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Study on survival of the sugarcane whitefly, *Neomaskellia andropogonis* (Hemiptera: Aleyrodidae) on two sugarcane varieties treated with different insecticides

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Abstract
Sugarcane whitefly, *Neomaskellia andropogonis* Corbett is one of the relatively new pests of sugarcane fields in Iran. Control of this pest is an arduous work if its populations reach outbreak level. It seems using chemical insecticides along with resistant varieties can reduce pest population to an acceptable level after reaching economic injury level. In this study, the efficacy of three insecticides with different mode of actions including; deltamethrin, dinotefuran, and spiromesifen was examined on survival percentage of different life stages of sugarcane whitefly on IRC99-02 and CP69-1062 varieties of sugarcane. Among evaluated insecticides, deltamethrin had the most toxic effect against the adults of *N. andropogonis* with LC_{50} values of 39 and 62 ppm on IRC99-02 and CP69-1062 varieties, respectively. The higher concentrations of all insecticides significantly decreased egg hatching rate, survival percentage of nymphs, pupae and adults on both sugarcane varieties. The results revealed that evaluated insecticides, considering their different mode of actions, can be used alternatively in integrated management of the sugarcane whitefly along with the mentioned sugarcane varieties. However, in order to confirm these findings, complementary experiments regarding ecological risk assessment and determination of insecticides MRLs in yield are necessary.
Keywords: deltamethrin, dinotefuran, spiromesifen, sugarcane whitefly, variety.

بررسی بقای سفیدبالک نیشکر، *Neomaskellia andropogonis* (Hemiptera: Aleyrodidae) روی دو رقم نیشکر تیمار شده با حشره‌کش‌های مختلف

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چکیده
سفید بالک نیشکر، *Neomaskellia andropogonis* Corbett یکی از آفات نسبتاً جدید مزارع نیشکر ایران است. کنترل این آفت به ویژه زمانی که جمعیت آن به سطح طغیانی برسد دشوار است. به نظر می‌رسد بکارگیری حشره‌کش‌های شیمیایی همراه با ارقام مقاوم بتواند جمعیت آفت را پس از رسیدن به سطح زیان اقتصادی به میزان قابل قبولی کاهش دهد. در این مطالعه، کارایی سه حشره‌کش با نحوه تاثیر متفاوت شامل دلتامترین، دینتفوران و اسپیرومسیفن روی درصد بقای مراحل مختلف زیستی سفیدبالک نیشکر روی رقم‌های IRC99-02 و CP69-1062 بررسی شد. در میان حشره‌کش‌های مورد آزمایش، دلتامترین به طور معنی‌داری سمیت بیشتری روی حشرات بالغ *N. andropogonis* داشت و LC_{50} آن روی رقم‌های IRC99-02 و CP69-1062 به ترتیب ۳۹ و ٦۲ پی‌پی‌ام بود. غلظت‌های بالای همه حشره‌کش‌های مورد آزمایش به طور معنی‌داری نرخ تفریخ تخم، درصد بقای پوره‌ها، شفیره‌ها و حشرات بالغ را نسبت به تیمار شاهد در هر دو رقم نیشکر کاهش دادند. در برخی موارد، رقم IRC99-02 مقاومت بیشتری به مراحل مختلف زیستی سفیدبالک نیشکر نسبت به CP69-1062

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داشت. نتایج نشان داد که حشره‌کش‌های مورد بررسی، با توجه به نحوی تاثیر متفاوت، می‌توانند به صورت متناوب، همراه با ارقام مورد بررسی، در برنامهٔ مدیریت تلفیقی سفید بالک نیشکر استفاده شوند. در هر حال به منظور تایید این یافته، انجام بررسی‌های تکمیلی در ارتباط با ارزیابی میزان خطرات بوم شناختی و تعیین حداکثر مقدار مجاز باقیمانده سموم در محصول شکر ضروری است.

واژگان کلیدی: دلتامترین، دینتفوران، اسپیرومسیفن، سفید بالک نیشکر، رقم.

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Introduction

Sugarcane (interspecific hybrids of *Saccharum*) is a tall perennial gramineous crop which cultivated mainly in tropical and sub-tropical regions of many different countries. The main purpose of sugarcane cropping is production of white sugar and by-products such as paper and molasses as well as bio-diesel from energy-canes (James, 2004). This plant is classified as an industrial crop in Iran; it undoubtedly has a prominent role in socio-economic issues. The major production region in Iran is Khuzestan province where more than 80,000 hectares of arable fields is under cultivation of sugarcane. Sugarcane production is authorities under supervision of ten agro-industries in Iran (Sadeghzadeh-Hemayati *et al.*, 2011). Because of monoculture system, sugarcane is highly vulnerable to a wide range of biotic and abiotic stressors such as insects and mite pests, plant pathogens, salinity, drought and cold weather which impose economic damage on both quality and quantity. Askarianzadeh & Manzari (2006) was reported *Neomaskellia andropogonis* Corbett (Hemiptera: Aleyrodidae) from the sugarcane fields of Iran for the first time. Field assessments illustrated that besides sugarcane, *N. andropogonis* is constantly active on annual and perennial grass weeds including cogongrass, *Imperata cylindrical* (L.); barnyard grass, *Echinocloa colona* (L.); bearded sprangle-top, *Diplachne fusca* (L.); bermudagrass, *Cynadon dactylon* (L.); and Dallas grass, *Paspalum dilatatum* Poir (Nikpay & Sharafizadeh, 2017). Generally, the activity of this pest begins in Late-August and terminated in Late-November when the mean temperature dropped rapidly (Minaei-Moghadam *et al.*, 2010). However, the initiation of *N. andropogonis* have observed in Late-June under humid conditions (Nikpay, unpublished data). Immature stages of *N. andropogonis* settled underneath of the sugarcane leaves; suck the phloem sap and excrete honeydew and then fungal growth including *Capnodium* sp. (sooty mold) can lead to decrease in photosynthetic rates. Under heavy damage, the quality characteristics (brix and purity) of sugarcane varieties, especially in early-mature varieties, reduce and the whole plants eventually die (Askarianzadeh, 2011). The occurrence of sugarcane whitefly is not confined to Iran, indeed in several countries including Pakistan (Masood *et al.*, 2011) and India (Vemuri *et al.*, 2014; Vijayaraghavan & Regupathy, 2006) different species of the whiteflies cause damage on sugarcane. Generally, management of the

sugarcane pests, including the sugarcane whitefly is not solely based on a specific controlling strategy and several methods should be used for optimal results (Goebel & Nikpay, 2017). Different controlling methods including biological control (Khadempour *et al.*, 2014; Rajak & Varma, 2001), cultural control (Jena & Nayak, 1994), resistant varieties (Nikpay, 2017) and chemical control (Chaudhary & Jaipal, 2006; Koohzad-Mohammadi *et al.*, 2017) have been applied against the sugarcane whitefly. In the recent years, due to climate change, poor agronomic practices, excessive nitrogen fertilization and cultivation of different varieties, population increase of *N. andropogonis* has been observed in some of the sugarcane fields of Khuzestan province. In order to control of the sugarcane whitefly, chemical control can be considered as one of the controlling tactics when the population of the sugarcane whitefly increased more than economic injery level, considering all environmental and ecological conditions of the sugarcane fields in Iran. The aim of this study was to assess the efficacy of different insecticides on survival percentage of *N. andropogonis* life stages on two sugarcane varieties under laboratory conditions.

Materials and Methods

Sugarcane varieties

IRC99-02 (cross made in Cuba and selected in Iran) and CP69-1062 (Canal Point USA) varieties of sugarcane were used in the experiments. Buckets with the volume of 8 lit filled with sand, soil and fertilizer in a ratio of 1: 1: 1 and compacted to field density. Two sugarcane seed canes, each containing a healthy bud, were placed on the soil in each bucket and covered with a thin layer of soil. They were irrigated every three days, and after get five leaves, urea fertilizer was added to the soil. Sugarcane buckets were kept in greenhouse at 30±2°C temperature and 60±5% relative humidity.

Insects

Adults of the sugarcane whitefly, *N. andropogonis* were collected from the sugarcane field of the Salman Farsi Agro-industry Farms (48°35'E, 31º8'S) Ahvaz, Iran in summer 2017. Adults were introduced and maintained on cultivated varieties which were held in the cages with metal frame and muslin coverage (140×90 ×60 cm) at 30±2°C temperature, 60±5% RH and a photoperiod of 16:8 h (L:D).

Formulations

The insecticidal formulations that were applied in the present study were: pyrethroid insecticide, deltamethrin 2.5% EC (Bayer Crop Science, Germany), neonicotinoid insecticide, dinotefuran 20% SG (Mitsui Chemicals Agro Inc., Japan) and tetronic acid insecticide, spiromesifen 240 SC (Bayer Crop Science, Germany).

Bioassays

The insecticidal efficacy of deltamethrin, dinotefuran and spiromesifen on different life stages of *N. andropogonis* were evaluated using a leaf dipping bioassay procedure. Five concentrations of each insecticide were used for each insecticide. Preliminary concentration setting experiment was carried out to determine five concentrations that cause near 20–80% mortality on *N. andropogonis* adults. For each insecticide, concentrations were selected in the symmetric five-dose design (Robertson *et al.*, 1984). The concentrations were 10, 30, 50, 100 and 200 ppm for deltamethrin; 100, 200, 300, 500 and 750 g/ha for dinotefuran and 100, 200, 400, 500 and 800 ppm in the case of spiromesifen. All the insecticides were diluted in distilled water containing 1% Tween 20. Check treatment (control) was treated with only distilled water containing 1% Tween 20. For egg bioassay, 30 adults of *N. andropogonis* were introduced on sugarcane leaves (15 cm length) of each variety. The leaves were placed in flat-bottom transparent plastic bottles (5 cm diameter and 20 cm height) containing 2 ml distilled water to keep the leaves fresh. After 24 h, adults were removed and the number of laid eggs on each leaf was counted using a stereomicroscope (Wild M3c, Heerbrugg Switzerland). Then, sugarcane leaves were dipped for 10s into insecticide solution and let to air dried on filter papers for 1 h. According to Minaei-Moghadam *et al.* (2009), the incubation period of *N. andropogonis* egg is about 7 days. The eye marks are appeared on live eggs one or two day before hatching (Koohzad-Mohammadi *et al.*, 2017). The presence of eye marks on the eggs is considered as survival of pre-hatch stage. The number eggs in pre-hatch stage (eggs with eye mark but could not hatch) and hatched eggs were counted 7 days after treatment.

To evaluate the toxicity of insecticides against whitefly adults, the clean and un-infested sugarcane leaves (15 cm in length) of each variety were dipped into insecticide solution and after leaves were air dried, they were placed in the bottles as mentioned above. Subsequently, 10 adults of sugarcane whitefly were introduced on the leaves. The mortality of adults was measured after 24 h of exposure and immobile adults were considered as dead.

For nymphal bioassay, the sugarcane leaves in the buckets that were infested by different life stages of sugarcane whitefly were cut (15 cm in length) and transferred to the laboratory. The leaves were checked using stereomicroscope and 50 second instar nymphs were kept on each leaf, and the remaining stages were removed from leaves by brushing. The condition of the experiment and leaf dipping method was the same as described above. The leaves were dipped for 10s into the insecticide solution, air dried and monitored daily under stereomicroscope. The survival percentage of nymphs was determined after 1, 2, 3, 4, and 5 days of exposure.

Another experimental design was carried out to assess the efficacy of evaluated insecticides on pupae. The infested sugarcane leaves were cut (about 15 cm in length) and 25

last instar pupae were kept on each leaf. The leaves were dipped into the insecticide solution, air dried and placed in the bottles. Afterward, the bottles were transferred to the incubator set at experiments conditions and the leaves were monitored daily to determine the survival, parasitism and mortality percentage of pupae. The parasitized pupae are considered by a circular hole in the pupal case indicating the emergence of parasitic wasps. Whitefly adults emerge from the pupa through a T-shaped slit or ragged tear left in empty pupal case (Koohzad-Mohammadi *et al.*, 2017). Distilled water containing1% Tween 20 was also used as control. For nymphal and pupal experiments, nymphs and pupae that were dry and detached from the leaf when probed were considered dead (Sohrabi *et al.* 2011). All of the experiments were conducted at 30±2°C temperature, 60±5% RH and a photoperiod of 16:8 h (L:D) with 9 replications.

Statistical analysis

All data were checked for normality using non-parametric Kolmogorov-Smirnov test at $P = 0.01$. The percentage survival, parasitism and mortality data were transformed to square root of arcsine to normalize the data, but non-transformed data are presented in the Tables. All data were analyzed using factorial analysis of variance based on completely randomized design (first factor: variety and second factor: insecticide). For nymphal stage, comparison among exposure times was performed using one-way analysis of variance. Mean comparison was done by using HSD test at $P = 0.01$ using SPSS software 16.0. Lethal concentrations and their confidence limit were estimated by Probit regression (Finney, 1971) using SPSS 16.0 (Spss, 2007).

Results

The survival of pre-hatch eggs on check treatment (untreated plants) were 66.4 and 71.5% on IRC99-02 and CP69-1062 varieties, respectively. While, survival percentage of pre-hatch eggs on sprayed mentioned varieties with 200 ppm of deltamethrin were 27.6 and 33.8%. However, at this concentration only 17.7 and 28.7% of eggs were survived on IRC99-02 and CP69-1062 varieties, respectively (Table 1). There was not significant difference between survival of whitefly adults in untreated and treated leaves by the lowest concentration of deltamethrin. The survival percentage of adults were 81.3 and 88.3% for IRC99-02 and CP69-1062 varieties, respectively. While, only 13.3 and 10% adults survived after exposing them to the highest concentration of deltamethrin (Table 1).

Table 1. The survival percentage (± SE) of pre-hatch stage, egg and adult of *Neomaskellia andropogonis* exposed to sugarcane leaves treated with deltamethrin

Variety	Concentration (ppm)	Pre-hatch	Egg	Adult
IRC99-02	Control	66.4±8.6ab	57.8±8.1a	81.3±4.6a
	10	58.0±8.7abc	56.4±8.4a	77.6±1.9ab
	30	61.7±2.8abc	60.1±2.4a	62.4±2.3bc
	50	58.3±5.7abc	55.9±5.2a	26.0±4.7de
	100	40.7±6.7bcd	33.7±8.1ab	20.0±3.6de
	200	27.6±5.0d	17.7±5.2b	13.3±4.2de
CP69-1062	Control	71.5±6.2a	56.8±0.65a	88.3±3.0a
	10	41.8±3.6abcd	39.0±4.2ab	84.6±0.0a
	30	56.2±6.7abcd	36.6±3.7ab	72.0±3.2ab
	50	33.3±8.7cd	26.4±5.1b	51.7±5.4c
	100	36.3±3.2bcd	28.2±1.8b	28.4±4.8d
	200	33.8±4.3cd	28.7±2.8b	10.0±0.0e
df $_{error, total}$; *F; P*		11,70; 5.44; 0.000	11,70; 7.89; 0.000	11,69; 67.3; 0.000

Means followed by the same letter on each column are not significantly different using Tukey's Test at $P < 0.05$.

The three highest concentrations (300, 500 and 750 g/ha) of dinotefuran were very toxic against eggs of whitefly and less than 1% of the eggs were survived. For adult stage, 26.4 and 31.7% survival occurred when exposed to IRC99-02 and CP69-1062 varieties treated with 750 g/ha of dinotefuran, respectively (Table 2).

Table 2. The survival percentage (± SE) of pre-hatch stage, egg and adult of *Neomaskellia andropogonis* exposed to sugarcane leaves treated with dinotefuran

Variety	Concentration (g/ha)	Pre-hatch	Egg	Adult
IRC99-02	Control	66.4±8.6ab	57.8±8.1a	81.3±4.6ab
	100	59.5±6.7ab	27.4±3.8b	60.5±5.3bc
	200	40.3±4.7ab	6.6±2.0cd	55.0±3.4c
	300	33.5±12.4ab	1.0±0.70d	46.4±4.4cde
	500	33.9±9.07ab	0.31±0.31d	42.6±1.7cde
	750	33.8±6.8ab	0.07±0.07d	26.4±4.3e
CP69-1062	Control	71.5±6.3a	56.8±0.65a	88.3±3.0a
	100	34.0±9.6ab	20.3±6.2bc	58.3±4.9c
	200	32.0±8.7ab	13.5±5.4bcd	51.9±3.0cd
	300	31.5±8.6ab	0.73±0.49d	48.4±6.5cd
	500	34.0±7.7ab	0.0±0.0d	43.4±4.5cde
	750	29.0±7.0b	0.82±0.7d	31.7±3.0de
df $_{error, total}$; *F; P*		11, 84; 2.37; 0.014	11, 84; 31.3; 0.000	11, 70; 17.8; 0.000

Means followed by the same letter on each column are not significantly different using Tukey's Test at $P < 0.05$.

The survival percentage was higher in the case of spiromesifen and no significant differences observed among control and low concentrations of spiromesifen on pre-hatch, eggs and adults of *N. andropogonis* (Table 3).

Table 3. The survival percentage (± SE) of pre-hatch stage, egg and adult of *Neomaskellia andropogonis* exposed to sugarcane leaves treated with spiromesifen

Variety	Concentration (ppm)	Pre-hatch	Egg	Adult
IRC99-02	Control	66.4±8.6abc	57.8±8.1ab	81.3±4.6abc
	100	74.8±7.2a	56.3±5.8ab	71.1±6.6abcd
	200	58.1±5.3abc	42.7±6.1abc	68.5±3.5bcde
	400	54.7±8.0abc	36.3±4.0bc	66.7±2.1bcde
	500	47.1±4.3bc	38.1±3.6bc	62.7±3.1cde
	800	46.3±3.6bc	37.3±6.2bc	53.5±5.4de
CP69-1062	Control	71.5±6.3ab	56.8±0.65ab	88.3±3.0a
	100	79.5±4.1a	67.7±3.9a	83.3±2.1ab
	200	62.6±5.4abc	59.2±5.3ab	70.0±4.5abcd
	400	56.7±8.8abc	38.4±4.7bc	66.7±2.1bcde
	500	54.1±4.8abc	39.1±2.8bc	58.3±3.0de
	800	38.5±7.4c	24.7±5.8c	51.7±4.8e
df $_{error, total}$; *F; P*		11, 75; 4.15; 0.000	11, 75; 6.08; 0.000	11, 69; 8.22; 0.000

Means followed by the same letter on each column are not significantly different using Tukey's Test at $P < 0.05$.

The LC_{50} values of three insecticides against adult of the sugarcane whitefly on IRC99-02 and CP69-1062 leaves treated with different concentrations for 24 h are presented in Table 4. Based on LC_{50} values and 95% confidence limits, deltamethrin was more toxic than dinotefuran and spiromesifen against adults of sugarcane whitefly, *N. andropogonis* (Table 4).

Table 4. The LC_{50} values of deltamethrin, dinotefuran and spiromesifen on *Neomaskellia andropogonis* adults after 24 h of exposure

Insecticide	Variety	LC_{50} (ppm)	Confidence limit (ppm)		Slope ±SE	Chi-square	*P* value
			Lower	Upper			
Deltamethrin	IRC99-02	39	13	76	1.84±0.23	8.416	0.038
	CP69-1062	62	51	75	2.35±0.31	0.753	0.861
Dinotefuran	IRC99-02	319	216	481	1.07±0.27	1.681	0.641
	CP69-1062	354	241	568	1.04±0.28	0.356	0.949
Spiromesifen	IRC99-02	1835	781	-	0.72±0.31	0.951	0.813
	CP69-1062	917	606	3393	1.38±0.41	1.203	0.752

-: cannot be calculated

The survival percentage of the whitefly nymphs in the control was 100 and 98%, 1 d after treatment for IRC99-02 and CP69-1062 varieties, respectively. Deltamethrin was toxic against the second nymphal stage of *N. andropogonis*. So, at the concentration of 200 ppm, 3 days after treatment, no nymphal survival was reported on IRC99-02 variety, while at the same connotation, 22.3% of nymphs were survived on CP69-1062 variety (Table 5).

Table 5. The survival percentage (± SE) of *Neomaskellia andropogonis* nymphs exposed to sugarcane leaves treated with deltamethrin

Variety	Concentration (ppm)	Time (day)					df $_{4.54}$; *F; P*
		1	2	3	4	5	
IRC99-02	Control	100±0.0a	85.2±1.9a	77.9±1.7 ac	73.9±1.6ac	59.5±1.7bd	70.3; 0.000
	10	84.5±1.8abcd	69.0±3.4abc	43.6±6.1bcd	19.0±3.9cdec	16.8±3.4cde	56.0; 0.000
	30	80.4±2.9acde	52.3±6.6bcd	20.5±2.4efc	9.1±1.6efgc	7.9±1.3cefg	78.6; 0.000
	50	77.3±1.6acde	31.9±5.6befg	17.3±3.6fgc	2.2±0.9fgd	2.2±0.9dg	98.6; 0.000
	100	49.9±3.4af	26.2±3.0bfg	5.0±2.6ghc	2.0±1.0gc	0.0±0.0cg	77.9; 0.000
	200	43.1±8.0af	15.3±4.4bg	0.0±0.0bh	0.0±0.0gb	0.0±0.0bg	21.1; 0.000
CP69-1062	Control	98.2±0.7ab	81.6±1.1ab	80.0±1.2ab	76.4±2.0ab	69.2±2.0ac	47.2; 0.000
	10	88.3±2.5abc	68.0±2.9bc	60.3±2.7bc	49.7±3.5bc	36.2±3.7cd	40.2; 0.000
	30	85.2±1.3abcd	71.2±1.6ab	49.2±1.7bc	27.8±2.5cd	19.8±0.9de	263.5; 0.000
	50	77.2±3.9acde	46.7±3.7bde	39.8±3.2bcd	26.9±2.3c	17.0±1.8cde	54.7; 0.000
	100	71.4±1.7ade	40.8±2.7bdef	32.4±2.2cde	23.2±1.5cd	12.4±1.4def	128.1; 0.000
	200	68.4±2.0ae	36.5±2.2bdef	22.3±2.5cef	12.9±1.3def	3.8±0.6efg	177.0; 0.000
df $_{11, 113}$; *F; P*		29.56; 0.000	39.5; 0.000	74.7; 0.000	138.9, 0.000	134.9, 0.000	

Means followed by the same lower case letter on each column and upper case letter for each row are not significantly different using Tukey's Test at $P < 0.05$.

Similar results were observed for *N. andropogonis* nymphs exposed to dinotefuran where higher exposure time required for controlling the nymphs. On IRC99-02 variety, less than 20% of nymphs were survived after 5 d exposure to even low concentration of 100 ppm dinotefuran, while at the same time interval and concentration, only 31.6% survival was recorded on CP69-1062 variety (Table 6).

Exposure to spiromesifen led to a decrease in the survival percentage of *N. andropogonis* nymphal stage. The nymphs had a significantly lower survival percentage than control, 5 days after treatment (Table 7).

Pupae from the IRC99-02 variety exposed to deltamethrin had a lower survival percentage similar to those from CP69-1062 variety. The parasitism percentage of pupal stages was 67% for control of both varieties and was significantly more than other concentrations. The pupal mortality percentage significantly increased from 71.8% at lower concentration of 10 ppm to 95.5% on IRC99-02 treated with 200 ppm of deltamethrin and in the case of CP69-1062 variety from 60.3 to 70.5% (Table 8).

For dinotefuran, the survival percentage of *N. andropogonis* pupae decreased in comparison with control. The overall mortality percentage of pupal stages exposed to 750 g/ha of dinotefuran was 99.2 and 95.1% on IRC99-02 and CP69-1062 varieties of sugarcane, respectively (Table 9).

In the spiromesifen treated leaves, the survival percentage of pupae was 14.22% at 100 ppm which reached less than 2% at a concentration of 500 ppm. In the case of CP69-1062 variety, the survival of pupae was less than 2% even at lowest concentrations of 100 ppm.

The percentage of parasitism at this concentration (100 ppm) was reported about 40% for both varieties (Table 10).

Table 6. The survival percentage (± SE) of *Neomaskellia andropogonis* nymphs exposed to sugarcane leaves treated with dinotefuran

Variety	Concentration (g/ha)	Time (day)					df $_{4.54}$; *F; P*
		1	2	3	4	5	
IRC99-02	Control	100±0.0a	85.24±1.91ab	77.95±1.76ac	73.96±1.61ac	59.54±1.71bd	70.3; 0.000
	100	89.22±1.98abc	64.67±4.61cdeb	46.89±3.67cde	32.43.±4.04cd	18.13±2.94ed	60.5; 0.000
	200	81.74±2.38acd	60.45±3.07deb	44.41±4.02cde	23.17±4.41de	11.62±2.10de	73.8; 0.000
	300	80.10±1.00acd	52.13±3.19be	34.22±2.87cef	14.70±1.52def	5.40±4.25def	214.9; 0.000
	500	79.09±2.46acde	51.08±3.08be	26.06±3.44cfg	9.04±2.00df	3.30±0.59df	155.5; 0.000
	750	60.59±4.29af	26.73±5.13bf	13.68±2.82cbg	4.44±1.15cf	2.80±0.87fc	51.3; 0.000
CP69-1062	Control	98.15±0.76ab	81.59±1.15ab	80.01±1.20ab	76.43±2.07ab	69.17±2.09ac	47.2; 0.000
	100	83.25±2.07acd	79.08±1.31abc	62.89±0.89b	51.80±1.05bc	31.60±2.16cd	175.3; 0.000
	200	76.66±0.85ade	76.87±1.06abc	58.39±1.98bc	47.24±2.13bc	36.30±2.03cd	110.9; 0.000
	300	69.82±1.18aef	71.05±1.64abcd	57.08±1.75bcd	44.30±0.89bc	34.65±1.19cd	133.4; 0.000
	500	62.67±1.59af	70.44±0.67bcd	55.27±1.84bcd	43.96±1.26bd	32.79±0.80ce	129.0; 0.000
	750	49.47±1.19ag	69.72±1.39bcd	54.69±1.51bcd	40.86±0.93bcd	29.16±0.63ce	166.4; 0.000
df $_{11, 105}$; *F; P*		54.34; 0.000	31.43; 0.000	53.69; 0.000	106.78; 0.000	166.35; 0.000	

Means followed by same lower case letter on each column and upper case letter for each row are not significantly different using Tukey's Test at $P < 0.05$.

Table 7. The survival percentage (± SE) of *Neomaskellia andropogonis* nymphs exposed to sugarcane leaves treated with spiromesifen

Variety	Concentration (ppm)	Time (day)					df $_{4.54}$; *F; P*
		1	2	3	4	5	
IRC99-02	Control	100±0.0a	85.24±1.91ab	77.95±1.76ac	73.96±1.61ac	59.54±1.71bd	70.3, 0.000
	100	83.31±1.60ab	53.39±3.89cb	28.95±4.50cdc	19.80±3.38bcd	12.99±2.45cd	74.5; 0.000
	200	77.71±1.73abc	50.34±2.53cb	25.40±3.43cde	12.39±2.87cd	5.81±1.31efgd	140.5; 0.000
	400	69.16±1.93acde	41.73±3.69bcd	23.43±2.76cde	9.90±2.35cd	2.53±1.25fgd	111.3; 0.000
	500	59.69±3.18aef	36.77±2.99bde	15.52±2.13cef	6.55±1.72cd	1.55±0.93fgd	107.7; 0.000
	800	42.03±3.72ag	19.56±2.48bf	7.45±1.09f	2.28±0.59cd	0.22±0.22cg	68.3; 0.000
CP69-1062	Control	98.15±0.76a	81.59±1.15ab	80.01±1.20a	76.43±2.07ab	69.17±2.09ac	47.2; 0.000
	100	83.17±2.02ab	68.48±1.74b	48.19±3.25b	28.83±3.29bd	15.05±2.72ce	107.7; 0.000
	200	70.24±1.59acd	52.21±1.82bc	35.29±2.03c	18.87±2.24bcd	10.69±1.67cde	165.2; 0.000
	400	63.44±1.94ade	47.24±2.98bc	29.73±2.77cd	17.90±1.72cd	9.22±1.43cdef	95.1; 0.000
	500	51.14±1.17afg	28.11±2.01bef	18.07±1.95cdef	6.98±1.20d	4.83±0.82defg	156.1; 0.000
	800	45.38±2.10ag	21.34±2.14bf	14.39±2.61bef	4.73±1.60cd	1.18±0.86cg	80.3; 0.000
df $_{11, 114}$; *F; P*		84.69; 0.000	67.62; 0.000	80.45; 0.000	133.76; 0.000	198.51; 0.000	

Means followed by the same lower case letter on each column and upper case letter for each row are not significantly different using Tukey's Test at $P < 0.05$.

Table 8. The survival, parasitism and mortality percentage (± SE) of *Neomaskellia andropogonis* pupae exposed to sugarcane leaves treated with deltamethrin

Variety	Concentration (ppm)	Survival	Parasitism	Mortality
IRC99-02	Control	10.3±4.5ab	67.9±9.2a	21.7±5.2d
	10	3.9±1.7bc	24.2±5.8bcd	71.8±6.3bc
	30	6.7±2.4bc	14.0±2.9cde	79.2±4.6abc
	50	5.5±1.3bc	13.8±2.7cde	80.6±2.2ab
	100	0.5±0.4c	2.0±0.7e	97.4±0.7a
	200	0.2±0.2c	4.4±2.6de	95.5±2.7a
CP69-1062	Control	16.6±1.4a	67.3±1.8a	16.0±0.8d
	10	5.1±1.6bc	34.5±3.6b	60.3±3.6c
	30	1.9±1.1c	36.3±3.3b	61.7±3.3bc
	50	1.1±0.6c	33.2±5.1bc	65.7±5.4bc
	100	1.7±0.7c	29.9±4.8bc	68.4±4.6bc
	200	1.0±0.3c	28.5±2.8bc	70.5±2.9bc
	df $_{11, 91}$; *F; P*	9.23; 0.000	23.12; 0.000	32.64; 0.000

Means followed by the same letter on each column are not significantly different using Tukey's Test at $P < 0.05$.

Table 9. The survival, parasitism and mortality percentage (± SE) of *Neomaskellia andropogonis* pupae exposed to sugarcane leaves treated with dinotefuran

Variety	Concentration (g/ha)	Survival	Parasitism	Mortality
IRC99-02	Control	10.3±4.5b	67.9±9.2a	21.7±5.2d
	100	1.4±0.4d	19.9±5.7bc	78.7±5.6c
	200	6.6±0.7bc	16.5±0.9bcd	76.9±1.5c
	300	0.7±0.3d	17.3±5.2bc	81.9±5.2bc
	500	0.2±0.2d	15.6±3.3bcd	84.2±3.2abc
	750	0.3±0.2d	0.45±0.3d	99.2±0.3a
CP69-1062	Control	16.6±1.4a	67.3±1.8a	16.0±0.8d
	100	4.0±0.4cd	22.2±1.7b	73.7±2.0c
	200	2.6±0.7cd	25.7±4.2b	71.7±4.2c
	300	0.6±0.2d	14.6±1.8bcd	84.8±1.8abc
	500	0.8±0.3d	12.3±3.6bcd	86.9±3.5abc
	750	0.8±0.4d	4.1±0.8cd	95.1±0.7ab
	df $_{11, 93}$; *F; P*	23.98; 0.000	30.87; 0.000	54.02; 0.000

Means followed by the same letter on each column are not significantly different using Tukey's Test at $P < 0.05$.

Table 10. The survival, parasitism and mortality percentage (± SE) of *Neomaskellia andropogonis* pupae exposed to sugarcane leaves treated with spiromesifen

Variety	Concentration (ppm)	Survival	Parasitism	Mortality
IRC99-02	Control	10.3±4.5abc	67.9±9.2a	21.7±5.2cd
	100	14.22±4.ab	39.37±7.6b	46.4±9.46bc
	200	5.53±2.62bcd	30.72±4.34b	63.73±5.01ab
	400	6.6±2.4bcd	22.73±6.9b	70.65±5.66ab
	500	1.85±1.09cd	26.64±3.21b	71.5±3.0ab
	800	0.48±0.3d	17.66±5.15b	81.85±5.26a
CP69-1062	Control	16.6±1.4a	67.3±1.8a	16.0±0.8d
	100	1.83±0.44cd	40.2±6.73b	58.0±6.65ab
	200	1.64±0.53cd	37.95±5.44b	60.4±5.7ab
	400	2.6±0.55cd	34.33±2.26b	63.05±2.27ab
	500	1.22±0.29cd	34.45±4.09b	64.32±4.02ab
	800	0.8±0.27cd	33.16±3.43b	66.03±3.4ab
df $_{11, 103}$; *F; P*		6.59; 0.000	6.40; 0.000	10.27; 0.000

Means followed by the same letter on each column are not significantly different using Tukey's Test at $P < 0.05$.

Discussion

In this study, all insecticides reduced significantly the survival percentage of sugarcane whitefly, in comparison with check treatment (control). Among evaluated insecticides, deltamethrin followed by dinotefuran were the most toxic against adults of *N. andropogonis.* Our results are comparable to that of Qu *et al.* (2017) who reported that dinotefuran was the most toxic insecticide among six tested compounds against two invasive whiteflies *Bemisia tabaci* (Gennadius), Middle East-Asia Minor1(MEAM1or biotype B) and Mediterranean (MED or biotypeQ). Many other foliar-applied insecticides have been applied for the control of the sugarcane whitefly (Chaudhary & Jaipal, 2006; Kunjadia & Patel, 1993; Patel *et al.*, 2003). Kunjadia & Patel (1993) reported that triazophos (organophosphate insecticide) followed by quinalphos (organophosphate insecticide) and endosulfan (organochlorine insecticide) were the most effective insecticides among 10 tested compounds in sugarcane fields in Navsari, Gujarat, India, against sugarcane whitefly, *Aleurolobus barodensis* Maskell. In sugarcane fields of Navsari Gujarat, India, carbosulfan (organochlorine insecticide) was found to be the most efficient insecticide (Patel *et al.*, 2003). In the field trials conducted in Saptur, the order of insecticides potential toxicity was thiamethoxam> dimethoate > imidacloprid (Vijayaraghavan & Regupathy, 2006). Bhavani & Rao (2013) found that the removal of infested leaves plus spraying of imidacloprid (neonicotinoid insecticide) significantly reduced the whitefly population in sugarcane fields of Andhra Pradesh, India.

It is confirmed that all three insecticides even at the lowest concentration rate significantly decreased eggs survival and hatching. Similar finding was reported by Qu *et al.* (2017) that Sublethal concentration of dinotefuran (LC_{25}) significantly reduced fecundity and egg hatching rate.

Although the resistance of different whitefly species, such as *B. tabaci*, has been reported to the organophosphate and pyrethroid insecticides (Ahmad *et al.*, 2002; Gnankine *et al.*, 2013); no resistance report has yet been reported from sugarcane whitefly. Several factors including frequency of resistance alleles in the population, insect reproduction rate, migration and host range of the insects, timing and frequency of insecticide applications and insecticide mode of action, are involved in insecticide resistance development (Satyagopal *et al.*, 2014). Although pyrethroids, especially deltamethrin have lower toxicity to mammals and lack of persistence in the environment, however their broad spectrum control activity, (Rehman *et al.*, 2014) and side effects on physiological and behavioural traits of parasitoids (Garcia, 2011) are considered as its potential adverse effects.

Rotating insecticides with different mode of action may prevent or delay the occurrence of resistance in whitefly species population (Dreistadt, 2001). Therefore, in this study 3 insecticides belonging to different classes were assessed against sugarcane whitefly. In comparison with the other neonicotinoids, dinotefuran has not shown resistance to other species of whiteflies, with fairly low toxicity to mammals, birds, and the environment (Qu *et al.*, 2017). Thus, this insecticide could be a promising alternative to conventional synthetic insecticides for chemical control of whiteflies. The last evaluated insecticide was spiromesifen. Mentioned insecticide is an ovo-larvicidal pesticide, which is efficient on eggs, nymphs, pupae and adults of whitefly. Spiromesifen belongs to a new class of insecticides which interferes whitefly lipogenesis by preventing biosynthesis of fatty acids. This compound has low toxicity on mammals and short environmental persistence and it is recommended as an important tool in integrated pest management (IPM) programs (Krämer *et al.*, 2007).

Encarsia inaron Walker (Hym.: Aphelinidae) and *Eretmocerus delhiensis* Mani (Hym.: Aphelinidae) are present in native habitats of whitefly in sugarcane fields and control naturally the population of whitefly during September to November (Nikpay & Goebel, 2016). One of the main drawbacks of conventional chemical insecticides application is their incompatibility with biological control agents. According to our findings, 67% eclosion of the parasitic wasps from pupal stages was recorded in the control group of both tested sugarcane varieties. In the context of sugarcane whitefly chemical control, the data from Ananthanarayana *et al.* (1994) clearly revealed that the application Endosulfan (0.1%), monocrotophos (0.04%) and malathion (0.1%) caused 100% mortality of *Amitus minervae* Silvestri, a potential parasitoid of the sugarcane whitefly *A. barodensis*. However, regarding

examined insecticides in this study, approximately 40% parasitism rate was recorded on both sugarcane varieties, when the lowest dose of the insecticides was applied.

Another recommended method for integrated pest management in sugarcane fields is using resistant varieties (Goebel & Nikpay 2017). Based on Nikpay (2017) CP69-1062, IRC99-02 and CP57-614 were the most resistant varieties of sugarcane against whitefly. On the other hand, according to the results of current study, IRC99-02 variety showed considerably more resistance to the sugarcane whitefly than CP69-1062.

Finally, in order to conserve benefit biological agents and to avoid unnecessary spraying by chemical insecticides in the sugarcane fields of Iran, more attention to insect resistant varieties is recommended for controlling of the sugarcane whitefly than chemical spraying. Nevertheless, using low risk insecticides in limited areas can be considered as an IPM approach in the case of increasing the pest population above economic injury level (EIL), besides attention to maximum residue limit (MRL) of the pesticides in the yielded sugar.

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