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Management of whiteflies *(Bemisia tabaci)* in tomato by using different control methods

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Abstract
Bemisia tabaci was described more than a century ago and has since become one of the most important pests in subtropical and tropical agriculture, as well as in greenhouse production systems across the world.it has now been recorded from all the world's continents except Antarctica. The number of plant viruses transmitted by *Bemisia tabaci* has risen, resulting in total production losses for major food and industrial crops. Now, pesticides are the only effective means of control. Host plant resistance and other cultural techniques are also important components in developing integrated management systems. The proper use of natural enemies will aid in the reduction of whitefly populations, which may then be more easily managed using cultural and, if required, chemical pesticides. As a result, implementing IPM will relieve many of the issues connected with chemical use, such as those related to environmental contamination and the widespread resistance that *Bemisia tabaci* control.

Keywords: whitefly, management, IPM, tomato

Introduction

Bemisia tabaci is one of the serious pests found all over the world. It was first discovered by Gennadius in Greece as a pest of tobacco in 1889 the first name given as *Aleurodes tabaci*. Later this pest spread all over the world. It causes lot of damage to the different solanaceous and ornamental crops. Whiteflies, sucking pests, cause serious crop damage by spreading virus disease rather than directly feeding on the crop (Kumar *et al*., 2010). *Bemisia tabaci* directly cause damage to host crops in different ways by sucking sap of host plant and production of honey dew on the plant surface leads to development of black sooty mold which leads to inhibition of photosynthesis of host plant ultimately leading to death of host plant and causing immature and irregular ripening in some vegetable crops. *Bemisia tabaci* is a serious pest of many agricultural structures, including vegetables, ornamentals, and field crops (Byrne and Bellows 1991, Oliveira *et al*. 2001, Stansly and Naranjo 2010) [13, 60, 69]. *Bemisia tabaci* acts as vector for transmitting many virus begomoviruses, carlaviruses, ipomoviruses, and torradoviruses criniviruses, etc indirectly causing lot of damage to the different crops and economic yield loses. *Bemisia tabaci* has high host range and has been shown to grow or replicate on over 500 plant species from 74 different families. Its polyphagous behavior has been reported all around the world. Bird, 1957 [5]; Costa and Russell, 1975 [17]; Bird and Marmorosch, 1978; Butler *et al*., 1986 [11, 12]; Costa and Brown, 1990, 1991; Costa *et al*., 1991; Burban *et al*., 1992). It is associated with different plant species, including both annuals and perennials. Both nymph and adult are involved in the destruction of the host plant by sucking the phloem sap of the host plant. Cell sap is sucked by both nymphs and adults from the lower leaf surface. *Bemisia tabaci* takes 22-44days for development from the egg to adult. *Bemisia tabaci* contains six life stages when compared to males. Females have higher sex ratio in comparison to greenhouse whitefly, *Bemisia tabaci* causes more damage. Whitefly biotypes have been identified as economic pests in various parts of the world. Whitefly biotypes have been identified as economic pests in various parts of the world. *Bemisia tabaci* of the well-known biotype B is a significant pest of numerous crops and vegetables, generating annual losses of $714 million (Oliveira *et al*., 2013) [59]. Fruiting vegetables, Brassica, and cucurbits are among the agricultural crop types affected by Whitifies in the field and greenhouses. In many regions of the world, *Bemisia tabaci*-transmitted viruses have become a limiting factor in the production of food and fiber crops (Brown, 1994) [9]. For example, between the mid-1970s and the mid-1980s, *Bemisia tabaci* populations in the Imperial Valley of California grew 300-fold, and 1600-fold between the mid-1970s and the mid-1990s (Wisler *et al*., 1998) [73]. After China, India is the world's second-largest producer of vegetables. Tomatoes are native to Central and South America, and their use as a food began in Mexico after the Spanish colonized the Americas. Tomato is a most cultivated crop in the open condition. Tomato is high in vitamins and minerals, which are lacking in other foods. The tomato *(Lycopersicon esculentum.*) belongs to the Solanaceae family and is one of the most widely cultivated vegetables on the planet. Tomato is an essential vegetable crop that plays an important role in the diet of the humans. To make soup, juice, ketchup, puree, pickle, paste, and powder, large amounts of tomatoes are required (Choudhary 2002) Tomatoes are high in vitamins A, C, and E, as well as minerals that are beneficial to one's health (Olaniyi 2010) [58]. Tomato contains higher number of vitamins, mineral, carbohydrates. China, the United States, Italy, Turkey, India, and Egypt are major tomato production countries. There are different methods present to control the *Bemisia spp.* and increase the yield of tomato. Whitefly incidences and growth are influenced by weather conditions such as temperature, relative humidity, and precipitation. These weather factors mainly influence the population of whitefly. Insect growth, development, and reproduction are influenced by environmental variables, particularly temperature. To decrease whitefly damage, a variety of management methods may be utilized, including host plant resistance, biological control, cultural control, and chemical control.

Management
Chemical control
Biological control
Monitoring and management by using sticky traps
Control by using mulches.

Chemical control

Insecticides are the most often used method for controlling whiteflies. Early publications (e.g., Sharaf1986, Dittrich *et al*.1990, Horowitz and Ishaaya1996) provided evidence on more than 50 synthetic insecticides for population management and virus suppression by *Bemisia tabaci*. Insecticides, such as nicotinoids and insect growth regulators, have shown physical and immediate intervention in combating *Bemisia tabaci* and other pest-sucking insects over the last two decades. Carbamates, OPs, and pyrethroids were the most used conventional insecticides (Palumbo *et al*., 2001 and Naveen *et al*.,2017) [61, 56]. Systemic insecticides of the neonicotinoid family, such as clothianidin, dinotefuran, imidacloprid, thiamethoxam, chlorantraniliprole, spinosad, and flupyraifurone, can be applied as foliar which are highly effective in controlling of whitefly (Avery, 2019, Shinde;2018) [3, 66]. Buprofezin is a thiadizine-like compound that inhibits chitin synthesis and has a long residual activity. It has vapor activity, and it affects sucking insect nymphal stages, especially whiteflies (Ishaaya *et al*.1988, De Cock and Degheele 1998) [44, 25]. Due to chitin deficiency whitefly nymph loses its procuticle (De Cock and Degheele 1998) [25]. Buprofezin, like BPUs, is successful in immature stages but not in adults. Natural enemies are only mildly affected by the compound (De Cock and Degheele 1998) [25]. The neonicotinoids are a powerful class of insecticides. They have high residual activity and structural and translaminar properties (Elbert *et al*. 1990, 1998, Takahashi *et al*.1992, Horowitz *et al*, 1998) [27, 71, 40]. These insecticides are highly effective against the sucking pest like whitefly, leafhopper and aphids and coleopteran pest like Colorado potato beetle. Imidacloprid was the first neonicotinoid that was successfully used to control different agricultural pests on a commercial scale. Since it is considered a comparatively polar material with strong xylem stability, it has been commonly used as a seed dressing and in soil applications. Since1998, diafenthiuron has been used as an alternative to pyriproxyfen for *Bemisia tabaci* control in cotton, mostly in Europe and Israel. When adult females are introduced to treated plants, diafenthiuron inhibits the development of whitefly progeny, and it is more effective against nymphs than pupae or eggs (Ishaaya *et al*. 1993) [43]. Pymetrozine is a highly selective azomethine pyridine insecticide that kills sucking insect pests (Fluckiger *et al*. 1992ab, Fuog *et al*. 1998) [31]. It shows high toxicity to the pest like whiteflies (including *Bemisia tabaci* and *Trialeurodes vaporariorum* aphids and plant hoppers. Some of the novel insecticides are majorly involves in the control of whitefly. Spiromesifen is a new class of pesticides derived from spirocyclic tetronic acid that mostly affects whiteflies and mites. It works as a lipid biosynthesis inhibitor, interfering with egg and immature stage growth and lowering adult female fecundity (Bretschneider *et al*. 2003, Nauen *et al*. 2005) [8, 55]. Ryanodine is a natural botanical insecticide made from a plant alkaloid. Cyazypyrtm is an insecticide that kills sucking pests like whiteflies and aphids as well as other insects (Sattelle *et al*. 2008, Lahm *et al*. 2009) [64, 48]. Different types of pesticides like Profenophos, indoxacarb, and NSKE were shown to be extremely effective in controlling whiteflies, according to Meena and Ranju (2014). When compared to an untreated control, Hossain *et al*. (2013) [41] discovered that imidacloprid reduced whitefly population substantially. Sharaf(1986) [65] compiled information on the use of pesticides to control whitefly populations and prevent virus transmission by *Bemisia* adults. He said carbamates (such as aldicarb and carbaryl) were the most effective insecticides, followed by organophosphates (such as bromophos and methyl parathion) and pyrethroids (such as cypermethrin, fenvalerate, and fenpropathrin).

Some of the factors which are responsible for decreasing insecticide activity. Such as under-leaf shelter of immature stages and adults, the emergence of older larva in the crop's lower canopy, the pest's extremely polyphagous disposition, and the ease with which adults are dispersed by wind all make systematic management of *Bemisia tabaci* with traditional insecticides impossible. (Horowitz and Ishaaya 1996, Palumbo *et al.* 2001) [61]

For the control, several pesticides have lately been tested. Insecticides with new mechanisms of action, such as insect growth regulators (IGRs), which have been used to control whiteflies since the late 1980s, were included, as well as traditional insecticides including organochlorines, OPs, carbamates, and pyrethroids. The advantage of employing systemic insecticides over contact insecticides is that they often give continuous protection throughout the growth season without the need for repeated treatments.

Disadvantages of chemical monitoring for the handling of *Bemisia tabaci*

However, the widespread use of pesticides has contaminated the atmosphere, damaged humans, killed non-target organisms, lowered crop quality, and resulted in the growth of pest resistance (Kulat *et al*. 1999) [46]. Overuse of insecticides for such control also results in the production of resistance in certain cropping systems. Because whiteflies carrying the virus can infect a tomato plant with TYLCV within 4 hours of inoculation, insecticides with a quick killing effect on adults are required to prevent virus spread. In this case daily application of insecticides which leads to development of resistance against the insecticide. More than one-sixth of the pesticides used by farmers were very dangerous and had been prohibited for use in ordinary agriculture (Shrestha *et al.* 2010) [67]

Biological control

The use of natural enemies for biological control is thought to be a highly best method of used to manage the insect pests. Whiteflies are at the top of the list of promising cases in the history of biological regulation using predators and parasitoids (Gerling 1990) [34]. Work on the topic has resulted in the detection of various natural enemies, including the prospect of complex biotype-natural enemy interactions in *B. tabaci* (Kirk *et al*. 2000) [45].

Predators

Only a few of the more than 150 arthropod species now classified as whitefly predators have been thoroughly investigated, leaving many with limited laboratory observations or qualitative field data (Gerling *et al*., 2001;

Arnó *et al*., 2010) [32]. Some of the currently listed as whitefly predators, Ladybird beetles, predaceous bugs, lacewings, phytoseiid mites, and spiders are the most common predators of whiteflies. Gerling (1990a) [34] provided an overview of whitefly predators and parasitoids. *Bemisia tabaci* is being attacked by 34 predators and 7 parasitoid species. Ladybird beetles are effective natural enemies of whiteflies, which may display varying degrees of oligophagy. There have been reports of 40 species preying on *Bemisia tabaci* (Gerling *et al*., 2001; Arnó *et al*., 2010) [32]. Under greenhouse conditions, *Delphastus catalinae* is the most widely used predacious natural enemy for managing whiteflies on a variety of ornamental and vegetable crops. Immature stages, mostly eggs, were consumed by *Delphastus catalinae.* Female *Delphastus catalinae* consumed over 150 whitefly eggs or nymphs each day, and each larva consumed nearly 1000 eggs over the course of a two-week development cycle. The biological control of *Bemisia tabaci* by *Nephaspis oculatus* has showed promising contribution, particularly in greenhouses (Liu *et al*., 1997) [51]. Although *Nephaspis oculatus* devoured fewer whiteflies than *Delphastus catalinae* it exhibited a more efficient seeking habit. (Liu and Stansly, 1999; Ren *et al*., 2002; Huang *et al*., 2006; Legaspi *et al*., 2006) [52, 63, 42, 49]. Males lived 56.1 days on average, while females lived 67.5 days. Adult male–female couples consumed 184.1 eggs each day during the course of 16 weeks. Predators in order Heteroptera on *Trialeurodes vaporariorum*, pre-imaginal stages are attacked by *Macrolophus pygmaeus*, (Mohd Rasdi *et al*., 2009) [62] while older *Bemisia tabaci* nymphs are preferred (Bonato *et al.*, 2006) [6]. In order Neuropteran (Gerling *et al*.,2001; Arnó *et al*.,2010) [32] identified twenty-one Chrysopidae and two Coniopterygidae species as *Bemisia tabaci* predators. Gerling *et al*.,2001; Arnó *et al*.,2010) [32] found seventeen Phytoseidae species and one Stigmaeidae species to be whitefly predators. Adults ate up to three eggs or two nymphs each day, whereas immature mites required 15–20 whitefly eggs or nymphs for growth.

Parasitoids

Whiteflies contain about 500 parasitoid species divided into 23 genera and six families (Evans,2007; Noyes,2012; Liu *et al*., 2015) [29, 50]. The bulk of whitefly parasitoids are from the genera *Encarsia* and *Eretmocerus,* which belong to the Hymenoptera family (Aphylinidae*). Bemisia. tabaci* and *Trialeurodes vaporariorum* appear to be equally vulnerable to *Eretmocerus eremicus* (Stansly and Natwick, 2010). *Encarsia formosa* can oviposit in any of the four whitefly nymphal instars, but it mostly develops in the fourth, from which it emerges as an adult. The first-instar nymph is the least appropriate stage, with the highest parasitoid mortality and the slowest maturation. The *Encarsia formosa* host feeds on all whitefly nymphal stages, however the second and late fourth instars are more common than the first and third instars. All juvenile instars of *Bemisia tabaci* are parasitized by *Eretmocerus mundus* and *Eretmocerus eremicus* but the second and third instars are particularly vulnerable. Because the combination of *Amblyseius swirskii* and *Eretmocerus mundus* suppresses *Bemisia tabaci* much better than *Eretmocerus mundus* alone, it is recommended that this combination be used in commercial sweet pepper greenhouses (Calvo *et al*., 2009a). Due to sterility of unknown origin in both males and females in mass raising facilities, *Eretmocerus mundus* has a restricted commercial supply (Chiel *et al*., 2012 [15]. *Bemisia tabaci* was reduced by 92 percent when six parasitoids were applied per m^2 (Stansly *et al*., 2005b) [68]. *Trichogramma* species has been discovered as a possible biological control agent of *Tuta absoluta* eggs and is now being introduced in commercial tomato greenhouses. These are one of the natural enemies that may be utilized to limit *Tuta absoluta* population development in greenhouses and open field tomato crops.

Pathogens

Pathogens are the one of the effective methods used to control the whitefly which is beneficial to the environment, and which does cause any damage to the environment. Although substantial coverage is necessary on the abaxial (lower) foliar surfaces where whiteflies dwell, entomopathogenic fungi are simple to apply. *Beauveria bassiana* and *Isaria fumosorosea* are particularly harmful to second and third instar nymphs. All developmental stages of *Bemisia tabaci* were shown to have a high pathogenicity for *Lecanicillium lecanii*; however, the second instar nymphs were found to be the most vulnerable to infection. *Lecanicillium lecanii* kills 80–97% of nymphs, and subsequent infection kills many adults that emerge from the surviving nymphs. To manage *Bemisia tabaci*, commercial mycopesticides have been produced from the entomopathogenic fungus *Beauveria bassiana*, *Isaria fumosorosea*, and *Lecanicillium lecanii* (Faria and Wraight, 2001). When used in conjunction with pesticides, certain fungi have also been proven to give further control (Cuthbertson *et al*., 2005a; Borisade, 2015) Finally, the entomopathogenic worm *Steinernema feltiae* (Filipjev) has showed potential in the greenhouse for *Bemisia tabaci* management (Cuthbertson *et al*., 2007). When sprayed weekly, *Isaria fumosorosea* dramatically decreased *Bemisia tabaci* populations on ornamentals. Commercial products such as Mycotal® (*Verticillium lecanii-m*), Botanigard® (*Beauveria bassiana*), and PreFeRal® (*Paecilomyces fumosoroseus*) are now available; Stansly and Natwick(2010) provide a more comprehensive list.

Monitoring and management by sticky traps

Sticky traps are the important equipment which is used for to find out the pest population in the field and as well as in greenhouse Winged aphids, whiteflies, thrips, leaf miners, fungus gnats, and beach flies are all caught in large numbers using "yellow sticky cards." The attraction of whiteflies to yellow has been used as a useful tool in whitefly population sampling and monitoring (e.g., Gerling and Horowitz 1984). Whitefly (and other insect pest) visual cues were also used as a highly important, but frequently neglected, technique for pest population management in greenhouses Yellow sticky traps of various shapes and sizes may catch huge numbers of adult whiteflies. In 'hotspot areas,' large yellow-sticky boards or tapes are employed at a rate of roughly one per plant. Alternatively, reams of yellow, adhesive tape might be stretched between poles along plant rows. *Bemisia tabaci* is attracted to two sets of wavelengths of transmitted light, the blue/ultraviolet and yellow portions of the spectrum, according to Mound (1962) [54].

Control by using mulches.

Mulches is the one of the techniques which used to prevent the whiteflies in the field condition. Living mulches, which surround the protected crop with other plants that "mask" the target plant from whiteflies, are one technique. Whiteflies are best controlled using living mulches during the first five weeks following planting. When whitefly-vectored viruses must be protected and mulch plants must be inhibited to avoid competing with the main crop (Hilje *et al*., 2001). Another technique is to plant the protected crop by plastic mulches. These plastic mulches have been thoroughly tested and have been shown to affect whitefly alighting behavior and viral disease transmission in tomato plants (Csizinszky *et al*., 1995) [21]. Different colors have been tested, and Greer and Dole (2003) [36] analyzed the and found that aluminum foil and metal-painted mulches were the most successful in deterring whiteflies. Given the link between whitefly flight and UV light, this makes sense: creating UV reflectance near plants prevents whiteflies from “seeing” the yellow-green spectrum of their target host plants (Antignus, 2000) [1]. Plants planted on aluminum mulch exhibited lower densities of *Bemisia tabaci* and reduced incidence of tomato mottle virus, TMoV) (Csizinszky and colleagues, 1999) [22]

Conclusion

Tomato is an important vegetable crop which is generally used in our daily life as our diet. Whitefly is a serious pest in tomato which is mainly causing lot of economic loses to the crop yield. Whitefly issues are anticipated to worsen as global warming continues; Guo *et al*. (2012) [37] found that *Bemisia tabaci* can withstand lengthy periods of high temperature stress. Neonicotinoids are being used to control whiteflies, and new synthetic and natural treatments are being researched. As previously stated, a variety of different innovative techniques for whitely management are being investigated, and plant resistance is a fruitful research topic. The more diverse forms of controls we combine, especially in the context of other tomato pests described in this the greater opportunity we have of establishing economically and environmentally sustainable pest management strategies for whiteflies in tomatoes. Because *Bemisia tabaci*-transmitted viral plant diseases are incurable, the main treatment strategies should focus on preventing transmission and/or using host-plant resistance. The use of many forms of physical and visual impediments against whiteflies has been explored and applied, in addition to key measures such as cleanliness

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