider mites. University of Florida, Institute of Food and Agricultural Sciences Ext. Newsl. Berry/Vegetable Times, 3, 3–4.

80.Gillespie, D. R., Quiring, D. J. M., Greenwood, M. 1997. Collection and selection of natural enemies of twospotted spider mites for biological control. Journal of the Entomological Society of British Columbia, 94, 7–12.

81. Aline, M. P., Tairis, Da-Costa., Amanda, J. M., Eduardo, M. E., Bárbara, B., Geraldo, L. G. S., Noeli, J. F. 2024. The use of essential oils as an alternative for the control of Tetranychus urticae (Acari: Tetranychidae). Crop Protection,184,10686.

82. Priyanka, G., Tridip, P., Ratul, S. 2024. Systemic resistance induced by plant growth-promoting rhizobacteria in Bhut Jolokia (Capsicum chinense Jacq.) suppressed the collar rot disease, Scientia Horticulturae, 324, 112625.

83.Moloi, M.J., van der Westhuizen, A.J. 2006. The reactive oxygen species are involved in resistance responses of wheat to the Russian wheat aphid. Journal of Plant Physiology 163, 1118–1125.

84.Borkar, A. N., Kolhe, A., Undirwade, D. 2020. Biology and life studies of Tetranychusmacfarlanei on okra. Journal of Entomology and Zoology Studies, 8, 2411–2415.

85. Hata, F.T., Bega, V.L., Ventura, M.U., dos Santos, F., Poloni da Silva, J.E., Machado, R.R., Sousa, V. 2020. Plant acceptance for oviposition of Tetranychus urticae on strawberry leaves is influenced by aromatic plants in laboratory and greenhouse intercropping experiments. Agronomy 10, 193.

86.Simerjeet, K., Ramanjit, K., Bhagirath, S. 2018. Understanding crop-weed-fertilizer-water interactions and their implications for weed management in agricultural systems,Crop Protection, 103, 65-72.

87.Xu, D., Zhang, Y., Xie, W., Wu, Y., Jiang, L., Zhao, J., Guo, X., Li, J., Chen, L., Zhang, H. 2018. Status of pesticide resistance and associated mutations in the two-spotted spider mite, Tetranychus urticae, in China. Pesticide Biochemistry and Physiology, 150, 89–96.

88.Smissaert, H. R. 1964. Cholinesterase inhibition in spider mites susceptible and resistant to organophosphate. Science, 143, 129–131.

89.Kwon, D. H., Kim, Y. S., Park, Y. I., Kim, J. Y. 2010. Acetylcholinesterase point mutations putatively associated with monocrotophos resistance in the two-spotted spider mite. Pesticide Biochemistry and Physiology, 96, 36–42.

90.Yu, S. J., Rousch, R. T., Tabashnik, B. E. 1991. Pesticide resistance in arthropods. The Florida Entomologist, 74, 600.

91.Feyereisen, R. 1995. Molecular biology of insecticide resistance. Toxicology Letters, 82–83, 83–90.

92.Herron, G. A., Edge, V. E., Wilson, L. J., Rophail, J. 1998. Organophosphate resistance in spider mites from cotton in Australia. Experimental and Applied Acarology, 22, 17–30.

93.Erench, N., John, M. E., Wright, A. 1967. Chemical control of chrysanthemum leaf miner and some observations on varietal preference. Plant Pathology, 16, 181–186.

94.Faria, M. R. de and Wraight, S. P. 2007. Mycoinsecticides and mycoacaricides: A comprehensive list with worldwide coverage and international classification of formulation types. Biological Control, 43, 237–256.

95.Onofrey, D. 1998. We've got the power. Greenhouse Grower, 16, 1–6.

96.Opit, G. P., Nechols, J. R., Margolies, D. C. 2004. Biological control of twospotted spider mites, Tetranychus urticae Koch using Phytoseiulus persimilisAthias-Henriot on ivy geranium: Assessment of predator release ratios. Biological Control, 29, 445–452.

97.Escudero, L. A. and Ferragut, F. 2005. Life-history of predatory mites Neoseiulus californicus and Phytoseiulus persimilis on four spider mite species as prey, with special reference to Tetranychusevansi . Biological Control, 32, 378–384.

98. Ghaderi, S., Minaei, K., Rowshan, V., Ghamadyari, M. 2013. Toxicity and ovicidal activity of different plant extracts on two-spotted spider mite, Tetranychus urticae Koch. Archives of Phytopathology and Plant Protection, 46, 120–126.

99. Mohammadi, M., Moayeri, H. R., Kavousi, A., Bolandnazar, A. R. 2015. Ovicidal and adulticidal effects of synthetic menthol, thymol and their mixtures against Tetranychus urticae. Persian Journal of Acarology, 4, 1.

100. Panpatte, D.G., Shelat, H.N., Jhala, Y.K., Vyas, R.V. 2021. Fortified bacterial consortium – A novel approach to control root knot nematode in cucumber (cucumis sativum), Biological Control, 155, 104528, 4.

101. Ismail, M. S. M., Tag, H. M., and Rizk, M. A. 2019. Acaricidal, ovicidal, and repellent effects of Tagetes patula leaf extract against Tetranychus urticae Koch. Journal of Plant Protection Research, 59.

102. Debborah G. B., Gabriel M. B., Karina C. A. G., Cecília C., Edemilson C. C., Ivano A. .D., Joelma A. M. P.2024. Effect of microencapsulated/photoresistant extract of Azadirachta indica A. Juss seeds on Spodoptera frugiperda J.E. Smith (Lepidoptera: Noctudae) and its persistence in semi-field. Journal of Asia-Pacific Entomology, 27,4, 102335.

103. Usama S., Muhammad A., Farhat J., Syed M. H., Dilbar H. 2024. Determination of insecticidal potential of selected plant extracts against fall armyworm (Spodoptera frugiperda) larvae. Heliyon, 10, 20, e39593.

104. Venzon, M., Togni, P. H. B., Perez, A. L., Oliveira, J. M. 2020. Control of two-spotted spider mites with neem-based products on a leafy vegetable. Crop Protection, 128.

105. Tamara S., Óscar S., Jorge M., Jorge P. 2024. Seed extracts as an effective strategy in the control of plant pathogens: Scalable industry bioactive compounds for sustainable agriculture. Biocatalysis and Agricultural Biotechnology, 60, 103332.

106.Knapp, M., and Kashenge, S. S. 2003. Effects of different neem formulations on the two-spotted spider mite, Tetranychus urticae Koch, on tomato Insect Science and its Application, 23, 1–7.

107. Sarmento, R.A., Lemos, F., Bleeker, P.M., Schuurink, R.C., Pallini, A., Oliveira, M.G.A., Lima, E.R., Kant, M.R., Sabelis, M.W., Janssen, A. 2011. A herbivore that manipulates plant defense. Ecol. Lett. 14, 229–236.

108.Snoeck, S.,Wybouw, N., van Leeuwen, T.,Dermauw, W. 2018. Transcriptomic plasticity in the arthropod generalist Tetranychusurtciae upon long-term acclimation to different host plants. Genes Genomes Genetics 8, 3865–3879.

109.Pokle, P. P., and Shukla, A. 2015. Chemical control of two-spotted spider mite, Tetranychus urticae Koch on tomato under polyhouse conditions. Pest Management in Horticultural Ecosystems, 21(2), 145–153.

110.Van Leeuwen, T., Vontas, J., Tsagkarakou, A., Dermauw, W., and Tirry, L. 2010. Acaricide resistance mechanisms in the two-spotted spider mite Tetranychus urticae and other important Acari: A review. Insect Biochemistry and Molecular Biology, 40, 563–572.

111.Beers, E. H., Riedl, H., and Dunley, J. E. 1998. Resistance to Abamectin and reversion to susceptibility to Fenbutatin Oxide in spider mite populations in the Pacific Northwest. Journal of Economic Entomology, 91, 352–360.

112.Price, J. F., Legard, D. E., Chandler, C. K. 2002. Twospotted spider mite resistance to abamectin miticide on strawberry and strategies for resistance management. In Acta Horticulturae, 567, 683–685.

113.Bernardi, D., Oliveira, M. R., Picanço, M. C., Cruz, I., Lima, M. A. P. 2013. Effects of azadirachtin on Tetranychus urticae and its compatibility with predatory mites (Acari: Phytoseiidae) on strawberry. Pest Management Science, 69, 75–80.

114 Dimetry, N. Z., Amer, S. A. A., Reda, A. S. 1993. Biological activity of two neem seed kernel extracts against the two-spotted spider mite Tetranychus urticae Koch. Journal of Applied Entomology, 116, 308–312.

115. Jyotsna, B., Swaroopa P., Surya Prakash, Y., Rathnagiri, P., Kavi Kishor,P.B., Jalaja, N. 2024. Essential oils from plant resources as potent insecticides and repellents: Current status and future perspectives. Biocatalysis and Agricultural Biotechnology, 61, 103395.

116. Otávio A. L. S., Mayara S. S., Sérgio A. F., Bianca P. B. 2024. Nanotechnology for the control of plant pathogens and pests, Plant Nano Biology, 8, 100080.

117. Mingzhao H., Susilawati K., Zhongming Y., Xi D., Noor B. S., Md K. U., Effyanti M. S. 2024. Plant Extracts as Biostimulant Agents: A Promising Strategy for Managing Environmental Stress in Sustainable Agriculture, Phyton-International Journal of Experimental Botany, 93, 9, 2149-2166.

List of Tables

Table 1 List of agricultural pests and their target crops

Insect Pest	Scientific Name	Target Crop	Reference
Whitefly	*Bemisiatabaci (Gennadius)*	Cotton, tobacco	[11]
Brown planthopper	*Nilaparvatalugens (Stal)*	Rice	[15]
Fruit fly	*Bactrocera spp.*	Fruits and Vegetables	[16,17]
Green leafhopper	*Nephotettix spp.*	Rice	[19]
American bollworm	*Helicoverpaarmigera (Hubner)*	Chickpea, Sunflower, Cotton	[20-22]
Wheat aphid	*Macrosiphum miscanthi (Takahashi)*	Wheat, barley, oats	[23]
Diamondback moth	*Plutellaxylostella (Linnaeus)*	Cabbage	[24]
Pyrilla	*Pyrillaperpusilla (Walker)*	Sugarcane or rice sometimes	[25]
Gall midge	*Orseolia oryzae (Wood-Mason)*	Rice	[26]

Table 2 Worldwide losses of major crops due to diverse categories of pests [6,13, 32]

Crops	**Losses (%)**				
	Pests	**Weeds**	**Pathogens**	**Viruses**	**Total**
Cotton	12.3	8.6	7.2	0.7	28.8
Soybean	8.8	7.5	8.9	1.2	26.4
Maize	9.6	10.5	8.5	2.7	31.3
Potatoes	10.9	8.3	14.5	6.6	40.3
Wheat	7.9	7.7	10.2	2.4	28.2
Rice	15.1	10.2	10.8	1.4	37.5
Average	**10.8**	**8.8**	**10.0**	**2.5**	**32.1**

Table 3 Various crops affected by *Tetranychus urticae* in various states of India

S.No	**Crops affected by *Tetranychus urticae* in India**	**Region**	**Reference**
1.	Brinjal (*Solanum melongena L.*)	South Gujarat	[45]
		Bangalore and Varanasi	[51]
2.	Rose	Kerala (Vellanikkara, Madakkathara)	[46]
3.	Okra (*Abelmoschus esculentus L.)*	Jammu and Kashmir	[47]
		Maharashtra (Akola, Gadchiroli, and Nagpur)	[50]
4.	Cow pea (*Vigna unguiculata L.*)	Gujarat,Rajasthan, Karnataka, Kerala, Tamil Nadu and Maharashtra	[48]
5.	Jasmine	Tamil Nadu	[49]
6.	Cucumber	Himachal Pradesh	[52]
7.	Ashwagandha (*Withaniasomnifera L.)*	Amritsar District of Punjab	[58]

List of Figures

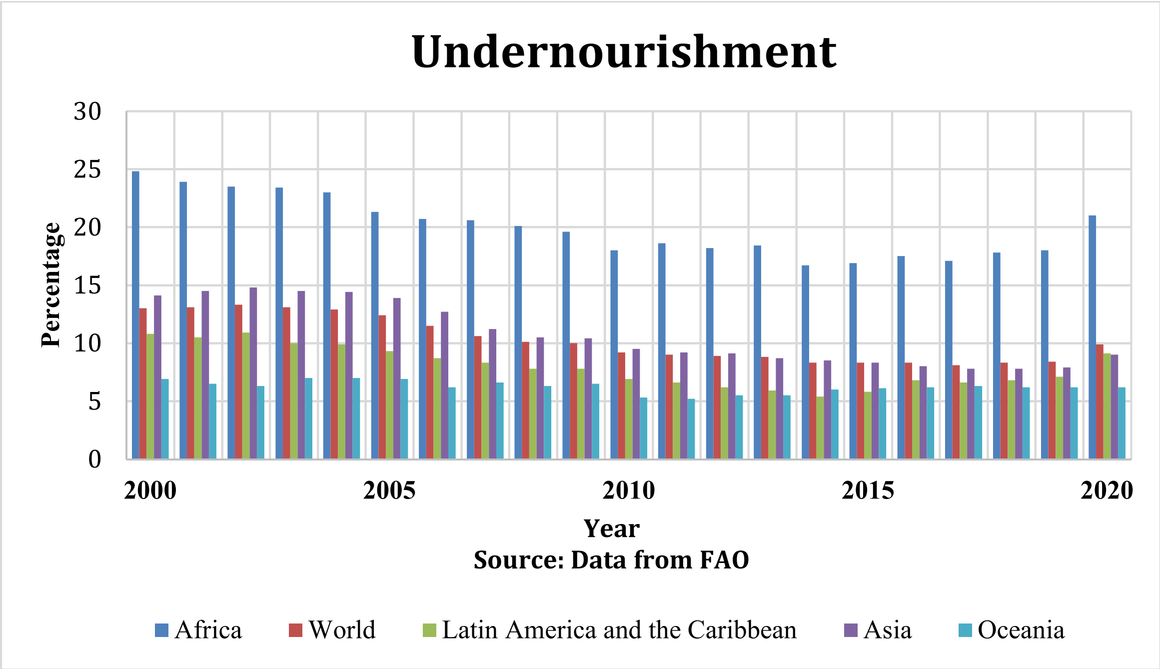

Fig.1. Percentage of undernourishment people by region based on the survey from FAO [2]

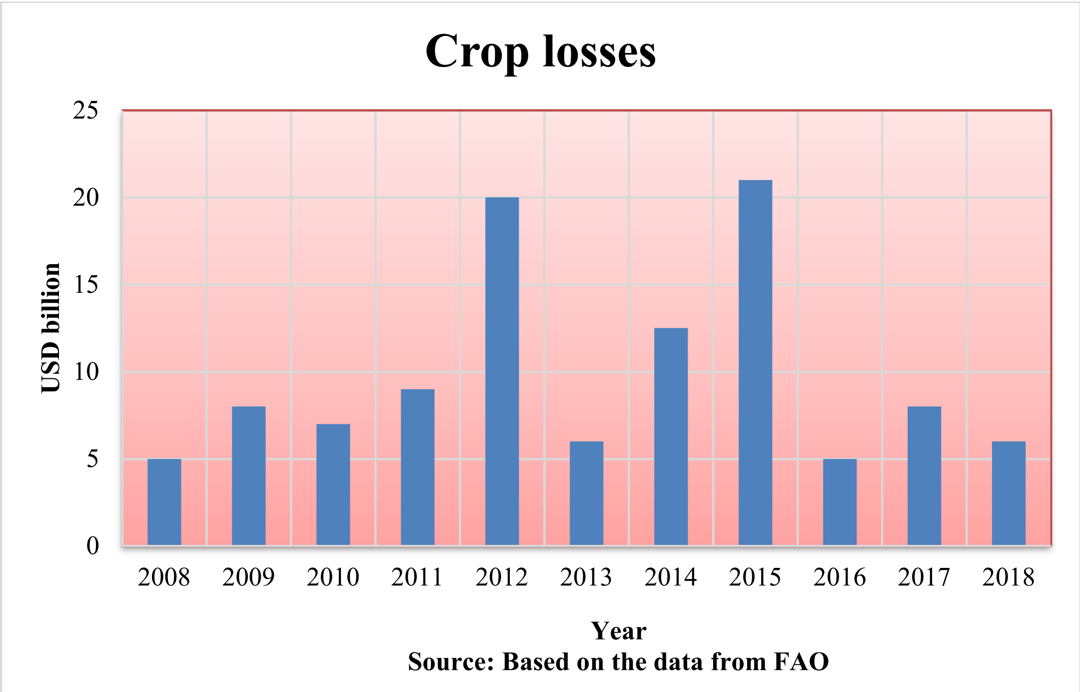

Fig.2. Total loss in crop and livestock production, in Asia, Africa, Latin America and the Caribbean 2008 –2018, USD billion [14]

Fig.3. Two-spotted spider mite (*Tetranychus urticae Koch.*) [27]

Fig.4 Mite Feeding and Plant Damage [30]

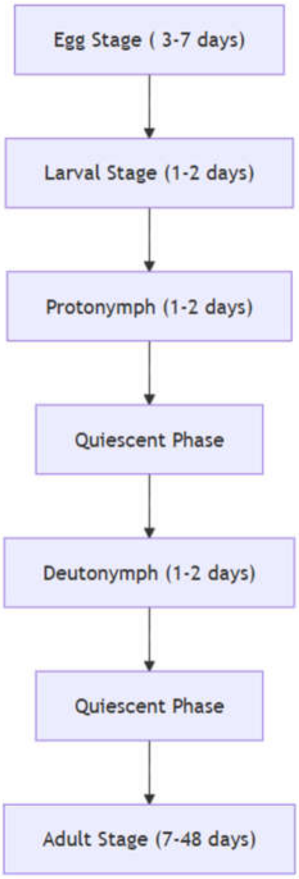

Fig. 5 (a). Complete life cycle of *Tetranychus urticae*

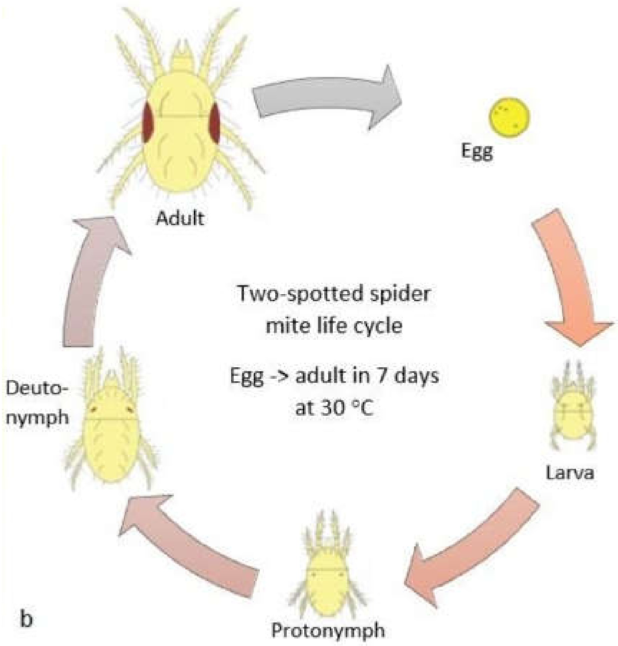

Fig.5 (b). Complete life cycle of *Tetranychus urticae* [31]

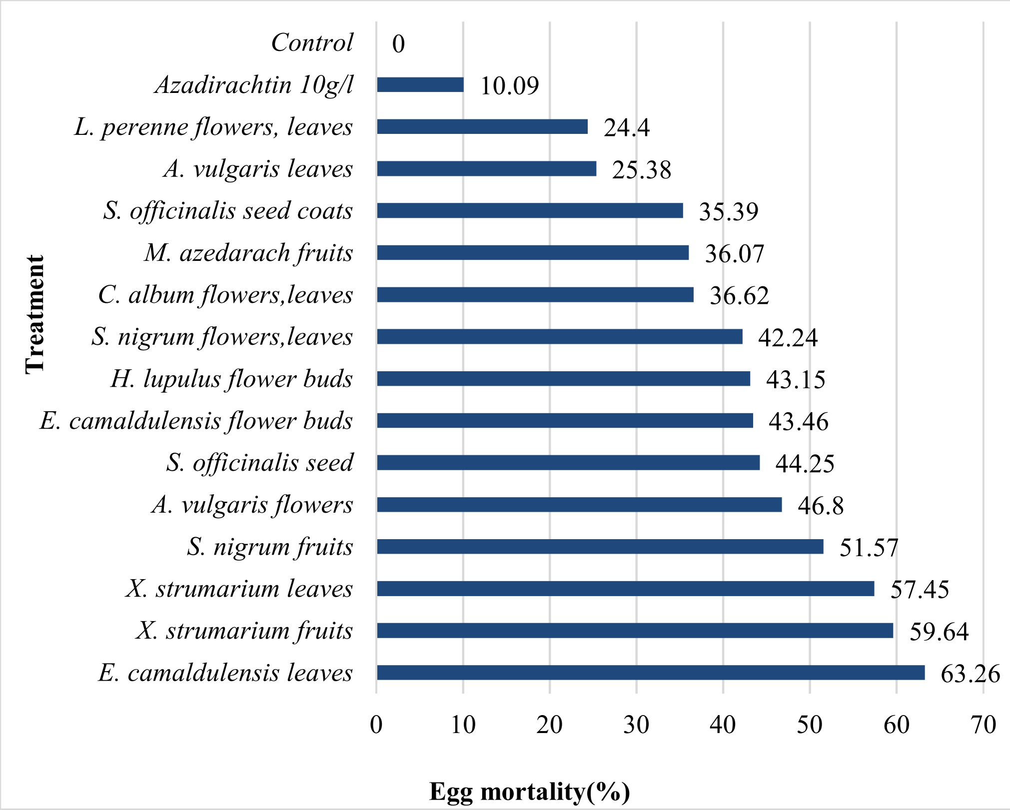

Fig. 6. Ovicidal effect of methanol extracts from different plant parts against *Tetranychus urticae* eggs [94]