The efficacy of certain insecticides against whitefly, *Bemisia tabaci* (Genn.) on tomato and their effects on fruit quality

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Abstract: The efficiency of sulfoxaflor, cyantraniliprole, imidacloprid and azadirachtin were evaluated against whitefly, *Bemisia tabaci* on tomato under field conditions. Two experiments in season 2021 showed that sulfoxaflor , cyantraniliprole and imidacloprid were the most effective insecticides compared to azadirachtin. Sulfoxaflor gave the highest reduction of *B.tabaci* one day after treatment (initial kill). The results also showed that the infestation of *B.tabaci* can be greatly reduced by spraying sulfoxaflor and cyantraniliprole. Tomato fruit yield was significantly increased after an application of all the tested insecticides when compared to untreated control. All the insecticides caused a slight but significant decrease in fruit quality attributes. Overall, our findings indicated that sulfoxflor and cyantraniliprole can suitably be included in IPM program of whitefly control in tomato. However, the potential side effects on tomato fruit should be considered.

Keywords: whitefly, tomato, sulfoxaflor, cyantraniliprole, fruit quality

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is an important vegetable crop grown worldwide, and the second after potato (Govindappa *et al*. 2013). According to data from FAO in 2020; the world produced 186,821 million tons of tomatoes cultivated on 5,051,983 hectares in which Egypt ranked fifth with 6,731.22 million tons cultivated on 170,862 hectares (FAO 2020). Tomato is a major component of Egyptian diet and is consumed almost daily – fresh, cooked or processed (canned product or paste). Tomato is globally more prone to insect pests, mainly due to its tenderness and softness as compared to other crops. A number of insect pests and non-insect pest species are reported to attack tomato fields (Lange & Bronson 1981, Wade *et al*., 2020). The most economically important insect pests substantially reducing yield and fruit quality are whitefly, aphids, caterpillars, leaf miner, fruit borers, thrips and jassids (Filho *et al.* 2006, Katroju *et al.* 2014).

However, among those insect pests, the sap-sucking insect whitefly *Bemisia tabaci* (Gennadius, 1889) is considered one of the most threatening and damaging insect pests worldwide. Gameel (1972) indicated that whitefly showed to deprive its host plants of growth and reduce the yield both quantitatively and qualitatively. The whitefly is a pest of more than 600 different cultivated and wild plant species (Oliveira *et al.* 2001). It causes direct damage through phloem feeding and injection of toxins and indirect damage due to its ability to transmit plant viruses (Pereira *et al.* 2004, Brown 2010). It is a vector of more than 300 plant viruses in which the tomato leaf curl virus (TLCV) causes significant yield loss (Jones 2003, Hogenhout *et al.* 2008). Moreover, whitefly infestation leads to the production of honeydew, which reduces photosynthesis and causes the growth of sooty mold fungi on the plant leaf and fruit

surface affecting photosynthesis efficiency (Stansly & Natwick 2010).

Chemical control of the whitefly with conventional insecticides (organophosphates, carbamtes and pyrethroids) is widely popular with tomato farmers and producers in Egypt. However, the recurrent use of these insecticides has led to insecticide resistance and loss of efficacy, as well as other side effects on the environment and non-target organisms. Sulfoxaflor is a new systemic insecticide belongs to sulfoximine acting on the nicotinic acetylcholine receptors (nAChRs) in the nervous system of pests (Cutler *et al.* 2013). It is highly effective against sucking insects and used in various vegetable, and fruit crops. It provides continuous protection through major period of the crop growing season. As sulfoxaflor binds much more strongly to insect neuron receptors, it is selectively more toxic to insects than mammals (Tomizawa & Casida 2003). The other novel systemic insecticide; cyantraniliprole which belongs to anthranilic diamide, is a powerful tool for controlling adult and immature stages of whitefly, and for reducing the transmission of plant viruses (Grávalos *et al.* 2015). It acts as a ryanodine receptor modulator by depleting calcium needed for insects' muscle contraction.

Therefore, the main objective of this study was to evaluate the bioefficacy of above mentioned insecticides under field conditions against whitefly on tomato compared with imidacloprid and Azadrirachtin.

Materials and methods

Four insecticides were tested in this study as shown in Table 1.

Table 1The tested insecticides.

Common name	Trade name/ formulation	Chemical group	Manufacturer
Sulfoxaflor	Closer 24% SC	Sulfoximine	Dow Agroscience
Cyantraniliprole	Benevia 10% OD	Anthranilic diamide	Du Pont
Azadirachtin	Neemix 4.5% EC	---------	Stanes
Imidacloprid	Mallet 35% SC	Neonicotinoids	Nufarm

Laboratory studies

Whiteflies were reared on cotton seedling in standard laboratory conditions according to the method of Dittrich & Ernest (1983). Tomatoes (var. Sama) were grown in an open field without exposure to any insecticide. Leaf discs (30 mm in diameter) were immersed into serial concentrations of aqueous solution of the commercially-tested insecticides for 20 seconds, and then air-dried for one hour, and laid in an adaxial side of petri dishes (3 cm diameter) containing 2% agar gel. Another set of leaf discs was dipped in water and served as control. The petri dishes had 4 holes covered with metal screen for ventilation and 5 replicates were used. Twenty adults of whitefly were transferred onto the treated leaf discs using fine brush. Mortality of adults was corrected after 24 h by Abbott's formula (Abbott 1925). The LC_{50} values were calculated with Probit analysis using Ldp line (Ehabsoft V.1.0 software).

Field evaluation

Two field experiments were carried out during the 2021 growing season to assess the biological evaluation of the four tested insecticides under open field conditions. The experiments were conducted at the Agricultural Experimental Station, Faculty of Agriculture, Cairo University, Giza, Egypt. Seedlings of tomato plants (var. Sama) were

transplanted on the first of August 2021. An area of 2,000 m² was divided into 5 equal plots (4 treatments of insecticides and one as untreated control) and separated from each other to reduce the drift effect. The experiment was set in a randomized block design and the insecticides were applied once in foliar at the recommended field rates using a knapsack sprayer. The application started on September 15 when infestation reached 5 nymphs per leaf. The efficacy of tested insecticides against nymphs was estimated after 1, 3, 5, 7, 10 and 15 days of spraying according to the official evaluation protocol of the Ministry of Agriculture. Twenty-five leaves were randomly collected and inspected in three levels of plant (the upper, middle and lower one) per each replication of treatment. The adults of whitefly were recorded in the field, and then the nymphs were examined in the laboratory under a binocular microscope. The percentage reduction in infestation was calculated according to Henderson and Tilton (1995). Fruit was harvested on 1/11/2021 and continued to 1/12/2021. Fruit sampling was made by weighing the fruit coming from 1 m² (3 times) in every plot. The mean of three m² was taken to represent the productivity of this plot. Tomato fruit was stored at -20° C until further biochemical analysis.

Determination of major chemical components in fruits

a - Protein content

The protein content was determined as the total nitrogen in the dried fruit using the modified- micro- Kjeldahl method as described by Peach and Tracy (1956):

$$\% \ Nitrogen = \frac{(ml \ standard \ acid \ - \ ml \ blank) \ x \ N \ of \ acid \ x \ 1.4007}{weight \ of \ sample \ in \ grams}$$

b- Carbohydrates

A known weight (0.2-0.5 g) of the dried ground sample was placed in a test tube, and then sulfuric acid (10 ml 1N) was added and the tube was sealed, and placed overnight in an oven at 100º C and the carbohydrate was measured according to Dubois *et al.* (1956).

c - Ascorbic acid

Vitamin C content as ascorbic acid (mg) was measured in fresh fruit spectrophotometrically according to Helrich (1990).

d - Carotenoids and lycopene

Carotene and lycopene were extracted from fresh fruit and quantified chromatographically using high performance liquid chromatography (HPLC) by the method of Khalil & Varananis (1996). Perkin Elmer HPLC with LC-1000 pump (Isocratic), having C_{18} column and connected with LC 250 UV/VIS detector was used. HPLC mobile phase (Acetonitrile, dichloromethane and methanol by the ratio of 70:20:10, respectively) at the rate of 2ml per minute. Wave length was fixed at 452 nm. The pressure of the column was kept 1800-2000 PSI. The peak was automatically identified and quantified by comparing the retention time of the sample with the standard retention time.

Statistical analysis

Data were analyzed using a one-way analysis of variance (ANOVA) with MSTAT-Cv.2.10 software package followed by LSD test at 0.05 for comparison between treatments and expressed as mean ±SD. Duncan's Multiple Range-test was used to determine significant differences between the mean values of treatments according to Snedector & Cochran (1989).

Results

Laboratory studies

The result in Table 2 shows the toxicity of the four tested insecticides: imidaclopride, cyantraniliprole, sulfoxaflor, and azadirachtin

to the whitefly. The tested insecticides were arranged according to their toxicity based on LC_{50} values in the following descending order: sulfoxaflor (17.11 ppm), cyantraniliprole (17.94 ppm), azadirachtin (36.41 ppm) and imidaclopride (38.43 ppm). Data indicated that sulfoxaflor was more effective than the other tested insecticides for *B. tabaci* adults. On the other hand, the neonicotonid insecticide imidaclopride was less efficacious. The results confirmed that sulfoxaflor, cyantraniliprole and azadirachtin were more toxic to whitefly than imidaclopride. The toxicity indices of the tested insecticides: cyantraniliprole, azadirachtin and imidaclopride were 95.37, 46.99 and 44.52% as toxic as sulfoxaflor.

Table 2. Toxicity of the tested insecticide to *Bemisia tabaci* adults.

Common name	Lethal concentration (LC) μg/ml			Slope	Toxicity index at LC_{50}
	LC_{25} Limit confidence	LC_{50} Limit confidence	LC_{90} Limit confidence		
Cyantraniliprole	8.24 (6.33 - 10.08)	17.94 (15.09 - 21.52)	78.72 (57.89 - 122.36)	1.995	95.37
Sulfoxaflor	7.63 (5.81 - 9.37)	17.11 (14.43 - 20.27)	79.35 (58.99 - 121.03)	1.923	100
Imidacloprid	19.06 (14.76 - 23.20)	38.43 (32.44 - 45.28)	145.69 (113.25 -206.19)	2.214	44.52
Azadirachtin	16.01 (11.87 - 19.99)	36.41 (30.25 - 43.72)	173.46 (127.08 -271.83)	1.89	46.99

Field evaluation of the tested insecticides

The first experiment

The first field evaluation experiment of the tested insecticides is presented in Figure 1.

Results indicated that there were significant differences in nymph numbers between the untreated control and the insecticide treatments and also differences occurred among the tested insecticides.
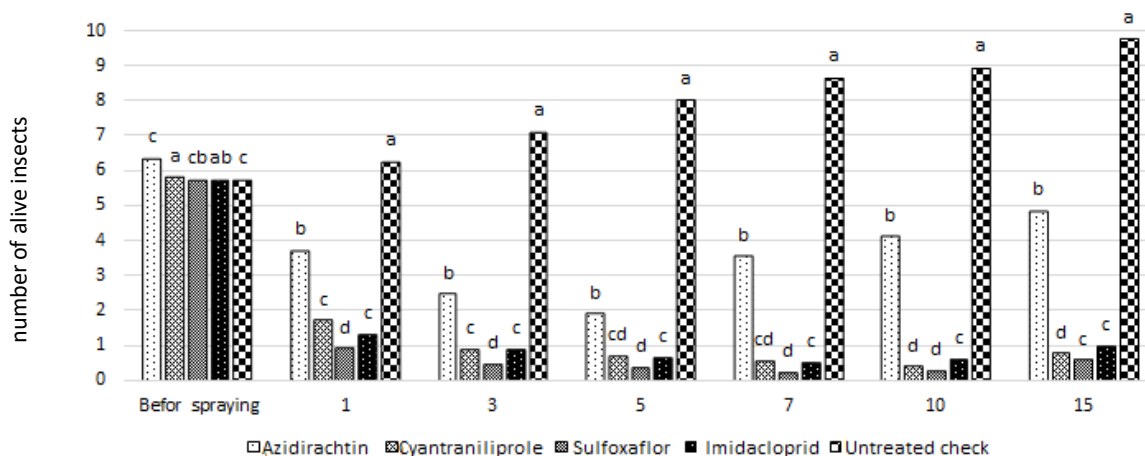

Fig. 1. Mean number of alive whitefly nymphs before and after spraying tomato plants during 2020 season (first experiment). Means followed by the same letter do not differ significantly.

The number of whitefly nymphs per leaf decreased from 5.75, 6.35, 5.8 and 5.75 before spraying to 1.3, 3.71, 1.7 and 0.9 after one day of application with imidacloprid, azadirachtin, cyantraniliprole and sulfoxaflor, respectively. Regarding the initial kill, all the tested insecticides gave excellent control of whitefly nymphs except for azadirachtin. However, sulfoxaflor was the most effective in decreasing the number of whitefly nymphs. The numbers of whitefly after three days of application were 0.44, 0.87, 0.87 and 2.45, for sulfoxaflor, cyantraniliprole, imidacloprid and azadirachtin respectively, whereas the corresponding values after five days were 0.35, 0.7, 0.63 and 1.9 respectively. A similar trend was obtained also after 15 days, as the numbers recorded were 0.57, 0.76, 0.97 and 4.53, respectively. Based on the mean number of whitefly nymphs at the estimated intervals, the highest effectiveness was found after the application of sulfoxaflor, followed by imidacloprid and cyantraniliprole. The data concerning percentage reduction in infestation is shown in Figure 2.
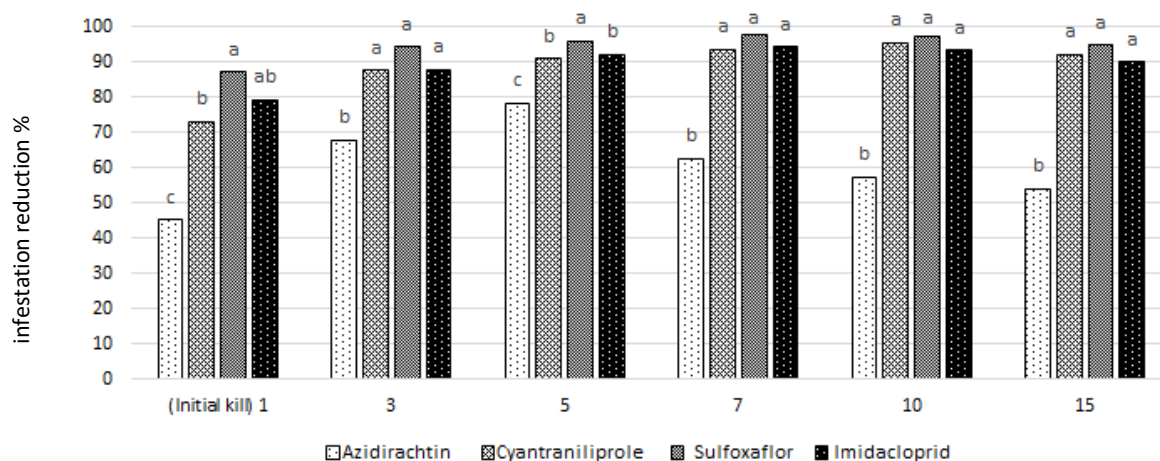

Fig. 2. Percent reduction in infestation of whitefly nymphs after spraying tomato plants during 2020 season (first experiment). Means followed by the same letter do not differ significantly.

Most of the tested insecticides reduced infestation with whitefly nymphs during time interval. One day after spraying (initial kill), sulfoxaflor, cyantraniliprole and imidacloprid caused infestation decline of whitefly nymphs, while azadirachtin offered the lowest initial kill. The percentage reduction in infestation was 87.3, 79.5, 73.3 and 45.4% after spraying sulfoxaflor, imidacloprid, cyantraniliprole and azadirachtin, respectively. After three days, the corresponding values were 94.5, 87.9, 87.8 and 68.1%, respectively. The percentage of reduction in infestation slightly increased in case of sulfoxaflor, imidacloprid, and cyantraniliprole to 97.3, 93.7 and 95.7%, respectively. On the other hand, these values decreased from 78.4% after five days to 57.5% after ten days of the application of azadirachtin. The tested insecticides can be arranged according to the residual effect into three categories: The first category includes sulfoxaflor (96.1%), the second group includes cyantraniliprole and imidacloprid (92.14 and 91.58%), respectively and the third group includes the botanical pesticide azadirachtin (64.22%).

The second experiment

There were no significant differences in the efficacy of the tested insecticides in the two experiments. Similar trend in the second experiment was obtained. As shown in

Figure 3 the infestation of tomato with whitefly nymphs decreased after one day of application to 1.13, 1.58, 2.09 and 3.42 per leaf with sulfoxaflor, imidacloprid, cyantraniliprole and azadirachtin, respectively.
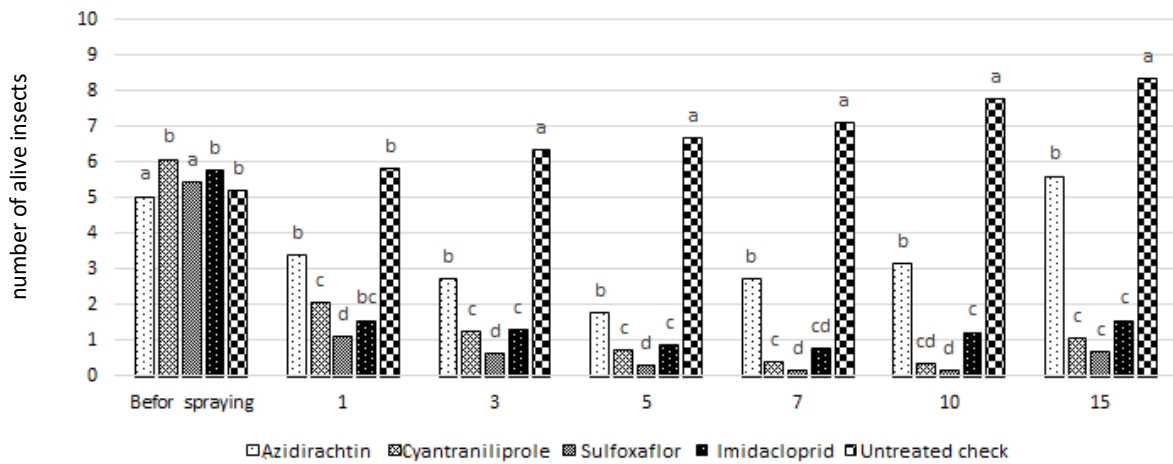

Fig. 3. Mean number of alive whitefly nymphs before and after spraying tomato plants during second experiment 2020 season. Means followed by the same letter do not differ significantly.

After three days, the number decreased after the application of sulfoxaflor, imidacloprid, cyantraniliprole and azadirachtin to 0.67, 1.33, 1.28 and 2.74, respectively. The corresponding values after seven days were 0.19, 0.78, 0.4 and 2.74, respectively. However, after 15 days, the recorded numbers were 0.72, 1.58, 1.07 and 5.62, respectively. The mean infestation number ranged from 0.53 per leaf in case of sulfoxafior to 3.25 after treatment with azadirachtin Figure 3. Data concerning percentage reduction in infestation were presented in Figure 4.
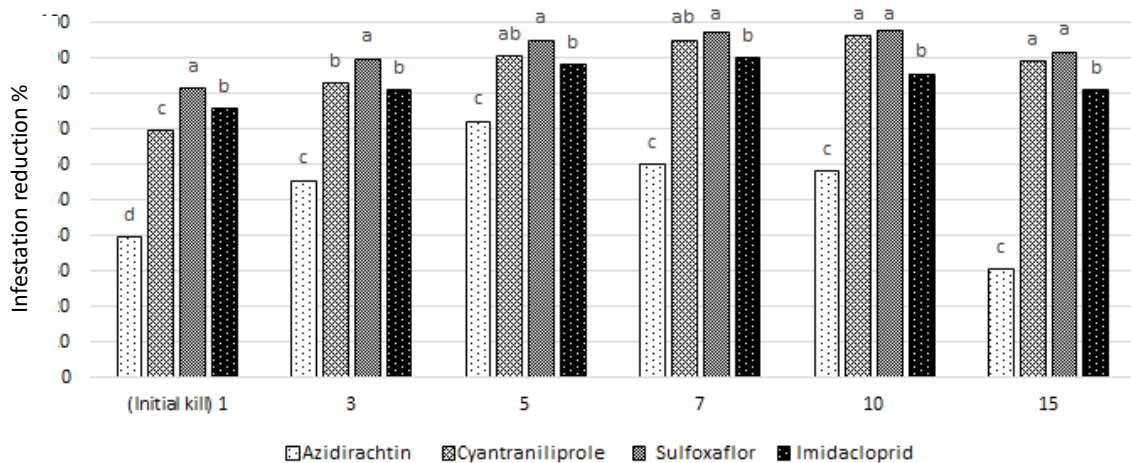

Fig. 4. Percent reduction in infestation of whitefly nymphs after spraying tomato plants during 2020 season (second experiment). Means followed by the same letter do not differ significantly.

After one day of application (Initial kill) infestation reduction was 81.6, 75.8, 69.7 and 39.8% for sulfoxaflor, imidacloprid, cyantraniliprole and azadirachtin, respectively. The corresponding values after five days were 95.2, 88.3, 90.7 and 72.4%, respectively. Seven days after application, the tested insecticides were able to keep the

reduction in infestation more than 90% except for azadirachtin, which gave only 60.3%. Also, all insecticide exhibited excellent control by more than 80% until fifteen days after application except for azadirachtin, which showed only 30.7%. The tested compounds could be arranged according to their reducing the population of whitefly nymphs in the following descending order: sulfoxaflor, cyantraniliprole and imidacloprid.

The data obtained from the two experiments indicated that the tested insecticides could be classified into four groups based on their initial kill and residual effect in the first and second experiment, respectively. The first group includes sulfoxaflor, with initial kill and residual effect more than 90 and 94.48%, respectively. The second group includes cyantraniliprole with initial kill more than 82.9 and the residual effect more than 90.82%. The third group includes imidacloprid, which had initial kill of 79.5% and 75.8%. Azadirachtin represented the fourth group, as lower control was obtained.

Effect of the tested insecticides on yield and some quality attributes

The results in Figures 5 & 6 indicated that plants treated with sulfoxaflor and cyantraniliprole significantly increased tomato yield as they exhibited the maximum fruit yield increase of 63.1 and 52.6% respectively, compared to the untreated plots. While there were no significant differences of tomato yield in plants treated with azadirachtin and imidacloprid related to untreated check. This result supports our efficacy studies in the field, as sulfoxaflor and cyantraniliprole were the most efficient insecticides for *B. tabaci*. This may be due to lower plant sap sucking by insect in the treated plants which reflect on and contribute to higher yield.

Regarding major parameters of fruit chemical constituents, (Fig. 5 & 6), plots treated with insecticides significantly reduced ascorbic acid, lycopene, carotene and carbohydrate contents in fruits compared to untreated plants. However, no significant differences in protein were found among the four insecticides and/or related to the control plots.
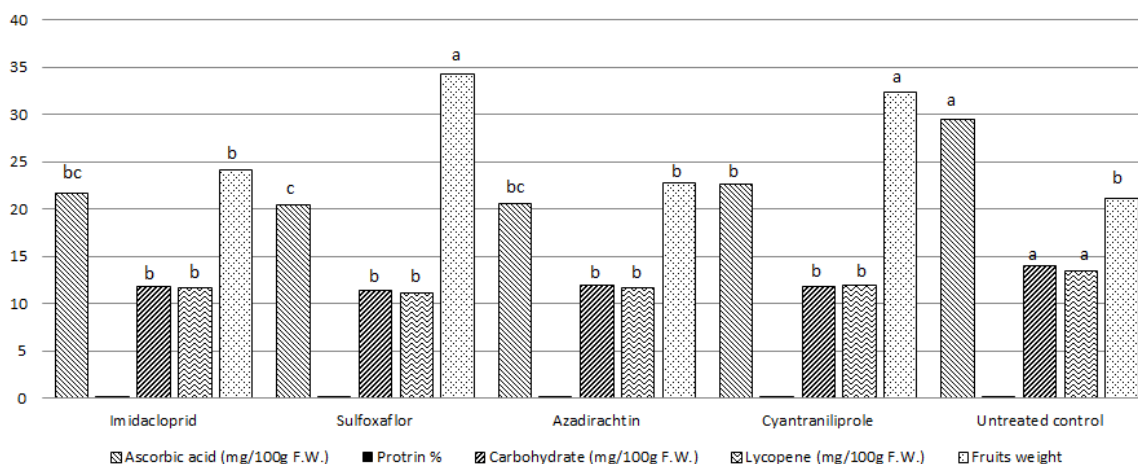

Fig. 5. Effect of the tested insecticides on fruit yield and quality attributes. Means followed by the same letter do not differ significantly.
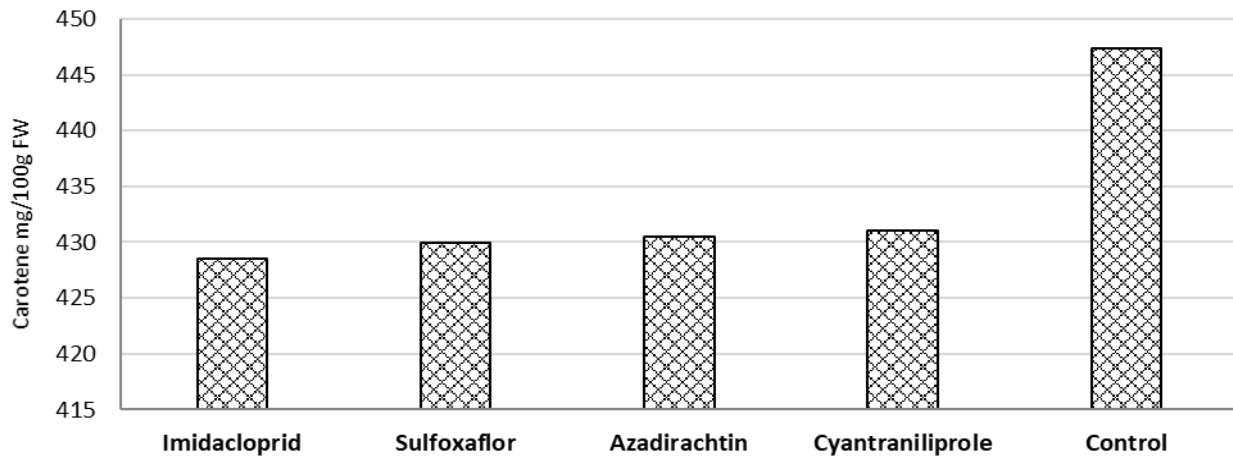
Fig. 6. Effect of the tested insecticides on carotene content in tomato fruits.

Disucssion

The overall results manifest that to achieve effective control of whitefly soon after infestation (the first week after application), sulfoxaflor proved to be the most effective insecticide. This result agree with Jahel et al. (2017), Barrania et al. (2019) and Longhurst et al. (2012) who reported that sulfoxaflor exhibited very low resistance ratio when tested against strains of B. tabaci indicating that sulfoxaflor is a new effective tool for the controlling plant sap-feeding pests which are resistant to conventional insecticide groups. Cyantraniliprole as an xylem systemic insecticide in the new anthranilic diamide class provided excellent whitefly control which is in line with Caballero et al. (2015), Gouvea et al. (2017), and Kar (2017). Moreover, Govindappa et al. (2013) pointed out that cyantraniliprole 10% OD at 60 and 75 g.a.i ha^{-1} caused 100% mortality at 48 hrs after treatments and also recorded the least virus transmission (10 and 5%, respectively). Imidacloprid was the most effective treatment with 100% control of pest population at five days after spray also with minimum population at 10 and 15 days after spray (Kumar 2018, Abdel-Elrazik et al. 2018). Also, Thorat et al. (2020) and Simkhada & Paneru (2010) revealed that imidacloprid was more effective in decreasing whitefly

population. Additionally, lowest whitefly population (2.18 adults /leaf) was also recorded in imidacloprid treated plants. In the present study azadirachtin was found to be the least effective against population of whitefly. These results are similar to those attained by Jahel et al. (2017) and Thorat et al. (2020).

In general, our results showed that all the treatments were significantly superior over the untreated control plots in reduction of whitefly populations. Nevertheless, the tested insecticides exhibited fairly different effect which could be due to the variability in insecticide characteristics influencing the movement in plant tissues, such as water solubility, which greatly affect their toxicity, especially on plant sucking insects Cloyd & Bethke (2011). It could be also attributed to the recent introduction of sulfoxaflor and cyantraniliprole for controlling B.tabaci, which develops resistance to other classes of insecticides, including neonicotinoids Wang et al. (2017). The higher activity obtained by sulfoxaflor over other treatments may be due to its mode of action as an agonist at insect nicotinic acetylcholine receptors (nAChRs) and exhibits structure activity relationships that are different from other nAChR (Liao et al. 2017), Watson et al. (2017), Sparks et al. 2013).

Regarding fruit yield, Aktar et al. (2009) declared that substantial yield loss occurs

without use of insecticides, but significant yield increase is resulted from insecticide application. This result also agrees with Shiberu (2020), Kandil *et al.* (2020) and Glover *et al.* (2008) who stated that insecticides caused significant increase in fruit quantity values. Our data are also in par with Govindappa *et al.* (2013), who found that the tomato yield was higher in plots that received cyantraniliprole 10 OD. Very limited literature is available on the impact of pesticides on plant and their fruit quality. The effect of insecticides on major fruit chemical constituents is poorly investigated Saladin & Clément (2005). Our results as shown in Figures (5&6) illustrated that all plots treated with insecticides reduced ascorbic acid, lycopene, carotene and carbohydrate contents in fruits compared to untreated plants. However, protein content did not significantly change among the four insecticides and /or the control plots. This data disagree with Shalaby & Gad (2016) who found that carotenoids, ascorbic acid, lycopene, total protein in tomato fruits were significantly increased after insecticide application compared with those obtained for untreated control. Conversely, the present results are in line with Chauhan *et al.* (2013) who found that imidacloprid decreased carbohydrate, ascorbic acid contents of potatoes but increased the total protein content and antioxidant enzymes. AL-Eed (2007) also pointed out that carbohydrate contents were significantly decreased in the insecticide-treated tomato plots when compared with control, which is in harmony with the obtained data. Despite the role of insecticides to protect crops against insect pests, crops can be affected in a different manner. Pesticides are known to interfere with the biochemical and physiological processes of plants, lowering their food quality and negatively affect chemical composition and alter its quality attributes as reviewed by Chauhan *et al.* (2013) and Sharma *et al.* (2019). Moreover, in a study by

Radwan *et al.* (2004) the profenofos residues in eggplant fruits significantly decreased the total soluble sugars, % dry matter and total protein, but had no adverse effect on the ascorbic acid and carotene content . Costa *et al.* (1987) demonstrate that the possible effects on fruit quality should be considered and taken into account when insecticides are applied in order to avert their effects on fruit constituents. Carotenoid is important antioxidant and is essential to human growth, normal physiological functions, health of the skin as well as mucus membranes. Vitamin C is an antioxidant and is necessary to several metabolic processes as stated by Griffiths & Lunce (2001). The impact of insecticides on chemical composition of tomato might depend on the environmental factors and the chemical structure of the insecticide Al-Eed (2007). Sharma *et al.* (2019) referred this negative effect to the impact on plant growth and development, pigment system, photosynthetic efficiency and protein content.

It can be concluded that all tested insecticides were effective to control whitefly compared with the control. Furthermore, sulfoxaflor and cyantraniliprole are the preferred insecticides with higher efficacy and can be used for tomato in the IPM programs to provide growers with new options for whitefly control. The study also presented the potential effect of the insecticides on tomato fruit quality parameters that should be considered before marketing to avoid side effects of the insecticides.

Acknowledgements

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