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Bio-efficacy of different seed treatment chemicals against shoot fly, *Atherigona approximata* Malloch infesting foxtail millet

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Abstract
The present investigation was conducted at College of Agriculture, V. C. Farm, Mandya, University of Agricultural Sciences, Bangalore during *Kharif* 2019. Attack of shoot fly in foxtail millet causes significant loss of yield at the early stage of crop growth. Delay in the use of insecticide leads to high loss of yield. The most economical and easiest method for the management of shoot fly is seed treatment. In the present study eight different seed treatment chemicals and one standard check with soil application of carbofuran 3G at 33 Kg ha^{-1} were evaluated against infestation of shoot fly in foxtail millet. The observations were recorded on per cent dead heart from 14 to 35 days after sowing (DAS) at weekly interval. The data on per cent dead heart revealed that, among the different treatments clothianidin 50WG @ 1 g Kg^{-1} recorded significantly least per cent dead heart (14.84%) compared to rest of the treatments at 35 DAS. The grain and fodder yield were also significantly higher in case of seed treatment with clothianidin 50WG @ 1 g Kg^{-1} (15.07 and 24.31 q ha^{-1}) followed by thiamethoxam 25WG @ 2 g Kg^{-1} (14.32 and 22.19 q ha^{-1}). Cost economics of different seed treatment chemicals revealed that clothianidin 50WG @ 1 g Kg^{-1} recorded highest net returns with maximum cost benefit ratio (1:2.57).

Keywords: Shoot fly, dead heart, seed treatment, clothianidin, thiamethoxam

Introduction
Foxtail millet, generally referred to as German or Italian millet, among the most important small millets grown in the country and is the third largest millet crop in the world. This is drought tolerant, grows at high elevation (up to 600 ft) and is often planted as an alternative crop for sorghum on black cotton soils, where rainfall is deficient. Besides, its low yielding nature, it has unique nutritional properties, namely a rich source of carbohydrates (60.9 mg), protein (12.3 mg), fat (4.3 mg), minerals (3.3 mg) for 100 g dry weight and it has essential minerals such as calcium (31 mg), phosphorous (290 mg) per 100 g (Anon., 1991) [1]. The realistic yield gap seen between demonstration yield as well as the typical farmer yield was due to various biotic and abiotic factors, which are the key development constraints. Although pests and disease problems are minimal in this crop at times, in particular the species of shoot flies assume a serious pest status and cause a significant loss of yield. The incidence of shoot fly was recorded for the first time in south India during 1913 (Fletcher, 1914) [3]. Shoot flies (*Atherigona sp.)* infest different crops of the Poaceae mainly cereals and millets infesting only seedlings. It causes damage to seedlings of the age between 1-week up to 30 days. The common symptom of damage is central shoot drying, or 'dead heart.' Shoot fly is a major pest of economic significance. Among the major insect pests in millets, shoot flies are reported to be significant causing 25-90 per cent dead heart (DH) damage (Selvaraj *et al*., 1974) [12]. The eggs are white, have an elongated cigar shape and measure roughly 0.8 x 0.2 mm. The fully grown larva is 8-10 mm long and has a white or yellowish appearance. The adult fly is about 4 mm long and appears like a small house fly. The head and thorax of the female are light grey and abdomen is yellowish with brown spots, while the males are more blackish. The tiny maggots crawl down under the leaf sheath until they approach the base of the seedlings, then cut the growing point or central shoot which results in the development of the characteristic dead heart symptoms. The damaged plants that produce side tillers are also attacked by the maggots repeatedly (Kahate *et al*., 2014) [9].

The traditional methods for management of shoot fly have not been sufficient and cost effective in these low value crops like small millets. The earlier studies revealed limited information on the bio-efficacy of different seed treatment insecticides against shoot fly. Therefore, in accordance with all these viewpoints, the present investigations were carried out with the objective to evaluate different seed treatment chemicals and their cost effectiveness for the protection of early seedling stage of the crop from attack of shoot fly.

Materials and Methods

To study the management of shoot fly in foxtail millet, a field experiment was conducted in a Randomized Complete Block Design (RCBD) with 10 treatments replicated thrice with a plot size of 3 X 2.5 m at College of agriculture, V.C. Farm, Mandya. A popular and shoot fly susceptible foxtail millet variety SIA-3156 was sown in replicated blocks with a spacing of 30 X 10 cm between rows and plants, respectively. In each treatment, the required quantity of chemical was taken in a polythene bag and the known quantity of water was mixed and diluted. Further, a known quantity of foxtail millet seeds was taken inside the polybag containing insecticide solution and, both insecticide solution and the seeds were thoroughly mixed for about 15 minutes, and were sown after shade dry for about an hour. For each treatment, a separate and new polybag was used to avoid the residual effect of other treatments. In each treatment the observations on per cent dead heart was recorded on 10 randomly selected plants in each replication at 14, 21, 28 and 35 days after sowing. Cost economics of each treatment was worked out as per market price, labour wages and additional costs during the course of study and benefit cost ratio was calculated. The mean data on infestation and yield parameters was processed after suitable transformation, and was subjected for ANOVA (Gomez and Gomez, 1984; Hosmand, 1988) [6, 7] and means were separated by Tukey's HSD (Tukey, 1953) [14] for interpretation.

$$\text{Dead heart (\%)} = \frac{\text{Number of plants with dead heart/plot}}{\text{Total number of plants/plot}} \times 100$$

Results and discussion

On 14 days after sowing, each treatment differed significantly. Among the treatments, a significant lower dead heart (5.57%) was recorded in clothianidin 50WG @ 1 g Kg^{-1} seed. This was on par with thiamethoxam 25WG @ 2 g Kg^{-1} and imidacloprid 17.8 SL 2 mL Kg^{-1} which recorded 5.66 and 6.34 per cent dead heart, respectively. This was followed by acetamiprid 20 SP @ 2 g Kg^{-1} and carbofuran 3G @ 33 Kg ha^{-1} which recorded 6.52 and 7.65 per cent dead heart, respectively and were on par with each other (Table 1). The next best treatments were flonicamid 50 SG @ 1 g Kg^{-1} and thiacloprid 21.7 SC @ 2 mL Kg^{-1} which recorded 8.33 and 8.92 per cent dead heart, respectively and were on par with each other. Likewise, the per cent dead heart in fipronil 5G @ 4 g Kg^{-1} and chlorpyriphos 20 EC @ 4 mL Kg^{-1} was 9.32 and 9.45 per cent, respectively and were on par with each other. However, significantly higher per cent dead heart (15.89%) was recorded in untreated control.

At 21 days after sowing, significantly lower per cent dead heart was observed in clothianidin 50WG @ 1 g Kg^{-1} seed (8.02%) and it is on par with thiamethoxam 25WG @ 2 g Kg^{-1} (8.16%). This was followed by imidacloprid 17.8 SL @ 2 mL Kg^{-1} and acetamiprid 20 SP @ 2 g Kg^{-1} which recorded 9.45 and 9.50 per cent dead heart, respectively and were on par with each other (Table 1). The next best treatments were carbofuran 3G @ 33 Kg ha^{-1} and flonicamid 50 SG @ 1 g Kg^{-1} which recorded 12.63 and 12.73 per cent dead heart, respectively and were on par with each other. This was followed by thiacloprid 21.7 SC @ 2 mL Kg^{-1} and fipronil 5G @ 4 g Kg^{-1} which recorded 13.37 and 13.76 per cent dead heart, respectively. Similarly, chlorpyriphos 20 EC @4 mL Kg^{-1} recorded 14.81 per cent of dead heart. However, a significant higher per cent dead heart was recorded in untreated control (24.56% dead heart).

Likewise, at 28 days after sowing a significant lowest per cent dead heart was observed in clothianidin 50WG @ 1 g Kg^{-1} seed (9.22%) which was on par with thiamethoxam 25WG @ 2 g Kg^{-1} which recorded 9.32 per cent dead heart. It is followed by imidacloprid 17.8 SL @ 2 mL Kg^{-1} and acetamiprid 20 SP @ 2 g Kg^{-1} in which both recorded 12.66 per cent dead heart (Table 1). The next best treatment was carbofuran 3G @ 33 Kg ha^{-1} (16.36%), this was followed by flonicamid 50 SG @ 1 g Kg^{-1} and thiacloprid 21.7 SC @ 2 mL Kg^{-1} which recorded 16.37 and 17.53 per cent dead heart and were on par with each other. Fipronil 5G @ 4 g Kg^{-1} and chlorpyriphos 20 EC @ 4 mL Kg^{-1} recorded comparatively higher per cent of dead heart (18.34 and 20.40%, respectively). However, the per cent dead heart was significantly higher in untreated control (39.78%).

Table 1: Bioefficacy of seed treatment chemicals on the incidence of shoot fly, *Kharif* 2019

Sl. No.	Treatments	Dose (mL or g/ 20 mL water/ Kg seed)	Dead heart (%)#				Per cent reduction over control (@ 35 DAS)
			14 DAS	21 DAS	28 DAS	35 DAS	
1	Imidacloprid 17.8SL	02:20	6.34 (14.58)a	9.45 (17.90)b	12.66 (20.84)b	18.39 (25.39)b	66.15
2	Thiamethoxam 25WG	02:20	5.66 (13.76)a	8.16 (16.60)a	9.32 (17.77)a	15.27 (23.00)a	71.89
3	Fipronil 5G	04:20	9.32 (17.77)d	13.76 (21.77)cd	18.34 (25.36)d	27.85 (31.85)fg	48.74
4	Flonicamid 50SG	01:20	8.33 (16.77)cd	12.73 (20.90)c	16.37 (23.86)cd	25.50 (30.33)de	53.06
5	Acetamiprid 20 SP	02:20	6.52 (14.79)ab	9.50 (17.95)b	12.66 (20.84)b	23.81 (29.21)c	56.18
6	Clothianidin 50WG	01:20	5.57 (13.65)a	8.02 (16.45)a	9.22 (17.67)a	14.84 (22.66)a	72.69
7	Thiacloprid 21.7 SC	02:20	8.92 (17.38)cd	13.37 (21.45)cd	17.53 (24.75)cd	26.80 (31.18)ef	50.67
8	Chlorpyriphos 20EC	04:20	9.45 (17.90)d	14.81 (22.63)d	20.40 (26.85)e	29.42 (32.85)g	45.85

9	Carbofuran 3G	33 Kg ha^{-1}	7.65 (16.05)^{bc}	12.63 (20.82)^{c}	16.36 (23.85)^{c}	24.25 (29.50)^{cd}	55.37
10	Untreated control	-	15.89 (23.48)^{e}	24.56 (29.70)^{e}	39.78 (39.10)^{f}	54.33 (47.48)^{h}	-
SE m ±			0.27	0.25	0.29	0.20	
CD @ p=0.05			0.80	0.73	0.87	0.59	-

*DAS = Days after sowing; #Values in parentheses are arcsine transformed values; Values in the column followed by common letters are non-significant at p=0.05 as per Tukey's HSD (Tukey, 1953) [14].

At 35 days after sowing significantly lower per cent dead heart was observed in clothianidin 50WG @ 1 g Kg^{-1} seed which recorded 14.84 per cent dead heart and was on par with thiamethoxam 25WG @ 2 g Kg^{-1} (15.27%). Likewise, per cent dead heart in imidachloprid 17.8 SL @ 2 mL Kg^{-1} and acetamiprid 20 SP @ 2 g Kg^{-1} were observed 18.39 and 23.81 per cent, respectively and were differed significantly from each other (Table 1). Similarly, carbofuran 3G @ 33 Kg ha^{-1}, flonicamid 50 SG @ 1 g Kg^{-1} and thiacloprid 21.7 SC @ 2 mL Kg^{-1} recorded 24.25, 25.50 and 26.80 per cent respectively. In case of fipronil 5G @ 4 g Kg^{-1} and chlorpyriphos 20 EC @ 4 mL Kg^{-1} recorded dead heart of 27.85 and 29.42 per cent, respectively and were on par with each other. A significant higher per cent dead heart was observed in untreated control (54.33%).

Among the treatments at 35 days after sowing, the per cent reduction in dead heart over untreated control was varied between 45.85 and 72.69 per cent. The highest per cent reduction was observed in clothianidin 50WG @ 1 g Kg^{-1} seed (72.69%) and this was followed by thiamethoxam 25WG @ 2 g Kg^{-1} (71.89%), imidachloprid 17.8 SL @ 2 mL Kg^{-1} (66.15%), acetamiprid 20 SP @ 2 g Kg^{-1} (56.18%), carbofuran 3G @ 33 Kg ha^{-1} (55.37%), flonicamid 50 SG @ 1 g Kg^{-1} (53.06%), thiacloprid 21.7 SC @ 2 mL Kg^{-1} (50.67%), fipronil 5G @ 4 g Kg^{-1} (48.74%) and chlorpyriphos 20 EC @ 4 mL Kg^{-1} (45.85%) (Figure 1).

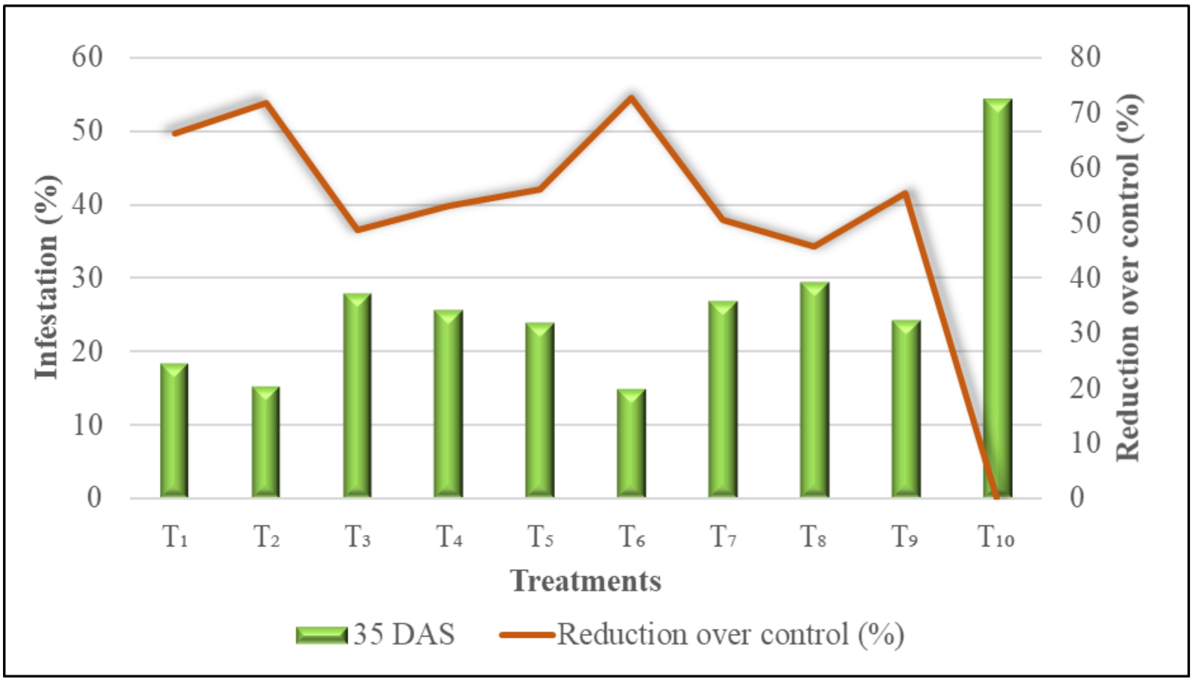

Fig 1: Impact of seed treatment chemicals on the reduction of foxtail millet shoot fly infestation over untreated control

The results are in conformity with the results of Jinfeng *et al.* (2018) [8] where they reported that treating corn seeds with thiamethoxam (1.0 and 2.0 g a. i. Kg^{-1} of seeds), clothianidin (1.0 and 2.0 g a. i. Kg^{-1} of seeds) and imidacloprid (2.0 g a. i. Kg^{-1} of seeds) reduced thrips infestations and prevented yield losses throughout the corn growing season. Further Gerald *et al.* (2004) [4] reported that clothianidin, imidacloprid 70WS (Gaucho, Prescribe) and thiamethoxam 70WS (Cruiser) significantly reduced chinch bug population in maize. Duraimurugan and Alivelu (2017) [2] reported that clothianidin 50WG @ 25 g a. i. ha^{-1}, flonicamid 50WG @ 50 g a. i. ha^{-1}, acetamiprid 20 SP @ 20 g a. i. ha^{-1}, thiamethoxam 25WG @ 50 g a.i. ha^{-1}, profenophos 50EC @ 250 g a.i. ha^{-1} and dimethoate 30EC @ 250g a.i. ha^{-1} have reduced leaf hopper population of 92.7, 83.7, 90.7, 84.0, 79.8 and 88.3 per cent over control, respectively. Similarly, Srinivasa *et al.* (2012) [13] stated that due to a different mode of action and systemic as well as contact insecticidal properties, clothianidin was found to be effective against populations of many species of aphids in wheat. Further Peng *et al.* (2015) [11], demonstrated that both imidacloprid and clothianidin seed treatments had prevented yield losses and wheat aphid infestations throughout the winter wheat growing season. The lowest recorded shoot fly (dead heart) infestation of 7.9 per cent with less shoot bug numbers (5.83 / five plants) and higher grain yield (31.93 q ha^{-1}) in addition to the highest stover yield (56.92 q ha^{-1}) was observed in seed treatment with thiamethoxam 70WS @ 2 g Kg^{-1} followed by imidacloprid 70WS @ 5 g ha^{-1} and carbosulfan 25DS at 40 g Kg^{-1} (Vijay and Prabhuraj, 2007) [15].

Table 2: Cost economics of different seed treatment chemicals for the management of shoot fly, *A. approximata* in foxtail millet

Sl. No.	Treatments	Dose (mL or g/ 20 mL water/ Kg seed)	Yield (q ha^{-1})		Gross returns (Rs)	Total cost (Rs)	Net profit (Rs)	B:C ratio
			Grain	Biomass				
1	Imidachloprid 17.8SL	2:20	13.66^{b}	20.30^{c}	50504.00	15588.00	34916.00	2.24:1
2	Thiamethoxam 25WG	2:20	14.32^{b}	22.19^{b}	53126.00	15647.40	37478.60	2.40:1
3	Fipronil 5G	4:20	10.33^{e}	13.43^{ef}	37808.00	15618.88	22189.12	1.42:1
4	Flonicamid 50SG	1:20	11.16^{d}	16.95^{d}	41334.00	15644.17	25689.83	1.64:1
5	Acetamiprid 20SP	2:20	12.73^{c}	18.09^{d}	46900.00	15605.20	31294.80	2.01:1
6	Clothianidin 50WG	1:20	15.07^{a}	24.31^{a}	56100.00	15711.00	40389.00	2.57:1
7	Thiacloprid 21.7SC	2:20	10.56^{de}	14.46^{e}	38796.00	15616.80	23179.20	1.48:1
8	Chlorpyriphos 20EC	4:20	9.40^{f}	12.84^{f}	34528.00	15581.44	18946.56	1.22:1
9	Carbofuran 3G	33 Kg ha^{-1}	12.25^{c}	17.13^{d}	45076.00	18310.00	26766.00	1.46:1
10	Untreated control	-	8.46^{g}	11.24^{g}	31012.00	15340.00	15672.00	1.02:1
SE m ±			0.15	0.25	-	-	-	-
CD @ p=0.05			0.44	0.75	-	-	-	-

*Price of grains = Rs. 3400-00 per quintal; Price of straw = Rs. 200-00 per quintal (As per APMC, Mandya, April 2020)

The grain yield from the bio-efficacy of different seed treatment chemicals against shoot fly were varied significantly between 8.46 to 15.07 quintal per hectare. The significant higher yield of 15.07 q ha^{-1} was recorded in treatment clothianidin 50WG @ 1 g Kg^{-1} seed and was followed by thiamethoxam 25WG @ 2 g Kg^{-1} which recorded 14.32 q ha^{-1}. This was followed by imidachloprid 17.8 SL @ 2 mL Kg^{-1} which recorded 13.66 q ha^{-1}. However, lower yield of 8.46 q ha^{-1} was recorded in untreated control (Table 2).

Significantly higher biomass yield was observed in clothianidin 50WG @ 1 g Kg^{-1} seed which recorded 24.31 q ha^{-1} and was followed by thiamethoxam 25WG @ 2 g Kg^{-1} which recorded 22.19 q ha^{-1}. However, significantly lower biomass yield with 11.24 q ha^{-1} was recorded in untreated control.

The results of the cost economics during *Kharif* 2019 revealed that clothianidin 50WG @ 1 g Kg^{-1} seed registered the highest gross return of Rs. 56100.00 ha^{-1} resulting in maximum net profit of Rs. 40389.00 ha^{-1}. This was followed by thiamethoxam 25WG @ 2 g Kg^{-1}, imidachloprid 17.8 SL @ 2 mL Kg^{-1} and acetamiprid 20 SP @ 2 g Kg^{-1} which recorded gross returns of Rs. 53126.00, Rs. 50504.00 and Rs. 46900.00, respectively with net returns of Rs. 37478.60, Rs. 34916.00 and Rs. 31294.80 respectively. Whereas, untreated control recorded minimum net profit (Rs. 15672.00) compared to rest of the treatments.

Similarly, the highest benefit cost ratio (1:2.57) was recorded in clothianidin 50WG @ 1 g Kg^{-1} seed followed by thiamethoxam 25WG @ 2 g Kg^{-1}, imidachloprid 17.8 SL @ 2 mL Kg^{-1} and acetamiprid 20 SP @ 2 g Kg^{-1} which recorded benefit cost ratio of 2.40, 2.24 and 2.01, respectively. Next best treatments were flonicamid 50 SG @ 1 g Kg^{-1}, thiacloprid 21.7 SC @ 2 mL Kg^{-1} and carbofuran 3G @ 33 Kg ha^{-1} with benefit cost ratio of 1.64, 1.48 and 1.46, respectively. However, very low benefit cost ratio among the treatments, recorded in fipronil 5G @ 4 g Kg^{-1} and chlorpyriphos 20 EC @ 4 mL Kg^{-1} with 1.42 and 1.22, respectively whereas, in control it was recorded least benefit cost ratio (1:1.02) (Table 2).

The results of the present findings are in close agreement with that of Duraimurugan and Alivelu (2017) [2], who reported that the cost effectiveness of clothianidin was high with benefit-cost ratio of 1.70, followed by acetamiprid (1.62) and profenofos (1.61) in controlling the sucking pests of castor. Further, Patil *et al.* (2016) [10] observed that the seed treatment with thiamethoxam 30FS, clothianidin 50 WDG and imidacloprid 48FS were found effective in controlling the jassids and shoot fly in wheat. The additional yield (21.14 q ha^{-1}) and income over control (Rs. 44480), monetary returns (Rs. 114607), net profit (Rs. 81377) and benefit cost ratio (3.44) was highest in thiamethoxam 30FS @ 1.00 mL Kg^{-1} seed. Similarly, the influence of clothianidin and thiamethoxam in maximizing seed yield and highest cost benefit ratio has been reported by Ghosal *et al.* (2013) [5] thus, supporting the present findings.

Conclusion

Seed treatment with clothianidin 50WG @ 1 g Kg^{-1} emerged as a better option for the management of shoot fly with least incidence of dead hearts as well as higher monetary returns. Controlling the pest in already established crop through spraying of chemicals has limited scope as frequent use of insecticides is necessary to obtain the desirable control level and this could also lead to increase production costs. Therefore, seed treatment at the time of sowing may advocated for the management of shoot fly as part of an IPM strategy against shoot fly in foxtail millet.

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