

## Plant Nutrition Impacts Host Selection in Red Spider Mites: A Mini-Review

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### Abstract

Plants are continuously challenged by pests and diseases both in greenhouses and in the open fields. The continuous exposure has led to plants developing a number of defence mechanisms against attacking herbivores that are largely characterized by antixenosis, antibiosis and tolerance. On the other hand, herbivores have evolved and developed complex strategies to overcome plant defences and successfully locate, feed and reproduce on plants. The complexity of herbivore-plant interactions has led to various studies seeking to reveal the main components of these relationships. The results of such studies involving various herbivorous mites are discussed herein. Although they point to plant nutrition as a key factor in these interactions, the results vary largely, suggesting that each interaction is plant-herbivore specific under prevailing conditions. This review therefore aims at highlighting the influence of plant nutrition on plant-mite interactions while focusing on the possibility of regulating plant nutrition as a tool for integrated pest management. The influence of external factors as determined by fertilizer and water regimes are also discussed.

**Key words:** plant-mite interactions, host quality, secondary metabolites

### Introduction

The process of host choice in arthropods is a complex phenomenon that involves a series of activities that include selection, acceptance and suitability of the host plant (West & Cunningham 2002; Sarmiento *et al.* 2011). In host selection the initiation stage includes host location where pests use volatile plant compounds as cues for host plant identification (Bruce *et al.* 2005). Host acceptance is characterized by brief probing into the leaf tissues to assess the nutritional value and secondary metabolite composition and when the host is suitable, then a prolonged ingestion follows (Powell *et al.* 2006). A plant is suitable as a host if it meets the dietary requirements of the pest and offers offspring development (West & Cunningham 2002).

Host selection in arthropods is described in a number of models which include hierarchy-threshold, preference hierarchies or preference-performance (Cunningham &

West 2008). In hierarchy-threshold models, the selection of a host plant by a herbivorous arthropod depends on the positive stimuli received by the pest from the plant (Courtney *et al.* 1989). In this case, the acceptance or rejection of the host plant is purely determined by herbivore behaviour. In preference hierarchies, herbivores make a choice from the available species according to their preference and only opt for the least preferred when the more preferred species are absent, i.e. decision based on experience made in the habitat (Courtney *et al.* 1989; West & Cunningham 2002). Preference-performance hypothesis postulates that females prefer host plants that offer their offspring best fitness and ensure survival (Gripenberg *et al.* 2010). Some pests have specific minimal carbon and nitrogen requirements that must be acquired from the host for sustained reproduction whereas, for others, reproduction is triggered by nutrient depletion (Analytic 2008). These

activities are all determined by various factors, key among them being the host nutritional value that depends on the environment within which the host grows (West & Cunningham 2002).

### **Components of host nutritional value for mite pests**

The nutrition of a host plant is vital in meeting the dietary requirements of herbivorous mites (Wermelinger *et al.* 1991). Mites feed by inserting their stylet 70-120 µm into the leaf surface, piercing the mesophyll cells where they inject saliva and then suck out the cytoplasm of the cells (Tomczyk & Kropczynska 1985). Since, their feeding induces defence response in the host plant, their saliva usually contain proteins that reduce the adverse effects of the plant defences (Villarreal *et al.* 2016). Egg laying females are known to cause the greatest damage to plants due to their increased energy demand during oviposition period (Boudreaux 1958). Leaf nitrogen, water and secondary metabolites are considered as the major constituents of leaf tissue that determine a host nutritional value to herbivores and all depend on the availability of plant nutrients (Eigenbrode & Pimentel 1988).

Nitrogen (N) in form of proteins and amino acids is required by arthropods for growth and development. With 8-10% dry weight of herbivores being nitrogen against 0.03-7% in plants, herbivorous pests like mites have to take up large amounts of food to obtain adequate nitrogen (Mattson 1980). Nitrogen is observed to influence population density, fecundity, oviposition, development time and survival of mites (Geddes 2010; Chow *et al.* 2009). This can be attributed to the fact that when N is relatively more than the other macronutrients, plants become more succulent because carbohydrates are utilized for protein synthesis rather than cell walls (Mellors & Propts 1983). Also, plants suffering nitrogen (N), phosphorus (P) and potassium (K) deficiency are known to accumulate soluble nitrogen compounds and

thus become more susceptible to sucking herbivores (Ashilenje *et al.* 2011; White 1984). In addition, because leaf nitrogen increases with the nitrogen available to a plant, high N application leads to more N in form of free amino acids and reduced concentrations of secondary metabolites which provides the perfect environment for increased population growth of herbivores (Herms 2002).

Leaf water content is considered to influence food utilization in arthropods (Mattson 1980) just as soil moisture influences total nutrient availability and effective nutrient balance. This is because nitrate ions are known to move by mass flow to the roots and are much more mobile in the soil than phosphate and potassium ions which move to the roots by diffusion (Mellors & Propts 1983). Consequently, soil moisture has been associated with mite feeding. For example, low soil moisture has been reported to promote the reproduction of *Tetranychus urticae* Koch (Acari, Tetranychidae) in strawberry (White & Liburd 2005). In addition, drought-stressed tomatoes were found to suffer high leaf damage caused by *Tetranychus evansi* Baker & Pritchard which was attributed to increased free sugars, amino acids i.e. proline which stimulated feeding and egg laying (Ximénez-Embún *et al.* 2016). In the case of bush beans where the plants were subjected to four levels of water supply, the population of *T. urticae* was highest in the well watered and severely drought stressed plants (English-Loeb 1990) highlighting the importance of establishing optimal irrigation regimes for spider mite management. These observations are due to an increase in soluble nitrogen and free amino acids, carbon-based and nitrogen-based secondary metabolites and leaf temperature that are typical in drought-stressed plants (Herms 2002). Also, it is known that during water stress, leaves retain more water and this reduces the humidity around the leaves. As a result mites increase their feeding to prevent dehydration but also excrete less water and therefore more energy

is available for reproduction (Boudreaux 1958).

Normally, plants cannot simultaneously allocate resources to growth and defence (Toor *et al.* 2006). Therefore, although high concentrations of secondary metabolites can result to a more resistant plant against pests, their production is usually costly and reduces plant growth and development (Mazid *et al.* 2011). Evidence of such trade-offs have been reported in a number of crops including *Senecio jacobea* in which plants with high concentrations of pyrrolizidine alkaloid grew slower than those with low concentration when grown under limited light, nitrogen and phosphorus (Vrieling & Vanwijk 1994). Also in Asteraceae plants whose growth was most restricted contained most toxic tissues (Almeida-Cortez *et al.* 2004). Another example of costs and benefits of secondary metabolite is that of *Cecropia Peltata*, a neotropical tree where plants with high Tannin concentration experienced low leaf damage but also low leaf production (Coley 1986). A number of secondary metabolites have been associated with plant defence against red spider mites by acting either as toxins, repellents, digestibility reducers, oviposition deterrents or promoting the effectiveness of natural enemies of mites (Dicke & Sabelis 1988). These secondary plant compounds include alkaloids, phenols and terpenoids among others.

Alkaloids are an important group of plant metabolites involved in defence against herbivorous pests in solanaceous plants (Chowanski *et al.* 2016). Water and soil fertility are considered as factors that influence alkaloid production. Brown & Molyneux (1996) reported that water and nutrient deficiencies reduced the total alkaloids by 50% in groundsel, *Senecio vulgaris* L. whereas the deficiency of water or nutrient alone did not significantly reduce the alkaloids. Total alkaloid content of datura, *Datura innoxia* Mill was also reported to increase with increasing levels of compound fertilizers (Al-Humaid 2003). In

potatoes tubers, high rates of nitrogen fertilizer is known to increase the concentration of glycoalkaloids (Love *et al.* 1994). Total alkaloid, vincristine and vinblastine content in periwinkle, *Catharanthus roseus* L seedlings were also reported to accumulate with increased water stress (Amirjani 2013). Similarly, the maximum total alkaloids in black henbane, *Hyoscyamus niger* L were realised in plants grown under severe and moderate water deficit stress combined with high nitrogen supply (Ghorbanpour 2014). However, in some plant species, the plants alkaloid content is greatly dependent on its genetics i.e. species. For example in African nightshades (Solanaceae), steroidal glycoalkaloids were present in the mite resistant *Solanum sarrachoides* compared to the mite susceptible species *S. villosum* Miller and *S. scabrum* Miller (Jared *et al.* 2015).

Phenols are chemical compounds involved in the development of plant resistance against various herbivores through causing mortality, repellence and deterring oviposition (Chen & Dai 2015). Red spider mites induce defence reactions in their host plants and an example in cucumber, *T. urticae* increased the total phenols six days after feeding on the plant (Tomcizyk A. 1992). The induced phenols act on the pest causing adverse effects like reducing its fitness. For example, phenols from strawberry have been reported to increase repellence and mortality while reducing ingestion and fecundity of *T. urticae* (Dabrowski & Bielak 1978). In the same plant, foliar catechol phenols known to bind to digestive enzymes and inactivate them, are associated with delayed developmental times of *T. urticae* (Luczynski *et al.* 1990). Similarly, in peppermint, increase in total phenols reduced the number of eggs laid, increased dispersal and development time of *T. urticae* (Larson & Berry 1984). Toxic, repellent and oviposition-deterrence activities have also been observed on

*Tetranychus cannibarinus* Boisduval from 2,4-di-*tert*-butylphenol (Chen & Dai 2015).

Terpenoids are highly volatile compounds that contribute to the aromatic properties of the plants that produce them and are used by the plant for its protection against herbivore damage either as toxins or attractants of natural enemies of their pests (Chowanski *et al.* 2016). In lima beans, (E)- $\beta$ -ocimene and (3E)-4,8-dimethyl-1,3,7-nonatriene are terpenoids that are considered as predator attractants induced by the feeding of *T. urticae* (Dicke & Sabelis 2000). Terpenoids such as gossypol found in cotton have been associated with reduced damage by *T. urticae* on cotton lines with high gossypol content (Schuster *et al.* 1972).

#### Impact of plant nutrition on herbivorous mites

Optimum plant nutrition offers protection against pest attack and conversely, the deficiency or excess of certain minerals may predispose plants to pest damage (Ashilenje *et al.* 2012). For example plants suffering nitrogen, phosphorus and potassium deficiency accumulate soluble nitrogen compounds and thus become more susceptible to sucking herbivores (Ashilenje *et al.* 2011; White 1984). In a similar way, high nitrogen application leads to more free amino acids and reduced concentrations of plant secondary metabolites, a perfect recipe for increased population growth of herbivores (Herms 2002). Table 1 lists a number of studies that have focused on the influence of plant nutrition on the development and population dynamics of spider mites on apple trees, cotton and maize among others (Chow *et al.* 2009; Wermelinger *et al.* 1991; Geddes 2010; Chen *et al.* 2007).

A study by Wermelinger *et al.* 1991 on the effects of four levels of the macronutrients, N, P and K on *T. urticae* on micro propagated apple trees confirmed that leaf nutrient concentrations correspond to respective treatments but phenolic

compounds in the leaves increased with N and P deficiency. For mites, preimaginal developmental rate and oviposition rate were reported to positively correlate with leaf N while fecundity often correlated positively to N and carbohydrates contents of the leaves but negatively to the phenolic content. In cut roses, red spider mites are a pest of economic importance as they directly affect the quality of the cut-flower. A study by Chow *et al.* (2009) are among attempts that have been made to use cultural practices like altering the fertilization levels of N to control *T. urticae*. The authors reported that eggs and mites per flower shoot on rose plants supplied with 100% of the recommended N level were double relative to those fertilized with 33% and 50%. Further, the fertilizer treatments did not affect the number of total shoots produced but influenced flowering and blind shoots. Those plants receiving 33% had significantly more blind shoots than those of 100% N.

Another study by Chen *et al.* (2007) reported that geraniums treated with different P rates had more *T. urticae* populations eight weeks after application but the plant quality and dry matter remained high, implying that these plants better compensate for mite feeding damage. In addition, the study by Chen *et al.* (2007) suggested that tissue nutrient content might have influenced selection of feeding sites by mites since there was a positive correlation between within-plant distribution of mites and tissue nutrient concentrations.

Life history parameters of several mite species indicate how plant-mite interactions are influenced by supply of fertilizers and possible outcomes in future work with other plants species (Table 1). These studies are particularly important in guiding research of less developed crops such as African leafy vegetables most of which are damaged by different spider mite species. These vegetables include Amaranth that is damaged by *T. urticae*, vegetable cowpea attacked by carmine spider mite, *Tetranychus cinnabarinus* Boisduval (Acari:

Tetranychidae), green spider mite, *Tetranychus arabis* Attiah (Acari: Tetranychidae) (Oyewale & Bamaiyi 2013), Ethiopian kale that hosts *T. urticae*, red legged earth mite, *Halotydeus destructor* Tucker (Acari:Penthaleidae) and blue oat mite *Penthaleus* sp. Koch (Acari: Panthaleidae) (Mcdougall et al. 2014), cucurbit leaves damaged by bean spider mite, *Tetranychus ludeni* Zacher, *H. destructor*, broad mite, *Polyphagotarsonemus latus* Banks (Acari:Tarsonemidae), blue oat mite, *Penthaleus major* Duges and clover mite, *Bryobia cristata* Duges (Acari: Postigmata)(Napier 2009), jute plant that is fed on by *P. latus* and *Oligonychus coffeae* Nietner (Acari: Tetranychidae (Sadat & Chakraborty 2015) and edible nightshades that are differentially attacked by *Tetranychus species* (Murungi et al. 2014). This mini-review will focus on African nightshade which is as an economically and nutritionally important leafy vegetable in African communities.

### African nightshade

African nightshade (*Solanum* sp.) is an important leafy vegetable in East Africa. In Kenya, the vegetable accounts for 29% of the domestic value of African leafy vegetables (HCDA 2012) and 35% market share of total indigenous vegetables in urban markets and supermarkets within Nairobi (Irungu et al. 2007). Its demand has been on the rise especially among urban dwellers due to increased awareness of its nutritional and medicinal value (Irungu et al. 2007). African nightshades thrive in soils rich in N, P and organic matter (Chris O. Ojiewo, Gedion N. Mwai, Mary O. Abukutsa-Onyango 2013). Applications of 2.5-5 g N plant<sup>-1</sup>, 40-52 Kg N ha<sup>-1</sup>, 6 kg M<sup>2-1</sup> of cattle manure or 8 tha<sup>-1</sup> fortified compost manure are recommended for the crop (Ondieki et al. 2011; Ashilenje et al. 2011 and Abukutsa-Onyango & Karimi 2005). However, the growing demand for the vegetable has not been met owing to a number of constrains in the value chain.

Among these are production constrains such as pest damage (Irungu et al. 2007).

African nightshades are damaged by arthropod pests such as aphids (Ashilenje et al. 2012), beetles (Boavida & Germain 2009), leaf miners (Foba et al. 2015), leafhoppers, grasshoppers, lepidopterans (Clarke 2005), mealybugs, nematodes (Nchore, et al. 2013), whiteflies (Caspi-Fluger et al. 2012) and red spider mites (Fiaboe et al. 2007). A recent field monitoring in Tanzania and Kenya underlined the general importance of the red spider mites as key pests of nightshades (Mureithi et al. 2015).

### Status of *Tetranychus evansi*

*Tetranychus evansi*, the tomato spider mite has become a serious invasive pest of solanaceous crops in Africa though it is also known to damage more than 30 other plant families (Navajas et al. 2013). From its area of origin in Brazil, where it was initially observed in 1952, it has successfully invaded various countries across the world due to its ability to survive in a wide range of temperatures (10-34°C) (Furtado et al. 2007), high reproductive rate (200eggs per female) at short generational time (13.5 days at 25°C) and high dispersal ability (Bonato 1999). Also, the mite is able to suppress the induction of salicylic and jasmonic acid signalling routes that are involved with induced defence of the host (Sarmiento et al. 2011). These has been demonstrated in experiments where *T. evansi* was shown to have a higher oviposition and adult survival on plants that were previously damaged by *T. evansi* due to reduced inducible defence compounds. The suppressed defence is partly due to effector-like salivary proteins that are secreted by mites to reduce the adverse effects of plant defence (Villarroel et al. 2016).

**Table1:** Direct and indirect effects of different host plant treatments with fertilizer on the performance of herbivorous mites.

Nutrient factor	Host plant	Host type	Mite species	Effect on mites	Reference
<b>Population density</b>					
N	Apple trees		<i>Panonychus ulmi</i>	Increased with high N	(Van de Vrie & Delver 1979)
N,P,K	Apple trees		<i>P. ulmi</i>	Higher with highest and lowest NPK	(Sharma <i>et al.</i> 2010)
N	Apple trees	Perennial	<i>T. urticae</i>	Increased with high leaf N	(Wermelinger <i>et al.</i> 1991)
P	Apple trees		<i>T. urticae</i>	Higher with P-deficiency	(Fritzsche <i>et al.</i> 1980)
N	Pecan		<i>Eotetranychus hicoriae</i> McGregor	Higher with N fertilization	(Jackson & Hunter 1983)
N	Ivy geranium		<i>T. urticae</i>	No difference in N rates	(Chen <i>et al.</i> 2007)
P	Ivy geranium		<i>T. urticae</i>	Higher with high P rates	(Chen <i>et al.</i> 2007)
N	Sorghum		<i>Oligonychus pratensis</i> Banks	No relationship	(Perring <i>et al.</i> 1983)
P	Sorghum/corn		<i>O. pratensis</i>	Slight influence	(Archer <i>et al.</i> 1988)
N	Cucurbits	Annual	<i>T. neocaledonicus</i> Andre	Higher populations	(Sharma & Pande 1986)
K	Cucurbits		<i>T. neocaledonicus</i>	Higher populations	(Sharma & Pande 1986)
N,P,K,S	Cowpea		<i>T. turkestani</i>	Higher with NPKS fertilization	(Rather & Lavdari 2006)
N	Brinjal		<i>T. macfarlanei</i>	Higher with high N	(Patil & Nandihalli 2008)
N	Common bean		<i>T. urticae</i>	Higher with high N	(Saeid <i>et al.</i> 2011)
N	Jute		<i>Polyphagotarsonemus latus</i> Banks	Higher with high N	(Gotyal <i>et al.</i> 2016)
<b>Fecundity</b>					
N,P,K	Lima beans	Annual	<i>T. telarius</i>	More progeny with higher NPK	(Henneberry 1962)
<b>Oviposition</b>					
N	Roses	Perennial	<i>T. urticae</i>	More with increasing N	(Chow <i>et al.</i> 2009)
N	Apple trees		<i>T. urticae</i>	Increased with increase in leaf N	(Wermelinger <i>et al.</i> 1991)
K	Grapes		<i>Eotetranychus willametei</i>	Higher density with increased K	(Geddes, 2010)
<b>Survival</b>					
N	Grapes	Perennial	<i>E. willametei</i>	Better on moderate than high N	(Geddes, 2010)
P	Beans	Annual	<i>P. ulmi</i>	Higher survival	(Suski and Badowska 1975)
K	Beans		<i>T. urticae</i>	Higher mortality	(Suski and Badowska 1975)

Results are structured according to effects on mite density, fecundity, developmental time, oviposition, survival, maturity, and longevity of the different mite species on treated host plants (annuals and perennials). N=nitrogen, P=phosphate and K=potassium

Although tomato red spider mite is closely related to *T. urticae* it has been shown to be more aggressive and difficult to control. Only recently has a predatory mite, *Phytoseiulus longipes* been shown to successfully control *T. evansi* (Furtado et al. 2007) (Silva et al. 2010) while *T. urticae* was effectively controlled using predatory mites, *Phytoseiulus persimilis* Athias-Henriot and *Neoseiulus californicus* McGregor that are commercially available. The two predatory mites have not been successful in controlling *T. evansi* due to reduced population growth when fed on *T. evansi* (Escudero & Ferragut 2005). This occurrence is thought to result from toxic and antifeedant effects of secondary plant metabolites found in solanaceous plants that *T. evansi* feeds on. Examples of such metabolites are methyl ketones (Chatzivasileiadis & Sabelis 1997), sesquiterpenes (Maluf et al. 2001) and glycoalkaloids (Jared et al. 2015). The reduction in the reproduction of the two predatory mites is thought to result from the antifeedant effects of secondary plant metabolites taken up by *T. evansi* from Solanaceous plants.

Fertilizer and water application are among cultural practices that can be explored in the management of *T. evansi*. Studies into the impact of either complete nutrient recipes or individual nutrient rates could reveal levels that can be useful in keeping mite damage at a minimum while supporting high productivity. Preliminary results are promising, showing that red spider mites prefer and develop best on well-nourished plants i.e. plants grown on 80% water field capacity and complete nutrient solution (Mworia et al. 2015). In addition, since fertilizers and water supply to plants are known to impact on the secondary metabolites that are involved in plant-pest interactions, it is worth investigating how major metabolites in African nightshades are influenced. Consequently, relationships can be established between metabolites and mite incidences in an attempt to identify those that can be manipulated for mite management.

## Conclusion

In general nitrogen application leads to elevated leaf N content that positively influences most life-history parameters of red spider mites. However, N ratio compared to other macro and micronutrients have shown varying effects. Therefore, host plant quality that depends on plant nutrition influence the choice and performance of mites. In this regard, there is need to study complete fertilizer and water regimes and establish their effects on the plant metabolites influencing the performance of spider mites. The results of which will point to possible optimal nutritional requirements of these vegetables that will lead to high plant defence against mites while maintaining acceptable yield levels. In so doing, fertilizer and water regimes could be used as an effective tool in an integrated pest management system of red spider mites in African leafy vegetables leading to higher yields, improved nutrition and food secure communities.

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