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Lethal and sublethal effects of insecticides on whitefly, *Bemisia tabaci* (Gennadius)- A review

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ABSTRACT

Bemisia tabaci (Gennadius) is widely distributed polyphagous pest, found in tropical, subtropical and temperate regions. The overall impact of whitefly has been very devastating with yield losses ranging from 20 to 100 percent, depending upon the crop, season and prevalence of the whitefly. Although excessive and injudicious use of insecticides have led to increase in resistance level of white fly but still insecticides are considered as important tool for control of this pest. The bio-efficacy of emerging chemicals including insect growth regulators and neonicotinoids against whitefly has been evaluated in different studies. These studies have reported both lethal and sub lethal effects of various insecticides on white fly. The insecticides alter physiological mechanisms in whitefly leading to pronounced changes in physiological system, affecting the reproduction and overall development. These bioassays could be helpful in enlisting various new chemicals that would be helpful in management of this pest.

Key words: Insecticides, Sub lethal effects, Toxicity, Whitefly.

The *B. tabaci* is one of the most devastating pest of many crops including cotton, vegetables, ornamentals and field crops (Nauen *et al.*, 2014). It has been recorded as one of the world's top 100 invasive organisms (De Barro *et al.*, 2011). Some evidence suggests that *B. tabaci* was native of India or Pakistan (Brown *et al.*, 1995) and now it was reported globally from all continents except Antarctica (Martin 1999, Martin *et al.*, 2000). It causes damage to more than 1000species of host plants (Abd-Rabou and Simmons 2010). It causes huge damage to cotton and other crops either by phloem feeding or curtailing the rate of leaf photosynthesis through the excretion of honeydew and provides adequate substrate for growth of sooty mould (Cuthbertson and Walters 2005, Jones *et al.*, 2008). The outbreaks of this pest were reported during 1985-87 and 1987-95 in Southern parts and Northern parts of India on various cultivated crops (Sharma and Batra 1995, Palaniswami *et al.*, 2001). Whitefly has been reported as a serious pest from past three years in a row in North India especially in Punjab, Haryana and Rajasthan (Kranthi 2015). Whitefly is multivoltine pest and has no diapause stage. Therefore, its adults reproduce continually throughout the year by moving sequentially among various host plants.

Insecticide application remains the most adequate way to control *B. tabaci* but indiscriminate use of insecticides, aggravated the cotton whitefly menace, on cotton. The first record of insecticide resistance in *B. tabaci* was reported from Sudanese cotton in early 1980's (Dittrich and Ernst 1983). Now, it has become very challenging to manage due to its ability to develop resistance to many commonly used insecticides i.e. organophosphates, pyrethroids, carbamates and neonicotinoids (Luo *et al.*, 2010, Wang *et al.*, 2017a). Recently, increase in resistance ratio was reported by Naveen *et al.*,(2017) for cypermethrin, deltamethrin, monocrotophos, triazophos, chlorpyrifos, thiamethoxam and imidacloprid from Punjab. Annexing diverseness to the insecticidal pool by divulging novel insecticides that are site specific by nature is one of the important strategy to conserve potency of insecticides for control of insect-pests.

Toxicity of insecticides: Laboratory bioassays are generally conducted to assess toxicity of any insecticide against any specific pest. These bioassays play an important role as they are less time consuming and in very short period of time one can obtain comparative toxicity data of various insecticides (Paramasivam and Selvi 2017)

Chandi *et al.*, (2017) recorded 79.97 and 82.68 per cent reduction in the population of whitefly after spraying with 50 mg a.i. per ha of pyriproxyfen. Kumar and Grewal (2014) reported LC_{50} values of various insecticides against whitefly adults. They reported 0.026, 0.119, 0.017, 0.046, 0.038, 0.036, 0.009 and 0.060 per cent LC_{50} values of pyriproxyfen against white fly from different locations in Punjab. They also reported 0.011, 0.015, 0.008, 0.011 and 0.023 per cent LC_{50} values of diafenthiuron against whitefly. Kumar *et al.*, (2016) reported 0.051 and 0.186 per cent LC_{50}

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values at 48 hours for pyriproxyfen and diafenthiuron against whitefly nymphs. The LC_{50} value after 72 hours was 0.013 per cent. Otoidobiga *et al.,* (2003) reported the susceptibility of first instar nymphs of *B. tabaci* to pyriproxyfen with LC_{50} values varying from 0.03-0.096 and 0.014-0.09 mg/l and with LC_{90} values varying from 0.24-1.59 and 0.11-0.9 mg/l. Similarly, for diafenthiuron LC_{50} varied from 5.1-8.8 and 3.5-6.7 mg/l and LC_{90} values varying from 15.1-25.4 and 11.1-31.3 mg/l were also reported for first instar nymphs of whitefly. Lee *et al.,* (2002) reported 86.8, 72.9 and 65.6 per cent mortality of nymphs of whitefly, when treated with 100, 50 and 25 ppm of pyriproxyfen, which was 37.9, 24.2 and 16.8 per cent in case of whitefly adults, respectively. The LC_{50} values of buprofezin and pyriproxyfen for laboratory population of whitefly second instar nymphs were 0.2 and 0.6 µg/ml and for field population, it was found to be 1.41 and 1.81 µg/ml, respectively (Basit *et al.,* 2012). The LC_{50} values of buprofezin for first, second, third and fourth stages of whitefly were 0.99, 10.93, 44.70 and 979.05 ppm, respectively (Sohrabi *et al.,* 2011).

Wang *et al.,* (2017b) found 8.45, 0.88, 6.28, 5.48 and 5.23 mg/l LC_{50} for imidacloprid, cycloxaprid, acetamiprid, thiacloprid and nitenpyram against whitefly adults using leaf-disc dip method, respectively. Recently, Naveen *et al.,* (2017) reported 780, 760, 428, 2114, 137, 664 and 109 mg/l LC_{50} values for cypermethrin, deltamethrin, triazophos, monocrotophos, chlorpyrifos, imidacloprid and thiamethoxam against whitefly from Punjab. Wang *et al.,* (2016) reported that the highest toxicity against *B. tabaci* adults was exerted by cycloxaprid followed by nitenpyram, acetamiprid, imidacloprid and thiamethoxam and also reported LC_{50} values 0.70, 4.55, 7.27, 15.70 and 19.28 mg per litre for these tested insecticides, respectively. LC_{50} and LC_{90} values of spirotetramat against various natural and resistant populations of second instar nymphs of *B. tabaci* varying from 0.91-27.98 and 8.79-133.55 µg/ml, respectively. The LC_{50} values of spirotetramat for third instar nymphs of *B. tabaci* were 2.12 and 4.30 µg/ml and LC_{90} were 25.21 and 40.59 µg/ml. Similarly, for fourth instar nymphs of *B. tabaci* the LC_{50} values of spirotetramat were 3.18 and 4.19 µg/ml and LC_{90} were 34.82 and 38.89 µg/ml (Prabhaker *et al.,* 2014). The LC_{50} values ranging from 0.2-0.65, 0.2-13.1, 0.2-31.3 and 0.2-25.1 µg/ml of acetamiprid, dinotefuran, imidacloprid and thiamethoxam were also reported for adults of whitefly, respectively (Castle and Prabhaker 2013). LC_{50} values 39.60, 52.35, 337.04 and 632.22 ppm for imidacloprid, bifenthrin, chlorpyrifos and carbosulfan, whereas the LC_{10} values 5.28, 10.02, 55.18 and 128.37 ppm for whitefly adults were reported by He *et al.,* 2013, using leaf dip method. Mann *et al.,* (2012) found LC_{50} value 0.53 mg/l for spiromesifen against laboratory population of *B. tabaci* nymphs. He *et al.,* (2011) reported 8.59, 30.86 and 53.54 ppm LC_{20}, LC_{40} and LC_{50} of imidacloprid for whitefly adults, in case of nymphs these were 44.98, 32.89 and 15.89 ppm, respectively. By using leaf dip method Naveen *et al.,* (2011) observed the LC_{50} values 0.0189, 0.0229, 0.0027 and 0.2748 per cent foracephate, acetamiprid, cypermethrin and imidacloprid, respectively against whitefly adults. Pinheiro *et al.,* (2009) calculated 0.24, 0.28, 0.38 and 0.56 per cent LC_{50} values of neem oil for first, second, third and fourth nymphal instars of whitefly, respectively.

Ovicidal effects of different insecticides: Several insecticides have ovicidal effects i.e. suppression of egg hatch. This effects the population of insect-pest. Ishaaya and Horowitz (1992) reported total suppression of egg hatch when eggs of *B. tabaci* were dipped in 2.50 mg a.i. per litre of pyriproxyfen. They also observed that older eggs of *B. tabaci* were less susceptible to pyriproxyfen than younger eggs. Ishaaya and Horowitz (1995) reported more than 90 per cent suppression of egg hatch of *B. tabaci* when 0 to 1 day old eggs were dipped in 0.1 mg per litre concentration of pyriproxyfen. Lee *et al.,* (2002) recorded 94.5, 85.7 and 79.6 per cent mortalities when the eggs of *B. tabaci* were treated with 100, 50 and 25 ppm concentration of pyriproxyfen, respectively and found pyriproxyfen (100 ppm) to be eight times more effective for egg hatch suppression than that of thiamethoxam (50 ppm). Xie *et al.,* (2014) reported different LC_{50} values for different insecticides against *B. tabaci* eggs. They reported 0.282, 0.330, 0.792 and 0.919 mg per litre LC_{50}values of pyriproxyfen against *B. tabaci* eggs and found that eggs were more susceptible to pyriproxyfen than cyantraniliprole and acetamiprid.

Sohrabi *et al.,* (2011) observed 88, 68 and 72 per cent mean egg hatch, when *B. tabaci* eggs were dipped in 2000, 8000 and 10000 ppm of buprofezin, respectively which was 91 per cent in case of control. They also calculated 151.0 ppm LC_{50} value for imidacloprid against whitefly eggs. He *et al.,*(2011) dipped *B. tabaci* eggs in different concentrations of imidacloprid and reported 83.77 ppm LC_{50} value for these eggs. Kontsedalov *et al.,* (2008) reported 2.6 mg per litre LC_{50} value of spiromesifen against whitefly eggs. They have also reported that eggs of *B. tabaci* treated with spiromesifen were significantly smaller in size, abnormally formed and improper localization of bacteriomes in it.

Sublethal influences of different insecticides on different parameters

Nymphal survival: Nymphal survival is generally a time period taken by the treated nymphs till development of 50 per cent formation of red-eyed nymphs. Mahmoud (2017) reported that pyriproxyfen gave the highest initial reduction in population of *B. tabaci* with mean 78.7 per cent, followed by orange oil and acetamiprid treatment of nymphal instars. Further, the residual effect also revealed that pyriproxyfen was the most effective treatment giving 81.2 per cent reduction in nymphal population of *B. tabaci*. Abbas and Farhan (2015) reported 78.1 and 80.4 per cent mortality of *B. tabaci* nymphs after 4 and 10 days of treatment with pyriproxyfen. Lee *et al.,* (2002) treated *B. tabaci* third instar nymphs with 100, 50 and 25 ppm concentration of pyriproxyfen and recorded 86.8, 72.9 and 65.6 per cent mortalities, respectively. Ishaaya and Horowitz (1995) recorded 38, 9 and 5 per cent adult emergence of *B. tabaci* when treated third instar nymphs with 0.008, 0.04 and 0.2 mg per litre of pyriproxyfen, respectively. Wang *et al.*, (2017c) reported that the survival percentage for different stages of *B. tabaci* by using leaf dip method for cyantraniliprole insecticide. The survival percentage of second nymphal instar of *B. tabaci* was significantly reduced from 96.47 per cent in case of untreated nymphs to 96.47 and 94.24 per cent in case of LC_{10} and LC_{25} treatments of cyantraniliprole. The survival percentage was significantly decreased of third instar nymphs of *B. tabaci* after LC_{10} (92.56 percent) and LC_{25} (90.15 percent) treatment as comparison to control (97.37 percent). There was no significant difference of survival percentage between cyantraniliprole treated adults and pseudopupal stages of *B. tabaci*.

Nymphal period: Nymphal period is total time taken from hatching of eggs (formation of first instar nymphs) to formation of red-eyed nymphs. Wang *et al.* ,(2017c) observed the sublethal effects on *B. tabaci* when the adults were exposed to LC_{10} and LC_{25} of cyantraniliprole. The development time of first, second, third and fourth nymphal instars of *B. tabaci* were significantly increased in cyantraniliprole exposed adults in comparison to control. The *B. tabaci* adults treated with LC_{25} of cycloxaprid leads to significantly increase in the duration of first, second, third and fourth nymphal instars in comparison to the adults treated with water (Wang *et al.*, 2016). When second nymphal instars of *B. tabaci* were treated with 100 and 200 mg per litre a.i. of piperonyl butoxide the nymphal period was increased to 3.90 and 4.15 days in comparison to 3.02 days in case of control (Qian *et al.*,2012).

Adult emergence: Certain insecticides suppress emergence of adult whitefly from nymphal stage. Ishaaya and Horowitz (1992) reported total suppression of adult emergence when second instar nymphs of *B. tabaci* were treated with 0.040, 0.200, 1.000 and 5.000 mg per litre of pyriproxyfen and similarly when third instar nymphs were treated with same concentrations more than 90 per cent suppression of adults was observed. Ishaaya *et al.*,(1994) when treated first instar nymphs of *B. tabaci* with 0.01 and 0.04 mg per litre of pyriproxyfen the per cent adult emergence was 88 and 40 respectively. Similarly, when third instar nymphs were treated with 0.01 and 0.04 mg per litre of pyriproxyfen the per cent adult emergence was totally suppressed. Ishaaya and Horowitz (1995) observed that when second and third instar nymphs of *B. tabaci* were treated with 0.04 to 1.00 mg per litre of pyriproxyfen, pupation level was similar to that of control, but more than 90 per cent of adult emergence was suppressed.

Adult longevity: Adult longevity is total survival period of an adult insect. Insecticides usually decrease adult longevity of insect-pests. Lee *et al.*,(2002) observed that the longevity of *B. tabaci* in case of males were significantly decreased to 7.6 and 4.7 days when pupae were treated with 0.1 and 10 ppm of pyriproxyfen which was7.1 and 3.5 days in case of females, respectively in comparison to 16.2 days in control. Sohrabi *et al.,* (2011) reported that buprofezin significantly reduced the adult longevity of *B. tabaci* to 4.9 days which was 11.7 and 8.3 days in case of imidacloprid and control treatments, respectively.

Sublethal influences of different insecticides on various reproductive parameters: Insecticides can affect various reproductive parameters of whitefly i.e. oviposition period, fecundity and egg hatchability.

Oviposition period: Oviposition is a complex event involving laying of eggs in insects. It is sub divided into pre oviposition and post oviposition. Insecticides affect both pre-oviposition and post oviposition in insect-pest. Lee *et al.*,(2002) reported increase in pre-oviposition period of *B. tabaci* adults to 3.4 and 4.1 days when pupae were treated with 0.1 and 10 ppm of pyriproxyfen, which was 2.5 days in case of control. Wang *et al.*, (2017c) reported that the oviposition duration of *B. tabaci* was reduced from 11.15 days to 9.80 and 9.65 days in case LC_{10} and LC_{25} treatments of cyantraniliprole, respectively. Wang *et al.*, (2016) observed that the oviposition period was significantly decreased when *B. tabaci* females were treated with LC_{25} of cycloxaprid in contrast to control.

Fecundity: Fecundity is measure of reproductive success of an insect, expressed as number of eggs laid by female. The number of eggs laid per female of *B. tabaci* treated with 10 ppm of pyriproxyfen decreased 95 per cent as compared to the control. Thiamethoxam affected the number of eggs laid by a decrease of 89.6 per cent as compared to control (Lee *et al.*,2002). Sohrabi *et al.,* (2011) observed that the egg laying of *B. tabaci* in case of imidacloprid and control treatments was 75.43 and 46.7 eggs, while it was significantly reduced to only 12.8 eggs in case of buprofezin treated adults. Qu *et al.,* (2017) observed reduction in egg laying per female of two cryptic species i.e. MEAM1 (112.47 eggs) and MED (129.67 eggs) of *B. tabaci*, when exposed to LC_{25} of dinotefuran, in contrast to 136.07 and 153.47 eggs in untreated adults, respectively. When *B. tabaci* adults exposed to LC_{10} and LC_{25} of cyantraniliprole fecundity was significantly reduced to 112.40 and 112.85 eggs per female, respectively as compared to the 131.55 eggs per female in case of control condition (Wang *et al.,* 2017c). There was also reduction in the fecundity of *B. tabaci* females treated with cycloxaprid in comparison to control (Wang *et al.,* 2016). *B. tabaci* adult females exposed to 40 ppm of bifenthrin and 200 ppm of chlorpyrifos leads to reduction in fecundity with 37.20 and 93.20 eggs, respectively in comparison to control (He *et al.,* 2013). The significant decrease in fecundity of *B. tabaci* females was observed when treated with LC_{20} and LC_{40} of imidacloprid to 2.24 and 1.96 eggs per female in contrast to 6.4 eggs per female in control (He *et al.,* 2011). Fang *et al.,* (2018) reported reduction in fecundity of *B. tabaci* when exposed to LC_{25} of clothiandin.

Egg hatchability: Egg hatchability is term basically used to describe viability of eggs in insect. Lee *et al.,*(2002) reported that the egg viability *B. tabaci* was decreased to 89.2 per cent when pupae were treated with 10 ppm of pyriproxyfen in comparison to control. Ishaaya and Horowitz (1995) observed that the treatment with relatively low concentrations (1-25 mg per litre) of pyriproxyfen on the upper surface of cotton leaves, totally suppressed egg hatchability of *B. tabaci* females present on the lower surface of leaves. Ishaaya *et al.,*(1994) exposed *B. tabaci* females to pyriproxyfen treated tomato leaves for 48 hours and recorded total suppression of egg hatch. The after effect or residual effect of pyriproxyfen is observed in exposed *B. tabaci* females even when they are transferred to un treated leaves i.e. there was only 43 percent egg hatchability in comparision to control group (98 percent). Ishaaya and Horowitz (1992) accounted totally suppression of egg hatch of *B. tabaci* females 48 hours after treatment with 5 and 25 mg a.i. per litre of pyriproxyfenon upper surface of cotton leaves. When, these *B. tabaci* females were transferred to untreated leaves the egg hatching was also suppressed which was only 6 and 7 per cent in treatment with 5 and 25 mg a.i. per litre of pyriproxyfen. Sohrabi *et al.,* (2011) observed that the egg hatching of *B. tabaci* in case of imidacloprid and control treatments was 87.42 and 87.73 per cent, while it was significantly suppressed to only 66 per cent in case of buprofezin treated adults. Wang *et al.,*(2017c) observed that the egg hatching of *B. tabaci* adults treated with LC_{25} of cyantraniliprole was suppressed to 86.46 per cent significantly as comparison to 92.51cent in case of control. Wang *et al.,*(2016) reported significantly decrease in the egg hatching of *B. tabaci* females treated with LC_{25} of cycloxaprid in comparison to untreated females. Kontsedalov *et al.,* (2008) found that when *B. tabaci*adults were treated with 0.05 and 0.5 mg per litre concentrations of spiromesifen the per cent egg hatch was significantly decreased as compared with the control. The per cent egg hatch of *B. tabaci* in the control was 90 per cent across seven days, however, when the females were treated with 0.5 mg per litre of spiromesifen, egg hatching was totally suppressed from the first day of treatment.

Translaminar effect of different insecticides: Translaminar insecticides are the insecticides which penetrate in the leaf tissues and form a reservoir of active ingredient within the leaf and which further provides a residual activity against certain pests which are feeding on these plants. The active ingredient of these insecticides can move through leaves so these can be effective against the insect-pests which normally feed on underside of the leaves e.g. whitefly, jassid and two spotted-spider mite in cotton plant. Pyriproxyfen also have a translaminar activity against B. tabaci (Ishaaya and Horowitz, 1995). The literature pertaining to the translaminar effect of various insecticides is reviewed as follows: Ishaaya and Horowitz (1995) treated upper surface cotton leaves having eggs of *B. tabaci* on underside of leaves, with different concentrations of pyriproxyfen and further observed the translaminar activity by calculating the per cent egg hatch. There was totally suppression of egg hatch of *B. tabaci* in case of leaves treated with 5 and 25 mg per litre concentration of pyriproxyfen. There was only one per cent egg hatching in case of plants treated with one mg per litre of pyriproxyfen and 84 per cent in case of plants treated with water. Similarly, Ishaaya *et al.,* (1994) observed only 53 and 8 per cent egg hatch of *B. tabaci* when the upper surface of tomato leaves, having eggs on lower surface were treated with 5 and 25 mg per litre concentration of pyriproxyfen, which was 90 per cent in case of untreated leaves. Ishaaya and Horowitz (1992) reported total suppression of egg hatch of B. tabaci eggs, when the eggs which were laid on the lower surface of cotton plant were treated with 1, 5 and 25 mg per litre of pyriproxyfen. Further, egg hatching was also suppressed for an additional period when the females of *B. tabaci* were transferred to untreated leaves. Valle *et al.,*(2002) observed the translaminar activity of pyriproxyfen, buprofezin, cartap, acephate and fenpyroximate by spraying on upper surface soybean leaves,having first instar nymphs of *B. tabaci* on lower surface of leaves. Only pyriproxyfen showed 84 per cent inhibition of adult emergence and the other insecticides does not have a significant effect on adult emergence of *B. tabaci* treated nymphs. Barry *et al.,* (2015) treated the upper surface of cotton and tomato plants having population of *B. tabaci* nymphs with cyantraniliprole to check its translaminar activity. The LC_{50} values of cyantraniliprole for cotton and tomato treated plants having population of *B. tabaci* nymphs was 154 and 11.2 mg per litre, respectively. Translaminar activity also reported for spiromesifen against first instar nymphs of *B. tabaci* with LC_{50} and LC_{90} of 18 and 106 mg a.i. per ml, respectively (Kontsedalov *et al.,* 2008). Nauen *et al.,* (2008) examined the translaminar activity of spirotetramat and imidacloprid against nymphs of *B. tabaci* after spraying it on the upper surface of cotton plant leaves. There was almost 98 and 82 per cent mortality of nymphs of *B. tabaci* at the concentration of 24 and 120 g per ha of spirotetramat and imidacloprid, respectively and further the fecundity of females were also reduced in case of insecticide treated females.

CONCLUSION

Insecticide causes direct toxic effects on the whitefly leading to mortality of pest and could also leads to sublethal effects such as, decreased nymphal survival and adult longevity, increased nymphal period, suppression of adult emergence, decreased oviposition period, fecundity and egg viability. The toxicity studies and physiological bioassays can help in screening of new insecticides that can act as good management tool for control of whitefly.

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