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Kanika Tehri
Department of Zoology
Kurukshetra University,
Kurukshetra, India – 136119.

Correspondence:
Kanika Tehri
Department of Zoology
Kurukshetra University,
Kurukshetra, India – 136119.

A review on reproductive strategies in two spotted spider mite, *Tetranychus Urticae* Koch 1836 (Acari: Tetranychidae)

Kanika Tehri

Abstract
This review summarizes some of the important reproductive strategies in phytophagous acarine pest, *Tetranychus urticae* Koch 1836. It is an economically important agricultural pest with a global distribution which feeds on a wide range of host plant species throughout the world. The rapid developmental rate, high reproductive potential, and arrhenotokous parthenogenesis in *T. urticae* allows them to achieve damaging population levels very quickly when growth conditions are good, resulting in an equally rapid decline of host plant quality. Moreover, webbing, habitat preference on the underside of leaves, ballooning and high dispersal rate provide additional benefit to the expanding populations of two spotted spider mite, *T. urticae*.

Keywords: Arrhenotoky, Ballooning, Diapause, Dispersal, *Tetranychus urticae* Koch, Reproductive strategies, Webbing

1. Introduction

Mites, the most diverse representatives of the phylum Arthropoda, belong to the subphylum Chelicerata and subclass Acari. Among the arachnids, Acari are the only group, which feeds on plants. Plant feeding mites play an important role as agricultural pests of fruits, vegetables, forage crops, ornamentals and other agricultural crops. The damage caused by many species is still innocuous and often mistaken. Around 7,000 species of phytophagous mites are known worldwide which occur in five families namely Tetranychidae, Tenuipalpidae, Eriophyidae, Tarsonemidae and Tuckerillidae [1]. Tetranychidae, also known as spider mites, is a large family including about 1,200 species belonging to over 70 genera of worldwide distribution [2]. The two spotted spider mite (TSSM), *T. urticae* is a member of the family Tetranychidae that contains many harmful species of plant-feeding mites [3]. It was first described by Koch in 1836 [4] and thought to originate from temperate climates [5].

T. urticae is known to attack about 1200 species of plants[6], of which more than 150 are economically important [1, 7, 8, 9]. It is a ubiquitous and economically important agricultural pest with a global distribution which feeds on a wide range of host plant species throughout the world [10, 11, 12, 13, 14]. Pest status of *T. urticae* on green house vegetables, ornamental and horticultural crops is well documented worldwide [15, 16, 17, 18, 19, 20].

Defoliation, loss of chlorophyll, leaf bronzing, and even plant death occur due to direct feeding in severe infestation [11, 21]. The degree of leaf damage by *T. urticae* is a function of its stylet length and leaf thickness [22]. The stylet length of *T. urticae* is typically 132±27 µm [23] and can vary from 103 µm (larvae) to 157 µm (adult females) depending on developmental stage [24]. *T. urticae* often feeds on cell chloroplasts on the underside of the leaf, while the upper surface of the leaf develops whitish or yellowish stippling characteristic, which may join and become brownish as mite feeding continues. It is estimated that an adult spider mite consumes at the rate of about 50 percent of its mass per hour. The number of photosynthetically active leaf cells that are punctured and emptied per mite, are hundred cells per minute [1]. Indirect effects of feeding thus include decrease in photosynthesis and transpiration [22] leading to reduction in the amount of harvestable material [25].

The life cycle of *T. urticae* has been studied by several authors [26, 27, 28, 29, 30] which passes through five developmental stages: egg, larva, protonymph, deutonymph, and adult.

Eggs are round and translucent, turn orange and larvae hatch in about 5 days under optimum conditions of 25-30 °C and 45-55% relative humidity. One generation is completed in 10-14 days when the temperature is between 21-23 ºC [29] and in 7 days when temperature is higher than 30 ºC [28]. Egg laying by adult females can begin as early as one or two days following maturity. Each female may lay up to 100 eggs in her 30 day life span. The egg-adult development of female *T. urticae* is completed in approximately 6.5 days at 30 ºC [31] while the males are reported to complete development earlier than females [32]. However, the population growth parameters of *T. urticae* such as developmental rate, survival, reproduction and longevity may vary in response to changes in temperature, host plant species, host plant nutrition, cultivar kind, phenological stage, exposure to pesticides, relative humidity etc. [16, 31, 33, 34, 35, 36, 37].

Environmental factors play significant role in distribution and abundance of mites. It is well documented that warm and dry weather is favourable for the multiplication and spread of red spider mite [38]. *T. urticae* can complete a generation in one week in green house crops [39]. Temperature was found as regulatory factor for *T. urticae* build up as most of the authors found positive correlation between mite population and temperature [40, 41, 42]. Gulati [43] revealed that *T. urticae* population showed positive correlation with maximum temperature and negative correlation with minimum temperature. But Sunita [44] reported positive correlation between mite population and minimum temperature. Haque *et al*. [45] found that, in vegetable plants temperature had direct positive impact on mite population on joscpks coat, kathua, lady's finger, cucumber, brinjal, tomato, bottle gourd, bean, angled loofah, rongon, daisy and negative impact on bitter melon, radish, morog-jhuti and zinnia. With relative humidity, positive correlation of mite build up was reported by Pande and Yadav [46] while non-significant negative correlation was observed by others [40, 41]. Putatunda and Tagore [42] also found no relation between *T. urticae* infesting okra and relative humidity. In brinjal and sondhamaloti mite number increased significantly with increase of relative humidity but on radish mite number decreased significantly with increase of relative humidity [45]. Singh and Singh [40] and Gulati [43] reported that rainfall and sunshine hours did not play any significant role in mite population build up but Pande and Yadav [46] and Qui and Li [47] recorded positive and negative correlation, respectively between mite population and rainfall. Low wind velocity was also reported to favour the population buildup of tetranychid mites [47].

Parthenogenesis is observed in various groups of invertebrates. This phenomenon consists of the development of an organism from an unfertilized egg. There are two major kinds of parthenogenetic reproduction: (1) thelytoky, in which only diploid female progenies are produced, and (2) arrhenotoky, in which progenies are produced by mated or unmated females; fertilized eggs yield diploid female offspring, whereas unfertilized eggs yield haploid males. Parthenogenesis can be a regular (e.g., stick insects), cyclical (a number of parthenogenetic generations precede a bisexual generation; e.g., aphids), or occasional phenomenon (e.g., non-parthenogenetic species such as butterflies of the family Sphingidae) [49]. In comparison with asexual reproduction, sexual reproduction offers many advantages. Firstly, it greatly and easily enhances genetic variation within the population. Secondly, sexual reproduction requires as few as two cells to form a zygote. This also saves energy that would otherwise be spent, for example, on the division of a parental organism into offspring. Finally, this phenomenon enables the production of a great number of offspring from the parental generation. On the other hand, parthenogenesis is more efficient than bisexual reproduction because it enables virtually geometric population growth. New individuals are produced by a single organism. Spider mites, like hymenopterans and some homopterous insects, are arrhenotokous: females are diploid and males are haploid [50]. When mated, females avoid the fecundation of some eggs to produce males. Fertilized eggs produce diploid females. Unmated, unfertilized females still lay eggs that give rise to exclusively haploid males. Therefore, parthenogenetic reproduction is particularly useful in areas where bisexual reproduction may be hindered by environmental conditions.

T. urticae, belongs to an assemblage of web spinning mites [38] and the name 'spider' highlights their ability to produce silk like webbing [51]. As mites move around, their webbing can span leaves and stems. Eggs are deposited beneath the webbing and larvae and nymphs develop within it. The webbing defines the colony boundaries [33], serves as a means of protection from rain, wind, and predators [51, 52]. If the webbing is dense enough, protection may also be provided from acaricide sprays [11]. It is thought that the webbing and deposition of faecal pellets within the webbing is a mechanism to regulate humidity [51]. Mites live on both sides of the leaves with a slight preference for the underside and for the vicinity of the veins. Eggs are deposited on the underside of leaves, providing protection from predators, adverse environmental conditions such as rainfall and pesticide sprays thus making control difficult. In addition, the habitat preference for underside of leaves makes the initial detection of mite infestation difficult, thus providing appropriate time for mating and population expansion.

Diapause is an adaptive strategy of many insects and mites in that it synchronizes their life cycle with the availability of food and enables them to avoid unfavourable physical conditions such as cold, heat or drought. Diapause occurs as an obligatory phase of individual development or in response to cue factors. In the temperate regions, photoperiod is the major cue, controlling diapause induction and maintenance [53]. In the spider mite *T. urticae*, diapausing females search for hibernation sites [54], whereas oviposting summer-form spider mites remain on their host plant [55]. Diapausing females or eggs are the most common overwintering stage for tetranychids [56] in response to short day lengths and cooling temperatures [32]. The egg diapause is considered as a derived ancestral trait, while the adult diapause as a secondary apotypic feature [57]. During diapause, *T. urticae* do not feed or oviposit, and they generally seek shelter in crevices in the bark of trees and shrubs, clods of dirt, and in leaf litter [58]. Diapause in the spider mite is induced by long night photoperiods experienced during preimaginal development and is expressed in the adult stage in females only. Mites which have entered diapause cannot leave this state instantaneously in response to favourable conditions [54]. Activity can only be resumed after completion of a physiological process called 'diapause development' [59]. According to Tauber *et al.* [53], diapause development ends when photoperiod control of diapause maintenance is lost. In *T. urticae* diapause development is accelerated and rapidly completed when short nights are experienced but persists for several weeks to two or three months when mites are kept under long nights. Thus, diapause development in *T. urticae* proceeds gradually under a long night photoperiod [60].

Populations of tetranychid mite species become limited in relation to food supply, if their increase in number is not controlled by some form of environmental or artificial resistance [61]. Spider mites are highly mobile and the redistribution of populations among hosts seems to be an important part of their life history. When the plant begins to decline, resulting in a reduced food supply, the mites enter a dispersal phase from sedentary phase [55] and aggregate on the uppermost parts of the plants [62]. Dispersal includes both intraplant and interplant movement. *T. urticae* disperses individually by walking from one plant to another [63], or aerially by positioning their bodies in such a way as to catch wind [55]. Under extreme conditions (overcrowding coinciding with food depletion), individuals gather at the plant apex to form a ball made by mites and silk threads [64], the phenomenon commonly called as ballooning. Ballooning leads to the aggregation of mites into a ball like structure and prevents random dispersal of individuals. Once formed, the balls are not firmly attached to the apex of the plant. In the field, the wind or a passing animal would be sufficient for the dispersal of the ball. In passive airborne dispersal such as individual ballooning or collective silk balls, the distance and the direction of travel are largely determined by the air currents [65]. Aerial displacements may be tightly linked to fitness because of direct mortality risks related to the potential (uncontrollable) dispersal distance [66, 67] and the spatial availability of other host-plants. Individual ballooning or collective balls in tetranychid mites is the result of an active behaviour that enhances the probability of mites being carried aloft from plant surface [55]. Newly emerged mated females are the stage most likely to disperse individually, through either aerial or ambulatory means [68]. However, recent reports suggest that the balls are mainly composed of immature stages. It could be possible that under the combined protection of aggregation and silk threads (webs), ball-dispersed eggs could hatch into the young larvae in an optimal environment [64]. Aerial dispersal begins with the mites aggregating on the uppermost portions of the plants. The mites produce threads of silk, which they use to "balloon" into the wind, which sometimes carry them great distances [55, 62].

T. urticae has different strategies to disperse: **1.** Dispersal by active movement – by walking [62] **2.** Phoresy – passive transport by another organism [69] **3.** Aerial displacement by air currents [70]. One important biological feature of *T. urticae* is its abundant silk production due to a continuous silk deposit while walking. Silk threads are used as a physical support for locomotion [69] and can be used for aerial dispersal [65]. This individual passive displacement called ballooning is a mechanical kiting that many small species of spiders (Araneae), spider mites (Acari), and some moth larvae (Lepidoptera) use to disperse through the air [65]. Some of the ballooning spider mites (e.g. *Metatetranychus citri*, *Tetranychus pacificus*) were found to travel a few hundred meters and might fly up to 3 km away [71]. **4.** In *T. urticae*, a collective displacement seems to occur in conditions of overcrowding and food depletion on a host plant: The formation of silk balls can be carried away by the wind or by a passing animal i.e. anemochory or zoochory [72]. As the population peaks, the mites congregate on leaf tips, spin silk threads, and form small masses from which mites can be observed to be carried aloft in light breezes. The aerial dispersal of these aggregates may be an important element in the spatial dynamics of *T. urticae* populations and it might explain the sudden outbreak of large spider mite populations in crops that, apparently, were previously uninfected. Until now, the processes involved in the formation of mites' aggregate and silk balls are still unknown [64].

In conclusion, this review summarizes some of the important reproductive strategies in phytophagous acarine pest, *Tetranychus urticae* Koch. This mite is polyphagous and attacks broad range of crops, limiting the yield and thus, leading to huge economic losses. Understanding *T. urticae* population, life cycle, and outbreaks require a knowledge of many factors which include the biotic potential of the species, the influence of meteorological factors, the availability and relative susceptibility of hosts, competition between mite species, structural and chemical adaptations of each kind of mite. The rapid developmental rate, high reproductive potential, and arrhenotokous parthenogenesis in *T. urticae* allows them to achieve damaging population levels very quickly when growth conditions are good, resulting in an equally rapid decline of host plant quality. Moreover, webbing, ballooning, high dispersal rate and habitat preference on the underside of leaves, provide additional benefit to the expanding populations of two spotted spider mite, *T. urticae*.

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