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Management of Oriental Fruit Fly, *Bactrocera dorsalis* (Hendel) in Custard Apple Ecosystem

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Abstract

Studies were made on the monitoring and management of fruit fly, *Bactrocera dorsalis* (Hendel) by installing different combinations of colour and shape of methyl eugenol based parapheromone traps during pre-harvest (September to October 2021) and post-harvest period (January to February 2022) in *Arka Sahana* custard apple ecosystem at the University of Agricultural Sciences, GKVK, Bengaluru. In the pre-harvest period, the data revealed that yellow colour with cylindrical shape trap attracted the highest mean number of fruit flies (300.30 ± 32.58), followed by transparent bottle trap (69.44 ± 46.21), yellow colour with sphere shape trap (64.63 ± 28.69) and white colour trap with trapezoidal shape (60.56 ± 39.64) which were on par with each other. The transparent trap with trapezoidal shape captured significantly the lowest number of fruit flies (28.75 ± 8.73). During the post-harvest period the maximum mean number of fruit flies were was attracted to yellow coloured traps with cylindrical and sphere shapes with 39.63 ± 9.29 and 31.75 ± 6.66, respectively. This was followed by transparent bottle trap (20.00 ± 6.33). The lowest mean numbers of fruit flies were captured in white colour (9.63 ± 2.76) and transparent colour (7.31 ± 2.44) traps with trapezoidal shapes, which showed lower trapping efficiency in the custard apple ecosystem. In the study bio-efficacy of five different insecticides treated along with jaggery, the results at 5, 10 and 15 days after treatments revealed that Acetamiprid + jaggery (65.04, 67.36 and 69.29%, respectively) and dinotefuran + jaggery (61.89, 62.25 and 63.55%, respectively) were found superior chemicals in reducing the mean per cent fruit infestation by the fruit flies. However, deltamethrin + jaggery (43.82, 43.86 and 47.45%, respectively) was found to be the least effective insecticidal treatment in reducing the mean per cent fruit infestation as compared to other chemical treatments in the custard apple ecosystem.

Keywords : Fruit fly, *Bactrocera dorsalis* (Hendel), Custard apple, *Arka sahana*, Insecticides, Management

Custard apple (*Annona squamosa* L.) is one of the most popular arid fruit crops, belongs to the family Annonaceae. The crop originated in West Indies, later it distributed all over the tropics and subtropics regions of the world, including Canada, Peru, India, Mexico, South and Central America, Brazil, Bermuda and Egypt. In the world, Canada is the largest exporter of custard apples contributing about 11.87 per cent of the world's share. In India, Assam, Bihar, Odisha, Rajasthan, Gujarat, Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu are the major states under custard apple cultivation. Among these, Maharashtra and Gujarat are the leading states in custard apple production (Annonymous, 2018).

The custard apple is an important dessert fruit crop, cultivated across the world and widely distributed in tropical and subtropical parts. Fruits are widely regarded as protective food necessary for maintaining human health due its nutritional values (Vittal *et al*., 2023). Similarly custard apple fruit has become more popular in recent years due to its medicinal value. As like jackfruit, the seed and fruit extract of custard apple exhibited antimicrobial activities and rich in antioxidant and phenol compounds (Valeeta *et al*., 2023). Fruits are very sweet, delicious and nutritionally rich in carbohydrates, proteins, minerals and antioxidants. Annona fruits are generally used fresh and also in preparing bakery products like nutritional custard apple powders, sweets and icecreams (Nair and Agrawal, 2017). Custard apple is thriving well in hot and dry climates as well as soils with little salinity or acidity (Kumar *et al*., 2021). The crop tolerates and survives in all the abiotic factors and it does not affect much in fruit production or yield. But biotic factors like insect pests are the major one that cause maximum yield losses in custard apples (Maruthadurai and Karuppaiah, 2014). There are about 20 species of insect pests have been reported to attack the crop. Among them Striped mealybug, *Ferrisia virgata* (Cockerell), Pink mealybug, *Maconellicoccus hirstus* (Green), Citrus mealybug, *Planococcus citri* (Risso), Passion vine mealybug, *Planococcus pacificus* Cox (Hemiptera: Pseudococcidae) and Mango mealy bug, *Perissopneumon ferox* Newstead are the major ones causing significant yield loss (Butani, 1976). The most destructive pest in the custard apple is mealy bugs, which cause about 50 to 60 per cent of yield losses. But in recent years, fruit fly has been an important threat in the custard apple production, causing 25-50 per cent yield loss in custard apple (Math, 2017).

The oriental fruit fly, *Bactrocera dorsalis* (Hendel) belongs to the order Diptera and family Tephritidae. It is characterized as an invasive polyphagous pest and has a severe impact on the global production of commercial fruits. The genus, *Bactrocera* comprises 651 described species, of which 50 were considered economically important pests of fruit crops (Vargas *et al*., 2015). Among the destructive category of the fruit fly species, *B. dorsalis* consisting of 52 species complexes, of these 8 are considered as economically important by Drew and Hancock (1994). As of 2017, *B. dorsalis* had been detected in four continents (Asia, Africa, North America and South America) and Oceania, including 75 countries and more than 124 regions. *Bactrocera dorsalis* has a global spatial expansion in the past 11 decades, which has been spread widely, especially in the last three decades (Zeng *et al*., 2019). The host range of *B. dorsalis* is associated with a total of 632 plant taxa, with key plant families including Anacardiaceae, Annonaceae, Clusiaceae, Lauraceae, Moraceae, Myrtaceae, Rutaceae, Sapotaceae and Solanaceae (Liquido *et al*., 2017). The extensive cultivation of custard apple, in turn enhances the incidence of insect pests. But now-a-days, fruit flies (Tephritidae) are becoming major pests, causing significant fruit yield loss in custard apple orchards (Maruthadurai and Karuppaiah, 2014). Fruit flies are an important quarantine pest that directly harms the fruit and indirectly reduce the quality, yield and fruit shipment (Clarke *et al*., 2005). Understanding the global distribution and expansion of *Bactrocera dorsalis* is crucial for developing effective pest management strategies to mitigate its impact on commercial fruit production worldwide.

The farmers are often unable to notice the fruit fly infestation in custard apple until the liquid oozes out from the ripened fruits, which leads to severe damage to the fruit yield and quality. Farmers have little idea about the management practices of fruit fly in custard apple since the early days until today. The total life cycle from egg to adult fly requires about 16 to 18 days. After mating, the gravid female starts laying eggs within 4 to 5 days. Under optimum conditions, a female fly can lay more than 371.9 ± 60.78 eggs on custard apple fruit during its lifetime. Eggs are laid on fruit rind by piercing the fruit with the help of a sharp ovipositor. The eggs of fruit flies are elliptical, smooth, elongated, slightly curved and tapering at one end. The incubation period is 1.50 ± 0.48 days. The hatched maggots are cylindrical, apodous with an elongated body pointed anteriorly. The larval duration is completed in 8.5 ± 0.84 days. The grown-up larva emerges from the fruit, drops to the ground, enters into the soil and pupation takes place in a dark brown puparium. The pupal period lasted for 12.1 ± 1.79 days. The total life cycle from egg to adult emergence is about 18 to 23 days (Naik *et al.,* 2017).

Among the various management strategies, the male annihilation technique with methyl eugenol para pheromone based trap is the most effective and environmentally friendly tool to manage the fruit fly (Ballo *et al.,* 2020). The response of fruit flies to visual stimuli like shape, size and colour helps to design better traps in order to increase the capturing efficiency for mass trapping and monitoring of fruit flies (Younus *et al*., 2022). Further, there are no official chemical management practices recommended either by State Agricultural Universities or National Horticultural Research Institutions specifically for controlling fruit flies in custard apple. The selection of insecticides for chemical trials was based on the published literature on chemical recommendations for fruit flies in other fruit crops. A few other chemicals, like lambda cyhalothrin and chlorantraniliprole, which have a shorter waiting period on vegetables and fruit crops and being relatively safer for human beings, were also chosen for chemical trials to evaluate their efficacy against fruit flies in the custard apple ecosystem.

MATERIAL AND METHODS

The experiment was conducted in *Arka Sahana* custard apple orchard situated at the All India Co-ordinated Research Project for Dry Land Agriculture, University of Agriculture Sciences (UAS), GKVK campus, Bengaluru. For the study, four different commercially available traps *viz.,* Pest Control India Pvt. Ltd. (PCI) trap, KVK Hirehalli trap, Bio-pest Management Pvt. Ltd. trap, Yellow trap (Brand) and self-prepared Bottle trap (Fig. 1), were evaluated. In all the traps, plywood blended with methyl eugenol from PCI Pvt. Ltd., was used. In order to kill the attracted fruit flies in the trap, a few drops of cypermethrin 10 % EC in the ratio of 1:1 with water were smeared on the surface of the methyl eugenol baits. The traps were tied to the custard apple trees at an average height of 1.2 to 1.5 m from the ground level following Randomized Block Design (RBD). Each custard apple tree was 5m apart.

Fig. 1: Four different commercially available traps used in the experiment

Preparation of Bottle Trap

The bottle trap was prepared by using a kinley water bottle of one liter capacity. At the top 1/3rd portion of the water bottle, 2 windows of 2.5 cm length x 2 cm width were cut at equal distance with the help of a red-hot needle. The windows were cut on two sides and bottom leaving the top side, which was used as a hinge by lifting up in order to prevent rainwater from entering the water bottle trap.

Experimental Layout

A block of 1.2 acres area containing uniform canopy sized custard apple trees of *Arka Sahana,* was selected for the field experiment. A single trap was tied to each tree and each tree represented one replication. Four such replications for each commercial trap design were maintained. The observations on trap catches were noted on a weekly basis by collecting the fruit flies in butter paper covers separately from each trap. The samples were labelled and brought to the lab where the number of fruit flies trapped in each trap were counted separately. These observations were continued for two months. Later the specimens were

TABLE 1

Different types of traps used for trapping fruit fly in custard apple ecosystem

Treatments	Commercial Traps	Colour and shape of the trap
T_1	PCI trap	Yellow colour with sphere shape
T_2	KVK Hirehalli trap	White colour with trapezoidal shape
T_3	Biopest trap	Transparent with trapezoidal shape
T_4	Yellow trap	Yellow colour with cylindrical shape
T_5	Bottle trap	Transparent water bottle

identified with the help of the taxonomist Dr. K. J. David at ICAR- National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru. The adult flies were identified as *Bactrocera dorsalis* and there was no species composition observed. This experiment was conducted in two phases, during pre-harvest (September-October, 2021) and post-harvest (January- February 2022) of custard apple fruits. Treatments and their details used in the experiment are listed in Table 1.

Evaluation of Efficacy of Insecticides against Fruit Fly

Evaluation of the relative efficacy of different insecticides against fruit fly on custard apple was conducted in two trials; one during the second fortnight of August and the other during first fortnight October, 2021 at All India Co-ordinated Research Project (AICRP) for Dry Land Agriculture, GKVK, Bengaluru. The experiment was laid out in Randomised Block Design with six treatments including untreated control. Each treatment was replicated four times with individual custard apple plant representing one replication. The *Arka Sahana* custard apple hybrid released by ICAR- Indian Institute of Horticultural Research, Hessaraghatta, Bengaluru, was selected for the experiment since it is highly susceptible to fruit fly infestation. The first insecticidal treatments were imposed during the month of August when fifty per cent fruits in the plants attained physiological maturity. The second trial was conducted in the month of October when the late borne fruits in the plants attain physiological maturity to check the efficacy of respective chemicals against the fruit fly infestation. The data on fruit infestation and number of maggots in 5 randomly selected fruits per replication was recorded by destructive sampling method at 5, 10 and 15 days after treatments imposition. Later the per cent reduction in fruit damage by fruit fly over control was worked out for each treatment.

Statistical Analysis

The trap catch data and the mean per cent fruits infested by *B. dorsalis* in custard apple after treatments imposition were worked out and values were then subjected to single factor analysis of variance (ANOVA) using SPSS Software. The critical difference (CD) at 5 per cent probability level was used as the test criterion.

RESULTS AND DISCUSSION

Trapping Efficiency of Different Commercially Available Traps during Post-Harvest Period (September - October, 2022)

The mean number of *B. dorsalis* fruit flies collected in each trap of different colours and shapes during the pre-harvest period is given in Table 2.

During the first fortnight of September 2021, the data on fruit flies trapped revealed that the highest mean number of fruit flies was captured in a yellow coloured trap with a cylindrical shape (292.00 ± 31.50) which was significantly superior over the other traps and showed higher trapping efficiency in the custard apple ecosystem. This was followed by a transparent bottle trap (134.50 ± 16.78) and the next best traps in the descending order of efficiency were white with a

TABLE 2

Trapping efficiency of different traps of fruit fly during pre-harvest period

Treatments	Mean number of fruit flies trapped				Pooled mean
	September 2021		October 2021		
	1ST Fortnight	2nd Fortnight	1st Fortnight	2nd Fortnight	
Yellow colour sphere shape trap	(104.50 ± 12.12) c	(39.25 ± 12.09)bc	(65.50 ± 3.51) b	(49.25 ± 4.65) bc	(64.63 ± 28.69) b
White colour trapezoidal shape trap	(116.75 ± 11.56) bc	(55.75 ± 3.30) b	(45.25 ± 4.79) bc	(24.50 ± 2.08) d	(60.56 ± 39.64) b
Transparent colour trapezoidal shape trap	(38.25 ± 4.99) d	(17.25 ± 3.59) d	(28.25 ± 6.85) c	(31.25 ± 5.74) cd	(28.75 ± 8.73) c
Yellow colour cylindrical shape trap	(292.00 ± 31.50) a	(257.75 ± 24.01)a	(328.25 ± 26.99)a	(323.21 ± 22.69) a	(300.30 ± 32.58) a
Transparent bottle trap	(134.50 ± 16.78) b	(25.75 ± 5.74) cd	(54.50 ± 4.51) b	(63.00 ± 3.37) b	(69.44 ± 46.21) b
SEm±	4.17	5.13	6.69	6.53	6.90
CD at 5%	12.84	15.79	20.60	20.11	21.28
CV	12.97	12.60	13.46	12.81	14.18

Data in each column followed by same alphabet/s are not differed significantly

trapezoidal shape (116.75 ± 11.56), which were statistically on par with each other with respect to their trapping efficiency of fruit flies. These were followed by yellow coloured trap with a sphere shape (104.50 ± 12.12). However, the lowest mean number of fruit flies was collected in a transparent trap with a trapezoidal shape (38.25 ± 4.99), which showed significantly the lowest trapping efficiency and captured minimum number of fruit flies as compared to the other traps (Fig. 2).

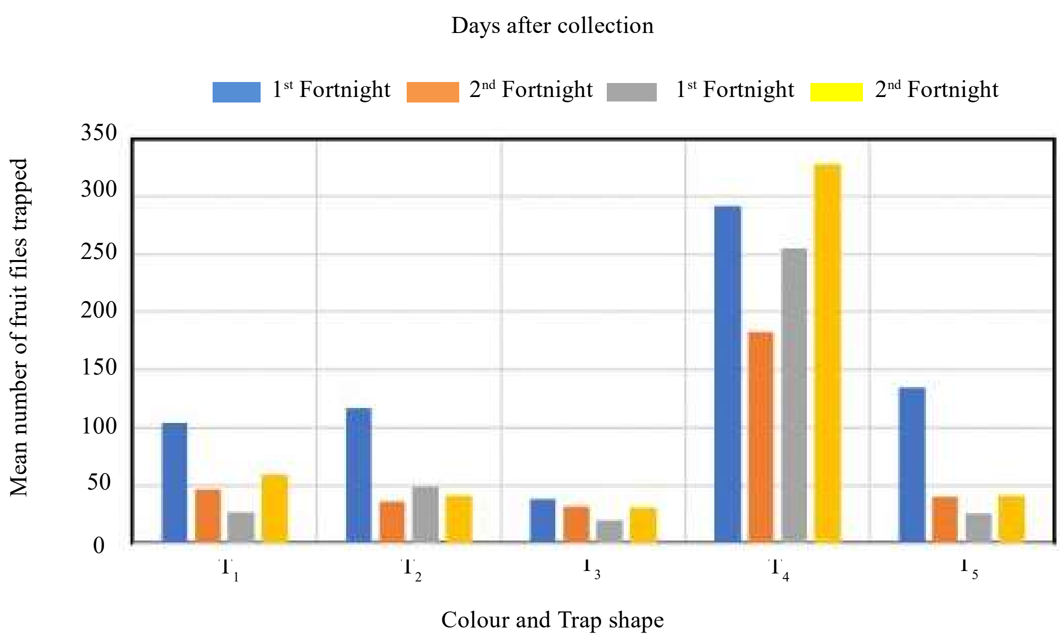

Fig. 2 : Mean number of fruit flies captured during Pre-harvest period (September- October 2021) of custard apple orchard

The observations on fruit flies trapped during the second fortnight of September (pre-harvest period) revealed that the yellow coloured trap with a cylindrical shape (257.75 ± 24.01), captured a significantly higher number of fruit flies as compared to others. This was followed by a white colour trap with a trapezoidal shape (55.75 ± 3.30), which is on par with yellow colour sphere shape trap (39.25 ± 12.09). The transparent bottle trap (25.75 ± 5.74) and transparent trap with trapezoidal shape (17.25 ± 3.59) showed similarity in trapping efficiency and captured significantly the lowest number of fruit flies.

During the first fortnight of October 2021, the yellow coloured trap with a cylindrical shape (328.25 ± 26.99), was significantly superior over other traps in fruit fly trapping. This was followed by yellow colour trap with a sphere shape (65.50 ± 3.51), transparent bottle trap (54.50 ± 4.51) and white colour trap with a trapezoidal shape (45.25 ± 4.79), which showed statistically similar in trapping efficiency. However, the lowest mean number of fruit flies, (28.25 ± 6.85) was captured in transparent trap with a trapezoidal shape, which trapped significantly the lowest number of fruit flies as compared to other traps.

The data on the trapping efficiency of fruit flies during the second fortnight of October revealed that among different traps, the yellow coloured trap with a cylindrical shape captured the highest mean number of fruit flies (323.21 ± 22.69), which was superior to all the other trap designs in trapping fruit flies in the custard apple ecosystem. The next best traps were the transparent bottle trap (63.00 ± 3.37) and the yellow colour trap with sphere shape (49.25 ± 4.65), which were statistically on par with each other and showed similar trapping efficiency towards fruit flies, *B. dorsalis*. These were followed by transparent trap and white colour trap with a trapezoidal shape with mean number of fruit flies trapped of 31.25 ± 5.74 and 24.50 ± 2.08, respectively, which were both lowest and statistically on par with each other with respect to their trapping efficiency.

Trapping Efficiency of Different Commercially Available Traps during Post-Harvest Period (January-February, 2022)

The mean number of *B. dorsalis* fruit flies trapped in different colour and shape traps during the post-harvest period is given in Table 3.

TABLE 3

Trapping efficiency of different traps of fruit fly during post-harvest period

Treatments	Mean number of fruit flies trapped				Pooled mean
	January 2022		February 2022		
	1ST Fortnight	2nd Fortnight	1st Fortnight	2nd Fortnight	
Yellow colour sphere shape trap	(28.00 ± 2.94) b	(24.50 ± 11.70) a	(35.50 ± 5.07) a	(39.00 ± 3.16) b	(31.75 ± 6.66) b
White colour trapezoidal shape trap	(11.75 ± 1.71) d	(6.25 ± 4.03) c	(12.00 ± 1.83) c	(8.50 ± 1.91) d	(9.63 ± 2.76) d
Transparent colour trapezoidal shape trap	(8.25 ± 0.96) e	(4.25 ± 1.50) c	(10.00 ± 1.41) c	(6.75 ± 2.06) d	(7.31 ± 2.44) d
Yellow colour cylindrical shape trap	(37.00 ± 2.16) a	(30.00 ± 6.68) a	(39.25 ± 2.22) a	(52.25 ± 3.40) a	(39.63 ± 9.29) a
Transparent bottle trap	(22.75 ± 2.75) c	(13.50 ± 5.07) b	(27.50 ± 4.20) b	(16.25 ± 2.22) c	(20.00 ± 6.33) c
SEm±	0.96	1.35	1.28	1.26	1.48
CD at 5 %	2.96	4.15	3.97	3.88	4.57
CV	13.04	12.46	11.38	11.81	13.39

Data in each column followed by same alphabet/s are not differed significantly

In the first fortnight of January during the post-harvest period, the data revealed that the yellow coloured trap with cylindrical shape captured the highest number of fruit flies (37.00 ± 2.16), which was superior to the other traps. This was followed by yellow color trap with a sphere shape (28.00 ± 2.94) and transparent bottle trap (22.75 ± 2.75) and these were on par with each other in trapping efficiency in the custard apple ecosystem. However, the least number of fruit flies were recorded in white coloured and transparent trap with a trapezoidal shape with 11.75 ± 1.71 and 8.25 ± 0.96, respectively.

The observations on the trapping efficiency of fruit flies by using different traps during the second fortnight of January, at the post-harvest period revealed that, among all the traps, the yellow coloured traps with cylindrical and sphere shapes captured the highest number of fruit flies 30.00 ± 6.68 and 24.50 ± 11.70, respectively, which were statistically on par in their trapping efficiency. These were followed by transparent bottle trap (13.50 ± 5.07). The white colour and transparent trap with trapezoidal shape recorded 6.25 ± 4.03 and 4.25 ± 1.50, respectively and thus captured the lowest mean number of fruit flies and were on par with each other in their trapping efficiency.

The data for the first fortnight of February revealed that the highest mean number of fruit flies were trapped in yellow coloured trap with cylindrical and sphere shape with 39.25 ± 2.22 and 35.50 ± 5.07, respectively. Both of these traps were on par with each other and were significantly superior to the other traps. The next best treatment was a transparent bottle trap with 27.50 ± 4.20 number of fruit flies captured during the first fortnight of February. However, lowest mean number of fruit flies *i.e.,* 12.00 ± 1.83 and 10.00 ± 1.41 were captured in white and transparent trap with trapezoidal shape, respectively and both traps showed statistically similar trapping efficiency with respect to *B. dorsalis* as compared to other traps in the custard apple ecosystem.

During the second fortnight of February at post-harvest period, yellow colour trap with cylindrical shape showed the highest trapping efficiency of fruit flies (52.25 ± 3.40) and was significantly superior over all the other traps. This was followed by yellow coloured sphere shaped trap with a mean number of fruit flies of 39.00 ± 3.16 being trapped during the same period. The next best trap was the transparent bottle trap with 16.25 ± 2.22 mean number of the fruit flies captured. The white colour and transparent trap with trapezoidal shape captured the lowest mean number of fruit flies *i.e.,* 8.50 ± 1.91 and 6.75 ± 2.06, respectively (Fig. 3).

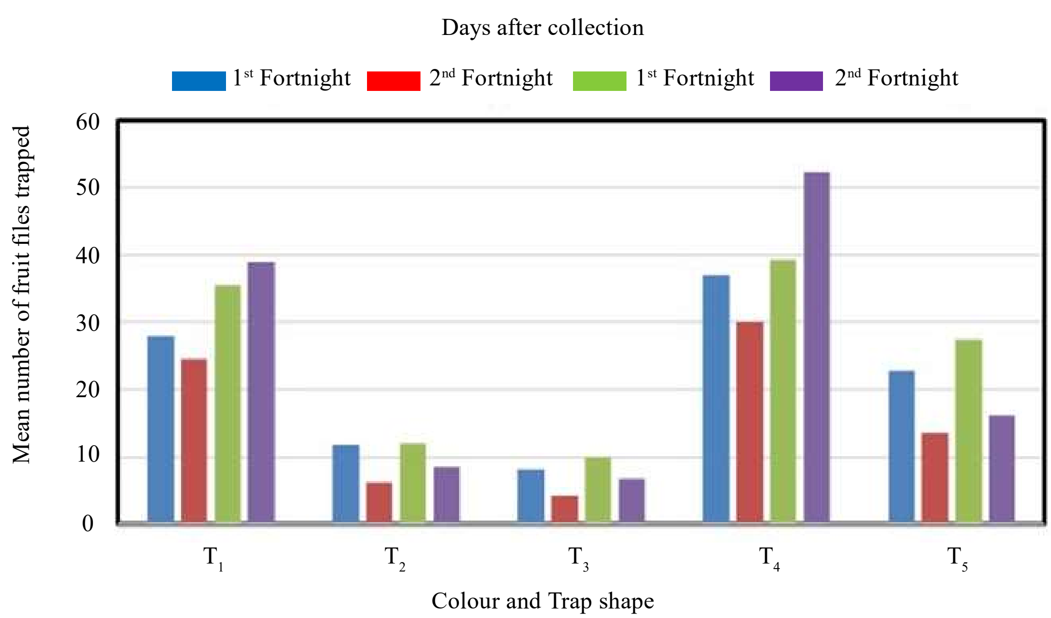

Fig. 3 : Mean number of fruit flies captured during Post-harvest period (January- February 2022) of custard apple orchard

In the present study, among commercially available traps of various colours and shapes that were evaluated for their trapping efficiency in custard apple ecosystem, the yellow colour trap with cylindrical shape captured the highest mean number of fruit flies and was significantly superior over all the other traps. This was followed by yellow coloured trap with sphere shape. Even though surface area of cylindrical shape trap was less, it attracted more number fruit flies, it may be due to presence of entry holes on either side of the trap. So, flies can easily get entry into the trap. But in case of yellow trap, the entry hole was below the trap, so it was difficult for flies to find the holes to enter the trap. The colour of the traps played an important role in attracting fruit flies in addition to methyl eugenol. The yellow colour traps attracted more fruit flies since the yellow/ orange or green colour resembles the host colour, as a visual cue for attracting the fruit flies. Further, earlier researchers have also reported that fruit flies are active during the morning and late afternoon. During this period, given a choice, fruit flies were attracted more to the colour green. This is clear evidence that fruit flies have colour choice. The present outcome was supported by earlier workers (Verghese *et al*., 2002 and Bajaj & Singh, 2020) who reported that deep yellow colour traps attracted a greater number of fruit flies as compared to the other coloured traps. Further, Stark and Vargas (1992) also observed that yellow and white coloured traps attracted a greater number of *B. dorsalis* as compared to green, red and black coloured traps in the guava orchard. They mentioned the reason for the preference of *B. dorsalis* to yellow colour which might be due to the better reflectance of yellow colour during the day under sunlight.

Agrawal and Yadav (2022) found that, yellow and green coloured vertical traps attracted more number of *B. dorsalis, B. nigrotibialis* (Perkins), *B. correcta* (Bezzi) and *B. zonata* (Saunders) species as compared to transparent traps in the guava orchard. Ravikumar (2006) observed that yellow coloured traps were more efficient in trapping a greater number of *Bactrocera* spp. flies in guava orchards. Further, they also reported that cylindrical shaped traps and sphere shaped traps attracted a higher number of *B. dorsalis* in guava and mango orchards, respectively.

The outcome of the current studies on the efficiency of selected among different commercially available traps in trapping fruit flies was also in close agreement with Younus *et al*. (2022) who have reported that among the tested traps, the cylindrical bottle trap trapped the highest number of *Bactrocera* spp. in peach orchards. Bajaj and Singh (2018) observed that triangular, cylindrical and sphere shaped traps provided with methyl eugenol para pheromone attracted a greater number of *B. zonata* and *B. dorsalis*. Kumar and Laskar (2019) also reported that yellow coloured traps attracted the significantly highest number of *B. cucurbitae*. Katsoyannos and Kouloussis (2001) also found that yellow and orange coloured sphere shaped traps attracted a greater number of olive fruit fly, *B. oleae* (Rossi) as compared to white and blue coloured sphere shaped traps. However, Rajitha and Viraktamath (2005) found that *B. correcta* (Bezzi) was attracted to sphere shaped and cylinder-shaped traps, while *B. zonata* (Saunders) was attracted more to bottle traps. Further, they also reported that *B. dorsalis* did not show any preference for trap shapes in guava orchard but, in mango orchard it showed preference for sphere shaped traps.

In the present investigation, it was found that the transparent bottle attracted more fruit flies next best in custard apple ecosystem. These findings were in comparable with those of Math (2017) who observed that, *B. dorsalis* were attracted more towards transparent bottle traps as compared to green, blue and white colour traps in the custard apple ecosystem, whereas Sikandar *et al*. (2017) reported that yellow and transparent traps attracted a greater number of *B. dorsalis* and *B. zonata* fruit flies in the citrus orchard. Susanto *et al*. (2020) have also reported that bottle traps impregnated with methyl eugenol trapped the highest number of fruit flies. Hussain *et al*. (2022) observed that pet bottle traps capture more *B. zonata* and *B. dorsalis*.

Efficacy of Selected Insecticides against Fruit Fly in the August Month (Trial-I), 2021

Efficacy testing trial of selected insecticides against fruit fly was conducted during second fortnight of August, 2021 at All India Co-ordinated Research Project (AICRP) for Dry Land Agriculture, GKVK, Bengaluru. The data on the efficacy of selected insecticides against the fruit fly, *B. dorsalis* infesting custard apple are presented in Table 4.

Five days post-treatment, in trial-I found that all five treatments were significantly superior over the control. Acetamiprid + jaggery (62.92%) and dinotefuran+ jaggery (59.36%) were the best treatments and equally effective in reducing the mean per cent fruit infestation over control. These were followed by chlorantraniliprole + jaggery (51.25%) and lambda-cyhalothrin + jaggery (47.93%) treatments which were on par with each other. Deltamethrin + jaggery (43.12%) was the least effective treatment against fruit fly infestation but, was found significantly superior over the untreated control.

The mean per cent reduction in fruit fly infestation at ten days after the post-treatment application revealed that, all the treatments were significantly superior over the untreated control. Acetamiprid + jaggery (63.89%) and dinotefuran + jaggery (62.14%) was the best treatments in reducing the mean per cent fruit infestation as compared to the other treatments. This were followed by chlorantraniliprole + jaggery (54.35%) and lambda cyhalothrin + jaggery (50.53%) treatments which were found equally effective in reduction of the mean per cent fruit infestation by fruit fly. Deltamethrin + jaggery (45.85%) was found be the least effective treatment in reducing the mean per cent fruit infestation but, was significantly superior over the control in reducing the fruit fly infestation.

The observations recorded fifteen days after post treatments revealed that, all five chemical treatments were significantly superior over the untreated control. Among them, acetamiprid + jaggery (69.47%) was found significantly superior over all other treatments in reducing the mean per cent fruit infestation. This was followed by dinotefuran + jaggery (65.26%). The next best treatments were chlorantraniliprole + jaggery (57.05%) and lambda-cyhalothrin + jaggery (55.62%) which were on par with each other in reducing the mean per cent fruit infestation by fruit fly. These were followed by deltamethrin + jaggery (44.78%) and it was found to be least effective treatment in reducing the mean per cent fruit infestation by fruit fly, but it was significantly superior over the untreated control (Table 4).

Efficacy of Selected Insecticides against Fruit Fly in the October Month (Trial-II), 2021

Five days after the treatment application, it was found that all the treatments were significantly superior over the untreated control by recording higher mean per cent reduction in fruit fly infestation. Out of five insecticides tested against fruit fly, acetamiprid + jaggery (67.33%) and dinotefuran + jaggery (63.94%), were the best treatments and were on par with each other in reducing the mean per cent fruit infestation as compared to other chemical treatments. These were followed by chlorantraniliprole + jaggery (55.91%) and lambda-cyhalothrin + jaggery (51.98%), which were equally effective against the fruit fly infestation. Deltamethrin + jaggery (46.81%) was found the least effective treatment but significantly superior over the untreated control in reducing mean per cent fruit infestation by fruit fly.

Ten days after the treatment imposition, the data revealed that acetamiprid + jaggery (69.37%) was found to be the best treatment in suppressing the fruit fly infestation and it was significantly superior over all other treatments. This was followed by dinotefuran + jaggery (64.63%) and chlorantraniliprole + jaggery (62.53%) which were on par with each other. These were followed by lambda-cyhalothrin + jaggery (57.25%) which was the next best treatment in reduction of mean per cent fruit infestation. The least effective insecticide treatment was the deltamethrin + jaggery (48.31%) against the fruit fly infestation as compared to all other chemical treatments but, it was found significantly superior over the untreated control.

The mean per cent reduction in fruit fly infestation at fifteen days after the treatments, data revealed that

Table 4

Efficacy of selected insecticides against fruit fly, *B. dorsalis* on custard apple in the months of August (Trial-I), October (Trial-II) and pooled data during 2021

Treatments + jaggery @ 5 g/l	Mean per cent reduction in fruit infestation (Trial-I)			Mean per cent reduction in fruit infestation (Trial-II)			Mean per cent reduction in fruit infestation (Pooled data)		
	5 DAT	10DAT	15 DAT	5 DAT	10DAT	15 DAT	5 DAT	10DAT	15 DAT
Chlorantraniliprole 18.5% SC @ 0.3 ml/l	60.79 (51.25) [b]	66.00 (54.35) [b]	70.41 (57.05) [c]	68.50 (55.91) [b]	78.66 (62.53) [c]	81.56 (64.58) [bc]	64.64 (53.54) [b]	63.95 (53.14) [c]	68.37 (55.78) [c]
Lambda-cyhalothrin 5% EC @ 0.5 ml/l	55.09 (47.93) [bc]	59.54 (50.53) [bc]	68.05 (55.62) [c]	62.03 (51.98) [b]	70.67 (57.25) [b]	78.21 (62.18) [c]	60.80 (51.24) [b]	66.73 (54.80) [c]	71.26 (57.63) [bc]
Dinotefuran 20% SG @ 0.3 g/l	73.87 (59.36) [a]	77.93 (62.14) [a]	82.37 (65.26)[b]	80.65 (63.94) [a]	81.61 (64.63) [b]	85.15 (67.37) [ab]	77.76 (61.89) [a]	78.18 (62.25) [b]	79.79 (63.55) [ab]
Acetamiprid 20% SP @ 0.3 g/l	79.23 (62.92) [a]	80.45 (63.89) [a]	87.59 (69.47) [a]	85.14 (67.33) [a]	87.55 (69.37) [a]	89.70 (71.39) [a]	82.19 (65.04) [a]	85.03 (67.36) [a]	86.70 (69.29) [a]
Deltamethrin 2.8% EC @ 1 ml/l	50.21 (43.12) [c]	51.47 (45.85) [c]	49.61 (44.78) [d]	53.14 (46.81) [c]	55.73 (48.31) [d]	59.23 (50.37) [d]	47.99 (43.82) [c]	48.02 (43.86) [d]	54.27 (47.45) [d]
Control (Untreated)	0.00 (0.00) [d]	0.00 (0.00) [d]	0.00 (0.00) [e]	0.00 (0.00) [d]	0.00 (0.00) [e]	0.00 (0.00) [e]	0.00 (0.00) [d]	0.00 (0.00) [e]	0.00 (0.00) [e]
SEm±	2.01	1.95	1.88	2.85	2.31	2.32	2.69	2.33	3.09
CD at 5%	8.34	6.78	7.32	6.98	8.76	7.41	8.47	7.35	8.75
CV (%)	10.65	7.89	9.58	8.49	7.49	8.76	8.38	7.03	8.92

DAT- Days after treatment. Values in parentheses are Arc sin transformed. Data in each column followed by same alphabet/s are not significantly different by DMRT at p=0.05

all the treatments were significantly superior over the untreated control. Acetamiprid + jaggery (71.39%) and dinotefuran + jaggery (67.37%) were found to be the best treatments in reducing the fruit fly infestation as compared to all other treatments and statistically on par with each other. The next best treatments were chlorantraniliprole + jaggery (64.58%) and lambda-cyhalothrin + jaggery (62.18%), which were equally effective in reducing the mean per cent custard apple fruit infestation by fruit flies. However, deltamethrin + jaggery (50.37%) was found to be the least effective insecticidal treatment in reducing mean per cent fruit infestation but was found significantly superior over untreated control (Table 4).

Efficacy of Insecticides against Fruit Fly, *B. dorsalis* (Pooled Data)

The pooled data on the efficacy of different insecticides against fruit fly, *B. dorsalis* infesting custard apple are presented in Table 4.

At fifth day after the post-treatments, all the chemical treatments were significantly superior over the untreated control by recording lesser mean per cent fruit infestation in all the insecticide treatments. Acetamiprid + jaggery (65.04%) and dinotefuran + jaggery (61.89%) were the best treatments in reducing the mean per cent fruit infestation by the fruit fly. These were followed by chlorantraniliprole + jaggery (53.54%) and lambda-cyhalothrin + jaggery (51.24%), which were equally effective against the fruit fly infestation. Deltamethrin + jaggery (43.82%) was found to be the least effective insecticidal treatment in reducing mean per cent fruit infestation as compared to other chemical treatments but was found significantly superior over the untreated control.

The observations revealed that ten days post-treatments, all the treatments were significantly superior over the untreated control. Among them, acetamiprid + jaggery (67.36%) was found to be the highly effective treatment in reduction of per cent fruit infestation by fruit fly compared to all other treatments. This was followed by dinotefuran + jaggery (62.25%) and significantly differ from lambda-cyhalothrin + jaggery (54.80%) and chlorantraniliprole + jaggery (53.14%), which were on par with each other. Deltamethrin + jaggery (43.86%) was found to be the least effective insecticidal treatment in reducing the mean per cent fruit infestation but it was found significantly superior over the untreated control.

At fifteen days after treatment imposition, the data revealed that, all the treatments were significantly superior over the untreated control. Acetamiprid + jaggery (69.29%) and dinotefuran + jaggery (63.55%) were found to be the best treatments and statistically on par with each other in reducing the per cent fruit infestation compared to all other treatments. These were followed by lambda-cyhalothrin + jaggery (57.63%) and chlorantraniliprole + jaggery (55.78%), which were equally effective against the fruit fly infestation in custard apple. The least effective treatment in reducing the mean per cent fruit infestation was deltamethrin + jaggery (47.45%) compared to other chemical treatments, but it was found significantly superior over the untreated control.

From the pooled data, out of five insecticides evaluated against fruit fly, *B. dorsalis* in *Arka Sahana* custard apple orchard, acetamiprid 20%SP @ 0.3 g/l + jaggery @ 5 g/l and dinotefuran 20%SG @ 0.3 g/l + jaggery @ 5 g/l were found as superior treatments and recorded lowest mean per cent fruit infestation at 5, 10 and 15 days post-treatments. The next best treatments were chlorantraniprole 18.5%SC @ 0.3 ml/l + jaggery @ 5 g/l and lambda-cyhalothrin 5 % EC @ 0.5 ml/l + jaggery @ 5 g/l and they showed equal effectiveness against the fruit fly infestation in custard apple. Deltamethrin 2.8 % EC @ 1 ml/l + jaggery @ 5 g/l was found the least effective treatment against the fruit fly infestation in custard apple ecosystem (Table 4). The effectiveness of acetamiprid against fruit flies in custard apple in the present study is in confirmation with the findings of Reynolds *et al.* (2017) who reported that fruits treated with acetamiprid and fenthion reduced the mean number of maggots and pupal formation (0.00 and 0.004) and (0.004 and 0.00), respectively, in peach against *Bactrocera tryoni*. Further, Olszak and Maciesieak

(2004) also reported that acetamiprid 20 % SP @ 0.125 kg/ha and thiacloprid 480 SC @ 0.1kg/ha were most effective insecticides in reducing the cherry fruit fly (*Rhagoletis cerasi*) damage in sweet cherry orchard which also supported the current findings. Ali *et al*. (2021) reported that trichlorfon insecticide showed highest mortality against *B. cucurbitae* followed by acetamiprid.

The next best treatments observed in the present chemical evaluation studies against fruit flies are chlorantraniliprole 18.5%SC @ 0.3 ml/l + jaggery @ 5 g/l and lambda cyhalothrin 5%EC @ 0.5 ml/l + jaggery @ 5 g/l. These results were in concurrence with that of Teixeria *et al*. (2009) who worked on lethal and sub-lethal chemical effects on three species of *Rhagoletis* fruit flies *i.e., R. pomonella* (Walsh) in apple, *R. mendex* (Curran) in blue berry and *R. cingulata* (Loew) in cherry, where they observed that 500 mg of chlorantraniliprole per litre of water caused significantly higher mortality of fruit fly maggot population in all of the three *Rhagoletis* spp. in the field trials. Oke (2008) reported that lambda-cyhalothrin was found to be better insecticide against melon fruit fly in cucumber compared to deltamethrin. Stark and Vargas (2009) studied the toxicity of thiamethoxam, tefluthrin, imidacloprid, fipronil and lambda-cyhalothrin after application to sand and soil as drenches for control of the melon fly, *B. cucurbitae* (Coquillett). They found lamda-cyhalothrin was the best insecticide in controlling melon fly infestation than the diazinon, tefluthrin, fipronil and thiamethoxam. The present findings are in close agreement with that Meena (2011) who reported that lambda cyhalothrin (0.004%) and spinosad (0.002%) were the most effective treatments against melon fruit fly infestation in tomato. Khatun *et al*. (2016) reported that per cent fruit infestation and number of marketable fruits/m^2 were higher in abamectin 1.8 EC (15.66 and 2.12, respectively) and lambda-cyhalothrin 2.5 EC treatments (17.23 and 1.85, respectively).

Similarly, Abrol *et al*. (2019) reported that lambda cyhalothrin (0.004%) treatment was best against the fruit fly in bottle gourd, followed by deltamethrin (0.0028%) and spinosad (0.002%). Sharma and Gupta (2019) reported that lambda-cyhalothrin (0.004%) was superior chemical against *Bactrocera* spp. in cucumber crop. Sawai *et al*. (2014) reported that deltamethrin (0.0016%), DDVP (0.05%), emamectin benzoate (0.0016%) recorded significantly the lowest fruit damage with 22.83, 24.05 and 24.79 per cent, respectively in ridge gourd. Srinivas *et al*. (2018) observed lowest number of ovipositional punctures, lowest number of maggots, lowest per cent fruit infestation and highest marketable cucumber fruit yield against melon fly in spinosad 45 SC (0.15 ml/l) and dichlorvos 76 EC (1.0 ml/l) treatments followed by deltamethrin 2.8 EC (1 ml/l).

From the obtained results, it is concluded that traps with yellow colour and cylindrical or sphere shape followed by transparent bottle impregnated with methyl eugenol can efficiently attract and catch a greater number of fruit flies in the pre and post-harvest period in a custard apple orchard. It is also an eco-friendly method for monitoring the fruit fly, *B. dorsalis* population. The management studies to test the efficacy of different chemical insecticides against fruit fly shows that acetamiprid + jaggery and dinotefuran + jaggery emerged as the most promising treatments.

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