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Management of sorghum grain midge, *Contarinia sorghicola* (Coq.) (Diptera: Cecidomyiidae) in sorghum (*Sorghum bicolor*) through insecticide molecules

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Abstract
A field experiment was conducted during Kharif, 2018, to evaluate the bio-efficacy of conventional and new insecticides, which were cost-effective and ecologically feasible against the management of sorghum grain midge, *C. sorghicola*. During 15 Days after Spraying (DAS), a lower population (3.45 midges/ear head) was observed in lambda cyhalothrin over other molecules. Among the insecticide tested, the maximum per cent reduction of sorghum grain midge population (86.23%) was recorded in lambda cyhalothrin, followed by carbosulfan and fipronil, which recorded 76.51 and 71.74%, the lowest midge population, respectively, over control. Among the treatments, significantly higher grain yield was recorded in lambda cyhalothrin treated plots (22.89 q ha-1) with a 126.73 per cent increase over control. Similarly, higher biomass yield was recorded in lambda cyhalothrin of 72.82 q ha-1 with a 13.57 per cent increase over control.

Keywords: *Contarinia sorghicola*, bio-efficacy, chemical management, insecticides, sorghum grain midge

Introduction
Sorghum is an important cereal crop grown in the tropics and sub-tropics (Reference). It is known as the "King of Millets" because it contains nutrients such as carbohydrates (72.41 per cent), protein (9.35 per cent), and fat (3.35 per cent) and ensures that calories, vitamins, proteins, and minerals are provided (Adebiyi *et al*. 2005) [1]. Its importance is increasing due to sorghum's established usage as cow feed, poultry feed, and potable alcohol, in addition to its traditional uses as food and fodder (Subramanian and Jambunathan, 1980) [2]. It has a remarkable range of adaptation and can withstand high temperatures and drought stress. It develops on soils with poor structure, low fertility, and low water holding capacity and soils with high radiation and insufficient and unpredictable rainfall (Jotwani *et al*., 1980; Derese *et al*., 2018) [3].
Sorghum midge. *Contarinia sorghicola* (Coquillet) is a major and widespread pest of grain sorghum. The larvae of the sorghum midge feed on newly fertilized ovaries, limiting kernel development and resulting in complete grain failure. Due to the lack of kernel development, the glumes of a sorghum midge-infested spikelet fit tightly together. Depending on the degree of damage, a sorghum panicle infested with sorghum midge will have varying amounts of normal kernels distributed among non-kernel bearing spikelets (Harris, 1964; Jotwani *et al.*, 1976) [4, 5]. As a result, the ovary remains undeveloped, and the spikelet develops chaffey characteristics. Furthermore, a pinkish-red fluid will exude when the contaminated grain is squeezed. Finally, afflicted heads seem blighted or blasted, with little, deformed grains. When farmers notice damage, they immediately use insecticides, regardless of their efficacy in the field. To overcome this problem and recommend suitable insecticides to the study locations, we have evaluated the bio-efficacy of different insecticides, which are essential to reduce insect damage.

Materials and Methods
To study the bioefficacy of selected new and conventional insecticides against sorghum grain midge, *C. sorghicola*, a field experiment was carried out at ARS, Haradanahalli, Chamarajanagara. The treatment has nine different insecticides and untreated control (Table 1). The experiments were laid out in an RCBD and were replicated thrice.

A popular and susceptible sorghum variety CSV-23 (110-120 days) was sown in Kharif, 2018, with 45 X 15cm spacing between rows and plants, respectively. A plot size of 4.5 X 3.0 m was maintained for each replication. All packages of practices were followed except plant protective measures, where the application of insecticides was selectively imposed in each block (Anon., 2016) [6].

The application of insecticide was started based on the Economic Threshold Level (ETL; 2 midge/panicle). In addition, depending on the economic threshold level, the second spray was initiated, and the midge population in each treatment was recorded a day before spray, then 5, 10, and 15 days after the first and second sprays. The interval between sprays was set at 15 days. In each treatment, ten plants were chosen and tagged, and the number of grain midges per panicle was documented by bagging the panicle in a 1000 ml polythene bag. The observations on grain midge per panicle were made one day before spraying and 5, 10, and 15 days after spraying (DAS), and the means were processed using appropriate transformation. The data from each treatment was subjected for ANOVA (Gomez and Gomez, 1984; Hosmand, 1988) [7, 8] and means were separated by Tukey's HSD (Tukey, 1953) [9]. Harvesting was made at physiological maturity.

Table 1: Treatment details for the management of *C. sorghicola* on sorghum

Sl. No.	Chemicals	Trade name	Dose (ml/a.i./ha)	Dose (ml/g/l)
1	Spinosad 45 SC	Tracer	28.13	0.125
2	Indoxacarb 14.5 SC	Avaunt	36.25	0.5
3	Carbosulfan 25EC	Marshall	187.5	1.5
4	Lamda cyhalothrin 5EC	Karate	25.00	1.0
5	Fipronil 5SC	Regent (SC)	25.00	1.0
6	Emamectin Benzoate 5SG	Proclaim	5.00	0.2
7	Quinalphos 25 EC	Ekalax	312.5	2.5
8	Dimethoate 30 EC	Rogor	300.0	2.0
9	Chlorpyrifos 36 EC (SC)	Dursban	200.0	2.0
10	Untreated control	-	-	-

SC: Standard Check

Per cent reduction over untreated control was worked out using modified Abbot's formula given below.

$$P = \frac{100 \text{ X } 1 - (\text{Ta X Cb})}{(\text{Tb X Ca})}$$

Where, P = Percentage population reduction over control

Ta = Population in treatment after spray

Ca = Population in control after spray

Tb = Population in treatment before spray

Cb = Population in control before spray (Fleming and Ratnakaran, 1985)

Results and Discussion

First spray

A day before the initiation of spray, the midge population in each treatment varied between 12.79 to 15.28 midge/ear head, and there was no significant difference among the treatment. At 5DAS, each treatment differs significantly concerning the incidence of the sorghum grain midge. A significant and lower population of adult midges/earhead was recorded in lambda cyhalothrin (4.42) and followed by carbosulfan (6.76) and dimethoate (6.83). However, a significantly higher grain midge population (14.17 midges/ear head) was recorded in the untreated control. During 10 DAS, the number of midges in each treatment differs significantly. The lower population was recorded in lambda cyhalothrin (3.92 midges/ear head) followed by carbosulfan (6.13 midges/ear head). Further, the grain midge population in chlorpyrifos and indoxacarb was 8.93 and 9.25 midges/ear head, respectively and were on par with each other. However, an increase in grain midge population was observed in the untreated control (15.13 midges/ear head) in Table 2.

A similar trend in population control was observed even in 15DAS, where each treatment differs significantly, and a lower population (3.45 midges/ear head) was observed in lambda cyhalothrin, and this was followed by carbosulfan, fipronil and dimethoate, which recorded 4.61, 5.65 and 5.85 midges/ear head, respectively. However, a significantly higher population (14.53 midges/ear head) was recorded in the untreated control. Among the insecticide tested, the higher per cent reduction of grain midge population (76.26%) was recorded in lambda cyhalothrin and followed by carbosulfan and fipronil, which recorded 68.27 and 61.11% reduction in midge population, respectively.

Second spray

The grain midge population was between 3.45 to 14.53 midges/ ear head a day before the second spray. However, the differences in the midge population between the treatments were significant (Table 3). One day after imposing the treatment, there was a significant difference between the treatments. At 5 DAS, the lowest midge population (2.97midges/ ear head) was observed in lambda cyhalothrin, followed by carbosulfan, dimethoate, and fipronil, which recorded 4.13, 4.91 and 5.17 midges/ear head, respectively and were on par with each other. However, a significantly higher grain midge population (13.98 midges/ear head) was recorded in the untreated control. Likewise, at 10 DAS, each treatment differs significantly, and a lower population (2.53 midges/ear head) was recorded in lambda cyhalothrin.

A similar trend in population control was observed at 15 DAS, where each treatment differs significantly, and a lower population (1.26 midges/ear head) was observed in lambda cyhalothrin, and this was followed by carbosulfan, fipronil and dimethoate, which recorded 2.61, 3.14 and 3.74 midges/ear head, respectively. Among the insecticide tested, the higher per cent reduction of grain midge population (86.23%) was recorded in lambda cyhalothrin, followed by carbosulfan and fipronil, which recorded 76.51 and 71.74%, respectively. The insecticides in the decreasing order of their efficacy were lambda cyhalothrin >carbosulfan >fipronil >dimethoate > emamectin benzoate > Spinosad > indoxacarb > chlorpyrifos > quinalphos (Rafiq *et al.*, 2014) [14] The present investigation is in close conformity with Kanojia (2016) [12], and Satapathy and Mukherjee (2012) [13], which also indicated lambda cyhalothrin is the best treatment to control major rice insect pests, mainly rice gall midge and stem borers. Further, Udikeri *et al.* (2010) [10] and Zidan *et al.* (2012) [11] also reported that lambda cyhalothrin gives better results in controlling major sucking insect pests of cotton.

Grain yield

Among the treatments, significantly higher grain yield was recorded in lambda cyhalothrin treated plots (22.89 q ha-1) with a 126.73 per cent increase over control (Table 4). This was followed by carbosulfan, fipronil, and dimethoate which recorded 20.15, 18.22 and 18.07 q ha-1 with 100.00, 80.20 and 79.21 per cent increase over control, respectively. However, lower grain yield (10.07q ha-1) was significant in the untreated control.

Plant biomass yield

Significant differences were observed among the treatments concerning biomass yield (Table 4). Significantly higher biomass yield was recorded in lambda cyhalothrin of 72.82 q ha-1 with a 13.57 per cent increase over control. This was followed by carbosulfan, dimethoate and fipronil, which recorded 71.93, 70.89 and 70.74 q ha-1 with 7.19, 7.09 and 7.07 per cent increase over control, respectively and were on par with each other. However, lower biomass yield (64.07q ha-1) was recorded in the untreated control.

Cost economics of *C. sorghicola* management

The results of the cost economics revealed that lambda cyhalothrin 5EC @ 1.0 ml/l registered the highest gross returns of Rs. 93,324ha^{-1} resulting maximum net profit of Rs. 77,614ha^{-1}. This was followed by carbosulfan 25EC @1.5 ml/l, fipronil 5SC @ 1.0 ml/l and dimethoate 30EC @ 2.0 ml/l which recorded gross returns of Rs.83,325, Rs.76,197 and Rs.75,687 with net profit of Rs.66,655, Rs.59,687 and Rs.59,457, respectively. Likewise, emamectin benzoate 5SG @ 0.2 g/l, chlorpyrifos 20EC @ 2.0 ml/l, indoxacarb 14.5 SC @ 0.5 ml/l, spinosad 45 SC @ 0.125 ml/l and quinalphos 25 EC @ 2.5 ml/l were recorded gross returns of Rs. 71,739, Rs. 70,614, Rs.69,954, Rs.67,698 and Rs.56,904 with net profit of Rs.55,554, Rs.54,704, Rs.53,644, Rs.50,088 and Rs.39,594, respectively and control recorded least gross returns of Rs.45,867 with net profit of Rs.30,867. (Table 5).

Similarly, the highest benefit cost ratio (4.94:1) was recorded in lambda cyhalothrin 5EC @ 1.0 ml/l followed by carbosulfan 25EC @1.5 ml/l, dimethoate 30EC @ 2.0 ml/l, fipronil 5SC @ 1.0 ml/l and chlorpyrifos 20EC @ 2.0 ml/l which recorded benefit cost ratio of 4.00:1, 3.66:1, 3.62:1 and 3.44:1, respectively. The next best benefit cost ratio observed in emamectin benzoate 5SG @ 0.2 g/l, indoxacarb 14.5 SC @ 0.5 ml/l, spinosad 45 SC @ 0.125 ml/l and quinalphos 25 EC @ 2.5 ml/l recorded 3.43:1, 3.29:1, 2.84:1 and 2.29:1, respectively. However, very low benefit cost ratio of 2.06:1 was recorded in untreated control.

Table 2: Bio-efficacy of insecticides against sorghum grain midge, *C. sorghicola*, kharif 2018 (I spray)

Sl. No.	Treatments	Dose (ml/a.i./ha)	Dose (ml/g/l)	No. of midge / 5 ear head				Per cent reduction over control (15 DAS)
				1 DBS	5 DAS	10 DAS	15 DAS	
1	Spinosad 45 SC	28.13	0.125	13.57 (3.75)^{a}	10.32 (3.29)^{cd}	8.40 (2.98)^{bcd}	7.57 (2.84)^{c}	47.90
2	Indoxacarb 14.5 SC	36.25	0.5	12.79 (3.65)^{a}	10.21 (3.27)^{cd}	9.25 (3.12)^{cd}	8.08 (2.93)^{c}	44.39
3	Carbosulfan 25EC	187.5	1.5	13.47 (3.74)^{a}	6.76 (2.70)^{b}	6.13 (2.57)^{b}	4.61 (2.26)^{ab}	68.27
4	Lambda cyhalothrin 5EC	25.00	1.0	14.29 (3.85)^{a}	4.42 (2.22)^{a}	3.92 (2.10)^{a}	3.45 (1.99)^{a}	76.26
5	Fipronil 5SC	25.00	1.0	14.37 (3.86)^{a}	7.52 (2.83)^{bc}	7.07 (2.75)^{bc}	5.65 (2.48)^{abc}	61.11
6	Emamectin benzoate 5SG	5.00	0.2	14.24 (3.84)^{a}	9.00 (3.08)^{bc}	8.49 (3.00)^{bcd}	7.20 (2.77)^{c}	50.44
7	Quinalphos 25EC	312.5	2.5	14.05 (3.81)^{a}	12.55 (3.61)^{de}	10.75 (3.35)^{d}	8.35 (2.97)^{c}	40.53
8	Dimethoate 30EC	300.0	2.0	15.28 (3.97)^{a}	6.83 (2.71)^{b}	7.11 (2.76)^{bc}	5.85 (2.52)^{bc}	59.74
9	Chlorpyrifos 20EC (SC)	200.0	2.0	14.58 (3.88)^{a}	9.22 (3.12)^{bc}	8.93 (3.07)^{cd}	7.23 (2.78)^{c}	50.24
10	Untreated control	-	-	14.56 (3.88)^{a}	14.17 (3.83)^{e}	15.13 (3.95)^{e}	14.53 (3.88)^{d}	-
SE m ±				NS	0.08	0.08	0.09	-
CD @ p=0.05				NS	0.25	0.23	0.28	-

* DBS: Day before spraying; DAS: Day after spraying; NS: Non significant; SC: Standard check; Values in the column followed by common letters are non-significant at p = 0.05 as per Tukey‟s HSD (Tukey, 196). Figures in the parenthesis indicate √x+0.5 transformed values.

Table 3: Bio-efficacy of insecticides against sorghum grain midge, *C. sorghicola*, kharif 2018 (II spray)

Sl. No.	Treatments	Dose (ml/a.i./ha)	Dose (ml/g/l)	No. of midge / 5 ear head				Per cent reduction over control(15 DAS)
				1 DBS	5 DAS	10 DAS	15 DAS	
1	Spinosad 45 SC	28.13	0.125	7.57 (2.84)^{c}	6.65 (2.67)^{c}	6.27 (2.60)^{c}	5.72 (2.49)^{d}	48.51
2	Indoxacarb 14.5 SC	36.25	0.5	8.08 (2.93)^{c}	7.25 (2.78)^{d}	6.52 (2.65)^{c}	5.95 (2.54)^{d}	46.44
3	Carbosulfan 25EC	187.5	1.5	4.61 (2.26)^{ab}	4.13 (2.15)^{ab}	3.90 (2.10)^{b}	2.61 (1.76)^{ab}	76.51
4	Lambdacyhalothrin 5EC	25.00	1.0	3.45 (1.99)^{a}	2.97 (1.86)^{a}	2.53 (1.74)^{a}	1.53 (1.47)^{a}	86.23
5	Fipronil 5SC	25.00	1.0	5.65 (2.48)^{abc}	5.17 (2.38)^{bc}	4.62 (2.26)^{b}	3.14 (1.91)^{ab}	71.74

6	Emamectin benzoate 5SG	5.00	0.2	7.20 (2.77)^{c}	6.85 (2.71)^{d}	6.15 (.58)^{c}	5.60 (2.47)^{cd}	49.59
7	Quinalphos 25EC	312.5	2.5	8.35 (2.97)^{c}	7.62 (2.85)^{c}	7.19 (2.77)^{c}	6.59 (2.66)^{d}	40.68
8	Dimethoate 30EC	300.0	2.0	5.85 (2.52)^{bc}	4.91 (2.33)^{b}	4.46 (2.23)^{b}	3.74 (2.06)^{bc}	66.34
9	Chlorpyrifos 20EC (SC)	200.0	2.0	7.23 (2.78)^{c}	6.63 (2.67)^{cd}	5.97 (2.54)^{c}	5.39 (2.43)^{cd}	51.49
10	Untreated control	-	-	14.53 (3.88)^{d}	13.98 (3.81)^{e}	13.52 (3.74)^{d}	11.11 (3.41)^{e}	-
SE m ±				0.09	0.06	0.04	0.07	-
CD @ p=0.05				0.28	0.17	0.12	0.20	-

* DBS: Day before spraying; DAS: Day after spraying; NS: Non significant; SC: Standard check; Values in the column followed by common letters are non-significant at p = 0.05 as per Tukey‟s HSD (Turkey, 1965). Figures in the parenthesis indicate √x+0.5 transformed value

Table 4: Bio-efficacy of insecticides on grain and biomass yield, kharif 2018

Sl. No.	Treatments	Dose (ml/ a.i./ha)	Grain yield			% Increase over control	Biomass			% Increase over control
			Plot basis (Kg/13.5m^2)	Hectare basis (q/ha)	Tons/ha		Plot basis (Kg/ 13.5 m^2)	Hectare basis (q/ha)	Tons/ha	
1	Spinosad 45 SC	28.13	2.15	15.93^{d}	1.59	57.43	9.32	69.04^{de}	6.90	7.64
2	Indoxacarb 14.5 SC	36.25	2.24	16.59^{d}	1.66	64.36	9.20	68.15^{ef}	6.82	6.40
3	Carbosulfan 25EC	187.5	2.72	20.15^{b}	2.02	100.00	9.71	71.93^{ab}	7.19	12.17
4	Lambda cyhalothrin 5EC	25.00	3.09	22.89^{a}	2.29	126.73	9.83	72.82^{a}	7.28	13.57
5	Fipronil 5SC	25.00	2.46	18.22^{c}	1.82	80.20	9.55	70.74^{bcd}	7.07	10.30
6	Emamectin benzoate 5SG	5.00	2.30	17.04^{cd}	1.71	69.31	9.36	69.33^{cde}	6.93	8.11
7	Quinalphos 25 EC	312.5	1.76	13.04^{e}	1.31	29.70	8.97	66.44^{f}	6.64	3.59
8	Dimethoate 30 EC	300.0	2.44	18.07^{c}	1.81	79.21	9.57	70.89^{bc}	7.09	10.61
9	Chlorpyrifos 20EC (SC)	200.0	2.26	16.74^{d}	1.67	65.35	9.32	69.07^{de}	6.91	7.80
10	Untreated control	-	1.36	10.07^{f}	1.01	-	8.65	64.07^{g}	6.41	-
	SE m ±		-	0.26	-	-	-	0.34	-	-
	CD @ p=0.05		-	0.76	-	-	-	1.02	-	-

***** SC: Standard check; Values in the column followed by common letters are non-significant at p = 0.05 as per Tukey‟s HSD (Tukey, 1965)

Table 5: Cost economics of different insecticides for the management of sorghum grain midge, *C sorghicola* in Sorghum

Sl. No.	Treatments	Dose (ml/a.i./ha)	Yield (q/ha)		Gross returns (Rs.)	Cost involved (Rs.)		Total Cost (Rs.)	Net Profit (Rs.)	B: C ratio
			Grain	Biomass		Grain midge management	Other expenditure			
1	Spinosad 45 SC	28.13	15.93	69.04	67698	2610.00	15000.00	17610.00	50088	2.84:1
2	Indoxacarb 14.5 SC	36.25	16.59	68.15	69954	1310.00	15000.00	16310.00	53644	3.29:1
3	Carbosulfan 25EC	187.5	20.15	71.93	83325	1670.00	15000.00	16670.00	66655	4.00:1
4	Lambda cyhalothrin 5EC	25.00	22.89	72.82	93324	710.00	15000.00	15710.00	77614	4.94:1
5	Fipronil 5SC	25.00	18.22	70.74	76197	1510.00	15000.00	16510.00	59687	3.62:1
6	Emamectin benzoate 5SG	5.00	17.04	69.33	71739	1185.00	15000.00	16185.00	55554	3.43:1
7	Quinalphos 25 EC	312.5	13.04	66.44	56904	2310.00	15000.00	17310.00	39594	2.29:1
8	Dimethoate 30 EC	300.0	18.07	70.89	75687	1230.00	15000.00	16230.00	59457	3.66:1
9	Chlorpyrifos 20EC (SC)	200.0	16.74	69.04	70614	910.00	15000.00	15910.00	54704	3.44:1
10	Untreated control	-	10.07	64.07	45867	-	15000.00	15000.00	30867	2.06:1

*Price of Sorghum grains = Rs. 3600-00 per quintal; Price of fodder = Rs. 1500-00 per tonnes (As per APMC, Mandya, July 2019); SC: Standard check

Conclusion

Sorghum is growing mainly in Northern Karnataka and some parts of Southern Karnataka. Farmers are unaware of the loss caused by grain midge in sorghum. To overcome the loss caused by these midges, insecticides such as lambda cyhalothrin, followed by carbosulfan and fipronil, can be used to manage grain midges in sorghum were found to be most effective.

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