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Bio-efficacy and phytotoxicity of Sulfoxalor 50% WG against tea mosquito bug (*Helopeltis theivora*) and green fly (*Empoasca flavescens*) and its effect against natural enemies in tea

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Abstract
A field experiment was conducted in the Experimental Garden for Plantation Crops, Assam Agricultural University, Jorhat-13 during 2016 and 2017 to evaluate the bio-efficacy of Sulfoxaflor 50% WG against the tea mosquito bug and green fly in tea. Six treatments at different doses, along with an untreated control, were used in the experiment. Results revealed that during 2016, Sulfoxaflor 50% WG @ 150 g ha^{-1} recorded significantly least twig infestation (1.0%) in case of tea mosquito bug, and least number of green fly population per leaf (0.50), as compared to the other insecticidal treatments, at 15 days, after the third spray. Thiamethoxam 25% WG @ 100 g ha^{-1}, Clothianidin 50% WDG @ 120 g ha^{-1} and Sulfoxaflor 50% WG @ 100 and 120 g ha^{-1} were the next effective treatments and were at par with each other in their efficacies. During 2017, Sulfoxaflor 50% WG @ 150 g ha^{-1}, at 15 days after the third spray showed similar result of least twig infestation (0.25% of TMB) and less population of green fly (0.25/leaf) as compared to the other treatments.

Keywords: Bio-efficacy, tea mosquito bug, green fly, sulfoxaflor, thiamethoxam, clothianidin

1. Introduction
Tea, *Camellia sinensis* (L.) O. Kuntze is an evergreen perennial crop grown intensively as a monoculture over massive areas on large and small scale plantations, with genetically diverse cultivars and interplanting of shade trees, particularly in South-east Asia. Discovered around 2700BC, tea is considered to be one of the most widely consumed non alcoholic beverages all over the world, having copious rejuvenating properties. It is cultivated within the tropics and the sub-tropics in different types of porous, well drained, acidic soils with a pH of 4.5 to 5.5, over a wide range of climatic conditions such as annual rainfall from 938 mm to 6000 mm, temperature from -12 °C to 40 °C, relative humidity from 30 to 90 per cent and radiation intensity from 0.3 to 0.8 cal $cm^{-2}min^{-1}$ [1, 2]. At present, tea is grown in more than 50 countries, from Georgia at 43°N latitude to New Zealand at 42°S latitude. China, being the prime tea producing country, reckoned for 42.6 per cent of world tea production, with an output of 2.44 million tonnes in 2016, followed by India, Sri Lanka and Kenya [3]. In India, tea covers an area of 566.6 thousand ha, producing annually 1233.14 million kg of made tea in 2015, of which approximately 53 per cent (652.95 million kg) is harvested from Assam [4]. Tea, being a monocrop, provides a favourable niche for more than 300 insects, mite pests and disease causing micro-organisms, thus resulting in 11-55 per cent yield loss [1, 5]. On a global scale, 1031 arthropod species are found to have been associated with tea [6], including 41 species of mirids of the genus *Helopeltis* in Asia, Australia, and Africa [1]. In recent years, two species of Helopeltis, *H. schoutedeni* Reuter (Hemiptera: Miridae) and *H. theivora* Waterhouse, have attained international importance as the greatest enemies of tea planters in Africa [7] and Asia [8], causing 55 per cent and 11 to 100 per cent crop loss, respectively [1, 9]. Among them, the tea mosquito bug (TMB), *Helopeltis theivora* Waterhouse (Hemiptera: Miridae) has emerged as the most prominent tea pest of North East India in recent years, causing substantial yield losses to the tune of 56-80 per cent, with its peak activity from June to September [8, 10, 11]. Within 2-3 hours of damage, primarily on the leaves and new flushes, a circular ring of 0.29 to 2.51 mm is formed around the feeding spot; in 24 hours, the inside portion of ring becomes translucent light brownish in colour and within a few days, the spot turns dark brown, sunken and

subsequently desiccates [1, 12], in response to the salivary enzymes, which, in presence of salivary amino acids, detoxify the defensive chemicals of the host [13, 14]. This, in turn, prevents the initiation of new shoots, thereby resulting in poor yields [15]. Another sucking pest *viz.* Green Fly, *Empoasca flavescens* (Homoptera: Cicadellidae), has gained substantial importance in almost all the sub-Himalayan tea plantations of North-East India. It is a polyphagous minute yellowish-green jassid, with less than ¼ inches in length. Nymphs and adults of *E. flavescens* are the most important stages that damage the tea plant [16, 17]. Early symptoms include the appearance of yellow or brownish patches at the margin of the leaves, followed by distortion of leaf veins and curling of leaves, known as "rim blight" [18]. This ultimately renders the leaf, brittle and dry. The pest remains active at various levels of intensity throughout the season, being the most devastative during dry and rainy seasons [17]. Too much rain or too dry weather is not favourable for the development of the insect [19].

To control these insect pests, a wide range of approved acaricides and insecticides belonging to different groups are used, particularly in tea plantations of North East India [20]. Over the recent two decades, neonicotinoids have turned up to be the most widely used insecticides in the global market [21]. The use of neonicotinoids is continually increasing because of their unique mode of action and the low levels of neonicotinoid resistance among insect pests [22]. Regardless of the manner of application and route of entry to the plant, they translocate throughout all plant tissues, making them toxic to any insects that feed on the plant [23]. Versatility is another feature of the neonicotinoids, rendering them suitable for many applications, including foliar, seed treatment, soil drench and stem injection [24].

Keeping this in view, the present study aims to evaluate the efficacy of Sulfoxaflor 50% WG insecticide against the tea mosquito bug (*Helopeltis theivora* Waterhouse) and Green fly (*Empoasca flavescens*) to facilitate efficient management.

2. Materials and Methods

A field experiment was conducted to determine the bio-efficacy of Sulfoxaflor 50% WG against tea mosquito bug (*Helopeltis theivora*) and green fly (*Empoasca flavescens*) in tea crop during 2016 and 2017 in the Experimental Garden for Plantation Crops, Assam Agricultural University, Jorhat-13, located at 26°44′ N latitude and 94°10′ E longitude, with an altitude of 91 m above mean sea level. The experiment was laid out in a randomized block design with seven treatments in four replications. The tea clone TV-23 was used for the experiment, with a plot size of 5m×2m (10m^2). There were 36 plants per plot per hectare, with a spacing of 105cm×60cm between the tea bushes. All the tea husbandry practices were followed as per the recommended package of practices. Three foliar sprayings operations were performed at an interval of one month, during early flashing stage of the crop. A knapsack sprayer, fitted with a hollow cone nozzle, was used to impose the spray treatments @ 500 litre ha^{-1}. The treatment details for bio-efficacy, natural enemies and phytotoxicity are listed herein in Table 1-3.

Table 1: Details of Treatments for Bio-Efficacy

Sl. No	Treatments	Dose ha^{-1}	
		a. i (g)	Formulation (g ml^{-1})
T1	Sulfoxaflor 50% WG	50	100
T2	Sulfoxaflor 50% WG	60	120
T3	Sulfoxaflor 50% WG	75	150
T4	Thiamethoxam 25% WG	25	100
T5	Clothianidin 50% WD	60	120
T6	Quinalphos 25% E	190	760
T7	Control	-	-

Table 2: Details of Treatments for Natural Enemies

Sl. No	Treatments	Dose ha^{-1}	
		a.i (g)	Formulation (g ml^{-1})
T1	Sulfoxaflor 50% WG	50	100
T2	Sulfoxaflor 50% WG	60	120
T3	Sulfoxaflor 50% WG	75	150
T4	Sulfoxaflor 50% WG	150	300
T5	Thiamethoxam 25%WG	25	100
T6	Clothianidin 50%WDG	60	120
T7	Quinalphos 25%EC	190	760
T8	Control	-	-

Table 3: Details of Treatments for Phytotoxicity

Sl. No	Treatments	Dose ha^{-1}	
		a.i (g)	Formulation (g ml^{-1})
T1	Sulfoxaflor 50% WG	50	100
T2	Sulfoxaflor 50% WG	60	120
T3	Sulfoxaflor 50% WG	75	150
T4	Sulfoxaflor 50% WG	150	300
T5	Control	-	-

2.1 Method of Recording Observation:

2.1.1 Tea Mosquito Bug (*Helopeltis theivora*)

Observations were recorded on 20 twigs, each bearing 2 leaves and a bud, per treatment selected randomly. Per cent twig infestation by TMB was worked out after 15 days of each treatment.

2.1.2 Green Fly (*Empoasca flavescens*)

Population of adults and nymphs of Green Fly were recorded on randomly selected 20 leaves/treatment, before and 15 days after each treatment.

3. Results and Discussion

3.1 Bio-efficacy

The data on bio-efficacy of several insecticidal treatments against tea mosquito bug and green fly along with natural enemies of tea during 2016-17 revealed that all the insecticide treated plots efficiently reduced the incidence of tea mosquito bug and green fly population, compared to untreated control (Table 4-7). Out of different insecticides tested, Sulfoxaflor

50% WG @ 150 g ha^{-1} significantly reduced the infestation of tea mosquito bug (1% and 0.25%) and green fly (0.50 and 0.25) per leaf at 15 days after 1st, 2nd and 3rd spray, during 2016 and 2017 respectively. Similarly, Thiamethoxam 25% WG @ 100 g ha^{-1} was the next best treatment which could significantly reduce the infestation of tea mosquito bug (4.50% and 2.50%) effectively during 2016 and 2017, respectively (Table 4-5).

Table 4: Bio-efficacy of different insecticides against twig Infestation (%) by Tea Mosquito Bug (*Helopeltis theivora*) during 2016

No	Treatment	Dose/ha		Per cent Twig infestation by Tea Mosquito Bug					
		a.i.	Formulation (ml g^{-1})	Pre-treatment before 1st Spray	15 Days After 1st Spray	Pre-treatment before 2nd Spray	15 Days After 2nd Spray	Pre-treatment before 3rd Spray	15 Days After 3rd Spray
T_1	Sulfoxaflor 50% WG	50	100	17.25 (24.49)	3.75 (10.95)	25.00 (29.97)	6.25 (14.36)	21.25 (27.40)	7.50 (15.74)
T_2	Sulfoxaflor 50% WG	60	120	18.50 (25.40)	3.75 (10.80)	27.50 (31.59)	3.75 (10.95)	20.00 (26.52)	5.50 (13.37)
T_3	Sulfoxaflor 50% WG	75	150	16.00 (23.51)	1.25 (5.36)	22.50 (28.28)	1.50 (5.95)	22.50 (28.28)	1.00 (3.92)
T_4	Thiamethoxam 25% WG	25	100	17.50 (24.67)	3.50 (10.63)	25.50 (30.29)	2.50 (8.84)	21.25 (27.39)	4.50 (11.97)
T_5	Clothianidin 50% WDG	60	120	16.75 (24.09)	3.50 (10.64)	24.00 (29.31)	2.50 (8.86)	20.00 (26.53)	4.50 (10.53)
T_6	Quinalphos 25% EC	190	760	16.00 (24.69)	11.00 (19.26)	25.50 (30.29)	15.00 (22.72)	18.75 (25.60)	10.75 (19.09)
T_7	Control	-		18.75 (25.63)	30.00 (33.18)	24.00 (29.29)	31.25 (33.95)	20.75 (27.06)	28.50 (32.22)
	SEM±			(0.66)	(1.73)	(0.74)	(1.39)	(0.90)	(1.86)
	CD 5%			(NS)	(5.20)	(NS)	(4.16)	(NS)	(5.59)

Figures in parentheses are angular transformed values

Table 5: Bio-efficacy of different insecticides against twig Infestation (%) by Tea Mosquito Bug (*Helopeltis theivora*) during 2017

No	Treatment	Dose/ha		Per cent Twig infestation by Tea Mosquito Bug					
		a.i.	Formulation (ml g^{-1})	Pre-treatment before 1st Spray	15 Days After 1st Spray	Pre-treatment before 2nd Spray	15 Days After 2nd Spray	Pre-treatment before 3rd Spray	15 Days After 3rd Spray
T_1	Sulfoxaflor 50% WG	50	100	25.75 (30.44)	6.25 (14.30)	16.25 (23.72)	8.75 (17.00)	31.25 (33.94)	3.75 (10.64)
T_2	Sulfoxaflor 50% WG	60	120	25.25 (30.13)	3.75 (10.52)	17.50 (24.68)	4.50 (11.85)	33.75 (35.49)	2.75 (9.23)
T_3	Sulfoxaflor 50% WG	75	150	25.00 (29.97)	1.25 (6.33)	16.25 (23.72)	0.75 (4.30)	31.25 (33.93)	0.25 (1.43)
T_4	Thiamethoxam 25% WG	25	100	26.25 (30.77)	2.50 (8.59)	18.25 (25.22)	5.00 (12.56)	31.25 (33.94)	2.50 (7.75)
T_5	Clothianidin 50% WDG	60	120	26.25 (30.78)	2.50 (8.72)	19.00 (25.79)	5.25 (13.02)	32.00 (34.40)	5.00 (11.16)
T_6	Quinalphos 25% EC	190	760	24.50 (29.62)	8.00 (16.26)	18.75 (25.56)	11.75 (20.00)	31.25 (33.92)	16.25 (23.67)
T_7	Control	-		24.25 (29.42)	30.00 (33.17)	18.75 (25.59)	37.50 (37.74)	31.75 (34.25)	37.50 (37.74)
	SEM±			(0.84)	(1.53)	(0.79)	(1.47)	(0.70)	(1.97)
	CD 5%			(NS)	(4.60)	(NS)	(4.41)	(NS)	(5.91)

Figures in parentheses are transformed values of √x+1

However, Thiamethoxam 25% WG @100 g ha^{-1} was at par with Clothianidin 50% WDG @ 120g ha^{-1} during 2016. On the contrary, Sulfoxaflor 50% WG @ 120 g ha^{-1} was the second best treatment, which significantly reduced the number of green flies population (2.50 and 2.25) per leaf during both the years (Table 6-7).

Table 6: Effect of different insecticides on population of Green Flies (*Empoasca flavescens*) per leaf during 2016

No	Treatment	Dose/ha		Number of Green Flies per leaf					
		a.i.	Formulation (ml g^{-1})	Pre-treatment before 1st Spray	15 Days After 1st Spray	Pre-treatment before 2nd Spray	15 Days After 2nd Spray	Pre-treatment before 3rd Spray	15 Days After 3rd Spray
T_1	Sulfoxaflor 50% WG	50	100	17.00 (4.23)	8.75 (3.11)	13.75 (3.83)	6.50 (2.70)	18.75(4.43)	5.10 (2.67)
T_2	Sulfoxaflor 50% WG	60	120	18.75 (4.43)	7.50 (2.89)	15.00 (3.99)	3.75 (2.12)	18.75 (4.44)	2.50 (1.81)
T_3	Sulfoxaflor 50% WG	75	150	17.75 (4.32)	1.50 (1.53)	13.75 (3.83)	1.00 (1.39)	19.25 (4.49)	0.50 (1.18)
T_4	Thiamethoxam 25% WG	25	100	18.50 (4.41)	6.50 (2.71)	15.00 (3.99)	3.75 (2.10)	18.75 (4.43)	3.75 (2.12)
T_5	Clothianidin 50% WDG	60	120	18.75 (4.44)	5.00 (2.43)	15.00 (3.99)	3.50 (2.10)	18.75 (4.43)	3.75 (2.15)
T_6	Quinalphos 25% EC	190	760	18.75 (4.43)	12.50 (3.67)	15.00 (3.99)	9.25 (3.16)	17.75 (4.32)	11.25 (3.49)
T_7	Control	-		18.25 (4.38))	27.50 (5.33)	14.00 (3.86)	22.50 (4.84)	17.00 (4.23)	27.50 (5.33)
	SEM±			(0.11)	(0.15)	(0.12)	(0.22)	(0.11)	(0.17)
	CD 5%			(NS)	(0.47)	(NS)	(0.68)	(NS)	(0.53)

Figures in parentheses are transformed values of √x+1

Table 7: Effect of different insecticides on population of Green Flies (*Empoasca flavescens*) per leaf during 2017

No	Treatment	Dose/ha		Number of Green Flies per leaf					
		a.i.	Formulation (ml g^{-1})	Pre-treatment before 1st Spray	15 Days After 1st Spray	Pre-treatment before 2nd Spray	15 Days After 2nd Spray	Pre-treatment before 3rd Spray	15 Days After 3rd Spray
T_1	Sulfoxaflor 50% WG	50	100	14.50 (3.93)	2.50 (1.79)	10.50 (3.37)	5.00 (2.43)	7.50 (2.88)	2.50 (1.84)
T_2	Sulfoxaflor 50% WG	60	120	15.00 (3.99)	2.75 (1.93)	11.25 (3.48)	2.25 (1.80)	6.50 (2.70)	2.25 (1.80)
T_3	Sulfoxaflor 50% WG	75	150	15.25 (4.02)	0.25 (1.10)	10.50 (3.37)	0.25 (1.10)	6.00 (2.61)	0.25 (1.10)
T_4	Thiamethoxam 25% WG	25	100	15.50 (4.05)	3.50 (2.10)	12.00 (3.59)	3.50 (2.02)	8.50 (3.05)	3.25 (2.02)
T_5	Clothianidin 50% WDG	60	120	12.00 (3.60)	3.25 (2.00)	11.75 (3.55)	2.50 (1.87)	7.50 (2.89)	2.50 (1.87)
T_6	Quinalphos 25% EC	190	760	12.50 (3.66)	7.00 (2.82)	10.00 (3.30)	6.50 (2.70)	7.00 (2.81)	4.25 (2.23)
T_7	Control	-		13.25 (3.76)	16.00 (4.11)	10.25 (3.34)	15.00 (3.99)	7.25 (2.84)	11.25 (3.49)
	SEM±			(0.12)	(0.22)	(0.14)	(0.23)	(0.23)	(0.22)
	CD 5%			(NS)	(0.68)	(NS)	(0.69)	(NS)	(0.67)

Figures in parentheses are transformed values of √x+1

There are several studies which reported the effect of insecticides in reducing infestation of tea mosquito bug and green fly. In this study, Sulfoxaflor was found to be the most effective insecticide, which is in conformity with the results perceived by [25]. Similar outcomes were also spotted by [26] and [27]; where Sulfoxaflor was found to be efficient in suppressing aphid populations in soybean and Tarnished Plant Bug in cotton, respectively. Another study by [28] reported the effect of Sulfoxaflor in the management of mealy bug (*Phenacoccus solenopsis*) in cotton. [29] also reported efficacious control of cotton leaf hopper, *Amrasca devastans* (Distant) with the use of Sulfoxaflor. Moreover, in this study, apart from Sulfoxaflor, another insecticide *viz.* Thiamethoxam was found to be effect against tea mosquito bug, which is in agreement with the results spotted by [30].

Amongst the different insecticides, highest number of coccinellid beetle were recorded in plot treated with Sulfoxaflor 50% WG @ 150 g ha^{-1} (1.50 beetles/bush) and the untreated control (1.50 beetles/bush), followed by Sulfoxaflor 50% WG @ 100 g ha^{-1}, which was at par with Sulfoxflor 50% WG @ 300 g ha^{-1} (1.25 beetles/bush) during 2016 (Table 8). In contrast, during 2017, highest number of coccinellid beetle was recorded in the plot treated Clothianidin 50% WDG @ 120 g ha^{-1} (1.50 beetles/bush) (Table 8). Moreover, highest number of adults of *Stethorus gilvifrons* was recorded in plot treated with Sulfoxflor 50% WG @ 150 g ha^{-1} (12.50 beetles/36bushes) during 2016. On the contrary, during 2017, *Stethorus gilvifrons* population was found to be highest in Sulfoxflor 50% WG @ 300 g ha^{-1} (Table 8).

Table 8: Impact of different treatments on natural enemies during 2016-17

No	Treatment	Dose/ha		Coccinella beetle population per bush		*Stethorus gilvifrons* adults population per 36 bushes	
		a.i.	Formulation (ml g^{-1})	2016	2017	2016	2017
T_1	Sulfoxaflor 50% WG	50	100	1.25 (1.49)	1.25 (1.47)	11.25 (3.49)	6.75 (2.77)
T_2	Sulfoxaflor 50% WG	60	120	1.00 (1.39)	1.25 (1.45)	11.50 (3.53)	5.75 (2.58)
T_3	Sulfoxaflor 50% WG	75	150	1.50 (1.57)	1.00 (1.35)	12.50 (3.65)	6.25 (2.67)
T_4	Thiamethoxam 25% WG	25	100	1.25 (1.49)	1.25 (1.45)	11.25 (3.42)	7.00 (2.82)
T_5	Clothianidin 50% WDG	60	120	0.75 (1.31)	1.25 (1.43)	12.25 (3.63)	5.75 (2.58)
T_6	Quinalphos 25% EC	190	760	1.00 (1.39)	1.50 (1.56)	10.25 (3.34)	6.00 (2.59)
T_7	Control	-		1.00 (1.35)	1.25 (1.44)	12.25 (3.63)	4.25 (2.26)
	SEM±			1.50 (1.53)	1.00 (1.39)	10.75 (3.41)	4.50 (2.33)
	CD 5%			(0.12)	(0.16)	(0.14)	(0.19)
				(NS)	(NS)	(NS)	(NS)

Figures in parentheses are transformed values of √x+1

3.2 Phytotoxicity

Phytotoxicity symptoms like epinasty, hyponasty, leaf tip injury, leaf surface injury, wilting, vein clearing, etc. were measured at 0, 3, 5, 7, 10 and 15 days after each spray. For recording Phytotoxicity (%), 0-100 per cent scale was followed where, 0-0.0%=0, 01-10%=1, 11-20%=2, 21-30%=3, 31-40%=4, 41-50%=5, 51-60%=6, 61-70%=7, 71-80%=8, 81-90%=9, 91-100%=10. Sulfoxaflor 50% WG did not produce any phytotoxic symptoms. No phytotoxic symptoms like epinasty, hyponasty, leaf tip injury, leaf surface injury, wilting, vein clearing, etc. were recorded in any of the treated plots, even with the two times dose (150 a.i. g/ha) of Sulfoxaflor 50% WG during this trial (Table 9).

4. Conclusion

Sulfoxaflor 50% WG @ 150 g ha^{-1} was found to be more effective against TMB *(Helopeltis theivora*) and Green Fly (*Empoasca flavescens*), as compared to check insecticides *viz.* Thiamethoxam 25% WG @ 100 g ha^{-1} and Clothianidin 50% WDG @ 120 g ha^{-1}. Sulfoxaflor 50% WG @ 150 g ha^{-1} was found to be the most effective dose, recording minimum per cent twig infestation in case of TMB, and minimum population per leaf in case of Green Fly, as compared to remaining doses and also other check insecticidal treatments, at 15 days after application of the third spray.

Table 9: Phytotoxicity of different treatments on tea during 2016-17

No	Treatment	Dose/ha		Phytotoxicity symptoms at 00-100% scale					
		a.i.	Formulation (ml g^{-1})	Observations at 1, 3, 5, 7, 10 and 15 DAS					
				Epinasty	*Hyponasty*	*Leaf tip injury*	*Leaf surface injury*	*Wilting*	*Vein clearing*
T_1	Sulfoxaflor 50% WG	50	100	0	0	0	0	0	0
T_2	Sulfoxaflor 50% WG	60	120	0	0	0	0	0	0
T_3	Sulfoxaflor 50% WG	75	150	0	0	0	0	0	0
T_4	Sulfoxaflor 50% WG	150	300	0	0	0	0	0	0
T_5	Control	-		0	0	0	0	0	0

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