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 shoot fly. 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 by suitable transformation, and was subjected for ANOVA

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 imidachloprid 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 imidachloprid 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 fipronil 5G @ 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 imidachloprid 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 per cent dead heart (18.34 and 20.40%, respectively). However, the per cent dead heart was significantly higher in untreated control (39.78%).

| Sl. No. | Treatments        | Dose (mL or g/ 20 mL water/ Kg seed) | 14 DAS | 21 DAS | 28 DAS | 35 DAS | Per cent reduction over control (@ 35 DAS) |
|--------|-------------------|-------------------------------------|--------|--------|--------|--------|------------------------------------------|
| 1      | Imidachloprid 17.8SL | 02:20                               | 6.34 (15.48) | 9.45 (17.90) | 12.66 (20.84) | 18.39 (25.39) | 66.15                                    |
| 2      | Thiamethoxam 25WG  | 02:20                               | 5.66 (13.76) | 8.16 (16.60) | 9.32 (17.77) | 15.27 (23.03) | 71.89                                    |
| 3      | Fipronil 5G       | 04:20                               | 9.32 (17.77) | 13.76 (21.77) | 18.34 (25.36) | 27.85 (31.85) | 48.74                                    |
| 4      | Flonicamid 50SG   | 01:20                               | 8.33 (16.77) | 12.73 (20.90) | 16.37 (23.86) | 25.50 (30.33) | 53.06                                    |
| 5      | Acetamiprid 20 SP | 02:20                               | 6.52 (14.79) | 9.50 (17.95) | 12.66 (20.84) | 23.81 (29.21) | 56.18                                    |
| 6      | Clothianidin 50WG | 01:20                               | 5.57 (13.65) | 8.02 (16.45) | 9.22 (17.67) | 14.84 (22.66) | 72.69                                    |
| 7      | Thiacloprid 21.7 SC  | 02:20                              | 8.92 (17.38) | 13.37 (21.45) | 17.53 (24.75) | 26.80 (31.18) | 50.67                                    |
| 8      | Chlorpyriphos 20EC | 04:20                               | 9.45 (17.90) | 14.81 (22.63) | 20.40 (26.85) | 29.42 (32.85) | 45.85                                    |
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 imidacloprid 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%), imidacloprid 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).

![Figure 1: Impact of seed treatment chemicals on the reduction of foxtail millet shoot fly infestation over untreated control](image)

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, imidaclopid 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, Srinivasan 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

| Treatment                  | Seed cost (Rs Kg⁻¹) | Chemical Cost (Rs ml⁻¹) | Total cost (Rs Kg⁻¹) | Yield (q ha⁻¹) | Stover yield (q ha⁻¹) | Yield w/o CT (q ha⁻¹) | Stover yield w/o CT (q ha⁻¹) | Cost of 1 q stover (Rs) |
|----------------------------|---------------------|-------------------------|---------------------|----------------|-----------------------|-----------------------|-----------------------------|------------------------|
| Untreated control          | -                   | -                       | -                   | -              | -                     | -                     | -                           | -                      |
| Carbofuran 3G              | 7.65 (16.05)        | -                       | 15.89 (23.48)       | 196.79         | 29.69                 | 267.10                | 24.69                       | 14.66                   |
| Thiamethoxam 70WS          | 12.63 (20.82)       | -                       | 24.56 (39.70)       | 123.30         | 33.15                 | 156.45                | 30.50                       | 11.60                   |
| Clofentezate 30EC          | 16.36 (23.85)       | -                       | 39.78 (65.38)       | 192.50         | 30.91                 | 223.41                | 31.39                       | 17.04                   |
| Carbosulfan 50DS           | 24.25 (39.50)       | -                       | 54.33 (85.88)       | 369.00         | 51.67                 | 417.33                | 48.00                       | 14.60                   |
| **Total**                  | **55.37**           | **-**                   | **94.00**           | **489.30**     | **85.38**             | **574.74**            | **88.33**                   | **16.06**               |

*CD @ p=0.05 = 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].

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].
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 imidacloprid 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).

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, imidacloprid 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) as 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, imidacloprid 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 Thiamicidam 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 chlorpyrifos 20 EC @ 4 mL Kg⁻¹ with 1.42 and 1.22, respectively whereas, in control it was recorded least benefit cost ratio (1.10) (Table 2).

The results of the present findings are in close agreement with that of Duraimurugan and Alivelu (2017) [1], 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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Table 2

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

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