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The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; SP-10(10): 385-391

www.thepharmajournal.com
Received: 13-07-2021
Accepted: 02-09-2021

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Evaluation of efficacies of newer insecticides against mango leafhoppers

Prasanthi SJ, Chalam MSV, Devaki K and Mohan Naidu G

Abstract
An experiment was conducted to evaluate the efficacy of nine insecticides *viz*., Dinotefuron 20 SG @ 0.3 g l^{-1}, Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1}, Flonicamid 50 WG @ 0.4 g l^{-1}, Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1}, Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1}, Spinosad 480 SC @ 0.3 ml l^{-1}, Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1}, Pymetrozine 50 WG @ 0.6 g l^{-1}, Imidacloprid 17.8 SL @ 0.3 ml l^{-1} along with an untreated control. Pooled efficacies of these treatments revealed that Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} and Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} have resulted in 95.68 and 94.88 per cent reduction of leafhopper population over control (ROC), respectively and were proved to be the most effective treatments followed by Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} (92.54 % ROC). The descending order of efficacy was Pymetrozine 50 WG @ 0.6 g l^{-1} (84.81 % ROC), Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (77.45 % ROC), Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (73.65 % ROC), Flonicamid 50 WG @ 0.4 g l^{-1} (69.83 % ROC) and Dinotefuron 20 SG @ 0.3 g l^{-1} (68.10 % ROC) where the latter two were at par with each other. The least per cent reduction of leafhoppers (53.85 % ROC) over control was recorded with Spinosad 480 SC @ 0.3 ml l^{-1}.

Keywords: Mango, leafhoppers, insecticides, combination insecticides

Introduction
Mango (*Mangifera indica* Linn.) is the most important commercial fruit of India and is considered as King of fruits. In India, 2.263 million hectares is under mango cultivation with the production of 19.687 million tonnes (Directorate of Economics and Statistics, 2017a) [7] and mango is extensively grown in Uttar Pradesh (23.86%), Andhra Pradesh (22.14%), Bihar (8.73%), Gujarat (6.00%) and Tamil Nadu (5.09%). During 2017-18, area, Production and productivity of mango in Andhra Pradesh were 2.85 lakh hectares, 20.95 lakh tonnes, and 7419 kg/ha, respectively (Directorate of Economics and Statistics, 2017b) [6] and Chittoor is the leading district with respect to area (77637 ha) and production (854007 T) of mango in Andhra Pradesh (Ministry of Agriculture, 2018) [22]. Quality and quantity of mangoes produced are mainly reduced by the incidence of about 400 insect pests (Thangam *et al*., 2013) [35] among which leafhoppers are the most serious and widespread pests throughout the country (Verghese, 2000) [40]. Twelve species of mango leafhoppers have been reported from various states of India (Srinivasa *et al*. (2017) [33]. *Amritodus atkinsoni* (Lethierry), *Idioscopus clypealis* (Lethierry), *I. niveosparsus* (Lethierry) and *I. nitidulus* (Walker) cause severe damage at flowering and fruiting stages and reduce the yield up to 100 per cent (Rahman and Kuldeep, 2007; Prabhakara *et al*., 2011) [28, 27]. Leafhoppers, during non-flowering period, hide themselves in moist areas of the tree or lower surface of leaves and migrate to the panicles during flowering. Large number of nymphs and adults puncture and suck the sap from leaves, tender shoots, and inflorescence of mango, which cause poor setting of flowers and premature dropping of fruits, thereby decreasing the yield. Besides, they also excrete honey dew which encourages the growth of sooty mould on the dorsal surface of leaves, branches, and fruits hampering the normal photosynthetic activity of the plant. Managing the leafhopper complex on mango with solo insecticides may require more number of insecticidal sprays and prone to high risk of resistance development. In this regard, experiment was planned with an objective to evaluate the efficacies of certain newer and bio-rational insecticides against mango leafhoppers.

Material and methods
The experiment was conducted in a fifteen year old mango orchard, Tirupati, Chittoor district

for two consecutive years *viz*., 2019-20 and 2020-21 to evaluate the efficacy of certain newer insecticides, including combination insecticides, against leafhoppers of mango. The treatments include Dinotefuron 20 SG @ 0.3 g l^{-1}, Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1}, Flonicamid 50 WG @ 0.4 g l^{-1}, Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1}, Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1}, Spinosad 480 SC @ 0.3 ml l^{-1}, Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1}, Pymetrozine 50 WG @ 0.6 g l^{-1} and Imidacloprid 17.8 SL @ 0.3 ml l^{-1}. Trees sprayed with water only were maintained as control. The experiment was laid out in a randomized block design with ten treatments including a check and an untreated control. All the treatments were replicated thrice with the widely cultivated variety, Bangalora. Three trees of Bangalora were randomly selected from each line having 8-10 trees for spraying the insecticide and the observations were taken on them considering one tree as one replication.

The data on leafhopper population were recorded one day before as well as 1, 7, 15 and 21 days after each spray application. The first spray was given at 50 per cent bud initiation and the second spray at 21 days after the first spray. Four panicles from each direction (east, west, north, and south) of the tree have been selected randomly per experimental tree for taking pre and post spray observations on leafhopper population. The hoppers were sampled by using polythene bag trap collection method described by Kannan and Rao (2006) [15] using a polythene bag (60 cm x 30 cm) with ethyl acetate swabbed cotton and the panicle was inserted into the bag between 8-9 a.m. Later the inflorescence is tapped gently and then the adults and nymphs were counted. The post treatment counts of leafhoppers from various treatments were used to calculate per cent reduction in the pest population over control using the following formula

$$\text{Per cent reduction over control (\%)} = \frac{\text{Population in untreated control} - \text{Population in treatment}}{\text{Population in untreated control}} \times 100$$

The values thus obtained were subjected to arcsine transformation and significant differences among the efficacies of various treatments were computed by the method of analysis of variance (ANOVA) meant for experiments planned in randomized block design.

Results and discussions

2019-20

A perusal at the number of leafhoppers on the inflorescences of mango before the imposition of treatments suggests a homogenous distribution of the leafhoppers over the experimental area during the year 2019-20. However, significant differences among the populations of leafhoppers were observed at 1, 7, 15 and 21 days after both the insecticidal sprays indicating varying levels in their cumulative efficacies. All the treatments, solo and combination insecticides, have resulted in significant reduction of leafhoppers over control. At 1 DAT (Days After Treatment), all the three combination insecticides namely, Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1}, Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} and Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} recorded 100 per cent reduction of leafhoppers over control and were found to be best treatments. Pymetrozine 50 WG @ 0.6 g l^{-1} emerged as the next best treatment recording 97.94 per cent reduction of leafhoppers which is followed by Imidacloprid 17.8 SL @ 0.3 ml l^{-1}, Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} and Flonicamid 50 WG @ 0.4 g l^{-1} where all the three chemicals were at par with each other and recorded 94.23, 92.96 and 91.92 per cent reduction over control, respectively. The next best treatment in the descending order of efficacy is Dinotefuron 20 SG @ 0.3 g l^{-1} which had registered 91.13 per cent reduction of leafhoppers over control. Spinosad 480 SC @ 0.3 ml l^{-1}, with 85.95 per cent reduction over control, was the least effective treatment when compared to other insecticides.

At 7 DAT, however, Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} and Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} recorded 100 per cent reduction of leafhoppers over control and were at par with Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} (99.35 % ROC). The next effective treatment in the descending order of efficacy was Pymetrozine 50 WG @ 0.6 g l^{-1} which reduced the leafhopper population by 94.97 per cent over control. The next best treatment was Imidacloprid 17.8 SL @ 0.3 ml l^{-1} with 87.83 per cent reduction of leafhoppers over untreated control and was at par with Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (83.10 % ROC) which in turn was at par with Flonicamid 50 WG @ 0.4 g l^{-1} (78.77 % ROC) and Dinotefuron 20 SG @ 0.3 g l^{-1} (78.15 % ROC). Spinosad 480 SC @ 0.3 ml l^{-1} was the least effective treatment and was recorded 63.35 per cent reduction over control.

More or less, a similar trend in the efficacies of treatments was observed at 15 and 21 DAT. Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} continued to record 100 per cent reduction over control even after 15 DAT and 85.90 per cent reduction on 21 DAT. This was followed by Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} (98.90 & 82.77 % ROC) which was at par with the former mentioned treatment along with Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} (96.50 & 76.43 % ROC) on both the days of observation. Pymetrozine 50 WG @ 0.6 g l^{-1} (81.31 & 57.43 % ROC) and Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (70.34 & 49.08 % ROC) were at par on 21 DAT. The next treatment in the order of decreasing efficacy was Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (63.43 & 45.59 % ROC) which was at par with Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (on 15 DAT), Flonicamid 50 WG @ 0.4 g l^{-1} (58.51 & 43.18 % ROC) and Dinotefuron 20 SG @ 0.3 g l^{-1} (56.71 & 39.66 % ROC). Least per cent reduction has been recorded in Spinosad 480 SC @ 0.3 ml l^{-1} with 40.25 and 16.80 per cent reduction of leafhopper over control on 15 and 21 DAT, respectively.

The overall mean of per cent reduction in the leafhopper over control indicated the superior efficacy of Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} (96.67 % ROC) and Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} (95.68 % ROC) followed by Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} (93.49 % ROC), Pymetrozine 50 WG @ 0.6 g l^{-1} (83.71 % ROC), Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (76.29 % ROC), Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (72.15 % ROC), Flonicamid 50 WG @ 0.4 g l^{-1} (68.98 % ROC) and Dinotefuron 20 SG @ 0.3 g l^{-1} (67.41 % ROC) where the latter two are at par with each other. Significantly least per cent reduction of leafhoppers is brought by Spinosad 480 SC @ 0.3 ml l^{-1} which has recorded 52.72 per cent reduction over control.

2020-21

Though a slight hike in the pretreatment counts of leafhoppers was observed in the second season, the population was found to be uniformly distributed among all the trees under the experiment. A considerable variation in the population of leafhoppers was observed following the insecticidal application. Almost a similar pattern in the per cent reduction of leafhoppers over control by insecticides was noticed during 2020-21. All the three combination insecticides *viz*., Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1}, Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} and Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} recorded 100 per cent reduction of leafhoppers over control and were followed by Pymetrozine 50 WG @ 0.6 g l^{-1} (98.23 % ROC). The next best treatments in the decreasing order of efficacy were Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (93.85 % ROC), Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (93.39 % ROC), Flonicamid 50 WG @ 0.4 g l^{-1} (91.21 % ROC) and Dinotefuron 20 SG @ 0.3 g l^{-1} (90.94 % ROC) and all were at par with each other. Spinosad 480 SC @ 0.3 ml l^{-1} was found to record 85.08 per cent reduction over control and was at par with latter two chemicals.

At 7 DAT, the treatments *viz*., Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} and Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} have recorded 100 per cent reduction of leafhoppers over control and were significantly superior to the rest of the treatments. The next effective treatment was Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} which was found to bring 98.66 per cent reduction of leafhoppers over control and was followed by Pymetrozine 50 WG @ 0.6 g l^{-1} (93.21 % ROC) and Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (86.69 % ROC) which in turn was at par with Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (85.22 % ROC). Flonicamid 50 WG @ 0.4 g l^{-1} had registered 80.95 per cent reduction over control and was found to be at par with Dinotefuron 20 SG @ 0.3 g l^{-1} (77.44 % ROC). With 63.02 per cent reduction of leafhoppers over control, Spinosad 480 SC @ 0.3 ml l^{-1} was least effective and significantly inferior to other insecticides.

At 15 DAT, all the three combination insecticides *viz*., Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} (97.00 % ROC), Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} (96.36 % ROC) and Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} (93.69 % ROC) have significantly reduced the leafhopper population when compared to solo insecticides and were followed by Pymetrozine 50 WG @ 0.6 g l^{-1} (82.57 % ROC) and Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (74.43 % ROC) where the latter mentioned insecticide was in turn at par with Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (68.91 % ROC), Flonicamid 50 WG @ 0.4 g l^{-1} (64.77 % ROC) and Dinotefuron 20 SG @ 0.3 g l^{-1} (62.91 % ROC). Spinosad 480 SC @ 0.3 ml l^{-1}, with 45.35 per cent reduction of leafhoppers over control, was significantly proved to be the least effective treatment.

At 21 DAT, Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} (80.99 % ROC) and Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} (9.19 % ROC) were the most effective treatments and were significantly superior to the other combination insecticide *i.e*., Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} (72.28 % ROC). Pymetrozine 50 WG @ 0.6 g l^{-1} (66.34 % ROC) and Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (56.11 % ROC) were the next effective treatments in the descending order of efficacy. The next best treatments were Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (49.08 % ROC), Flonicamid 50 WG @ 0.4 g l^{-1} (41.94 % ROC) and Dinotefuron 20 SG @ 0.3 g l^{-1} (40.56 % ROC) and all were at par with each other. Spinosad 480 SC @ 0.3 ml l^{-1} (22.07 % ROC) was the least effective treatment and was significantly inferior to other insecticides.

The overall mean per cent reduction of leafhoppers over control showed that treatments *viz.*, Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} and Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} have recorded highest per cent reduction over control *viz*., 94.87 and 94.25, respectively and were followed by Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} (91.77 % ROC). Pymetrozine emerged as the next best treatment with 85.70 per cent reduction over control. Next best treatments in the descending order of efficacy were Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (78.39 % ROC) and Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (74.87 % ROC) and were at par with each other. These were followed by Flonicamid 50 WG @ 0.4 g l^{-1} (70.49 % ROC) which was simultaneously at par with Dinotefuron 20 SG @ 0.3 g l^{-1} (68.67 % ROC) and Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1}. With 54.76 per cent reduction of leafhopper over control, Spinosad 480 SC @ 0.3 ml l^{-1} was the least effective treatment among all the insecticides evaluated.

Pooled efficacy

When the mean per cent reduction of leafhoppers by various treatments over control was pooled (Fig 1.) for two consecutive years (2019-20 & 2020-21), treatments *viz.*, Imidacloprid (40%) + Ethiprole (40%) 80 WG @ 0.6 g l^{-1} and Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC @ 1.0 ml l^{-1} have brought 95.68 and 94.88 per cent reduction over control, respectively and were proved to be the most effective treatments and were followed by Buprofezin (15%) + Acephate (35%) WP @ 2.5 g l^{-1} (92.54 % ROC). The treatments in the descending order of efficacy were Pymetrozine 50 WG @ 0.6 g l^{-1} (84.81 % ROC), Imidacloprid 17.8 SL @ 0.3 ml l^{-1} (77.45 % ROC), Lambda Cyhalothrin 5 EC @ 2.0 ml l^{-1} (73.65 % ROC), Flonicamid 50 WG @ 0.4 g l^{-1} (69.83 % ROC) and Dinotefuron 20 SG @ 0.3 g l^{-1} (68.10 % ROC) where the latter two are at par with each other. The least per cent reduction of leafhoppers (53.85 % ROC) over control has been noticed in the treatment, Spinosad 480 SC @ 0.3 ml l^{-1}.

In a nutshell, combination insecticides have resulted in significantly highest per cent reduction of leafhoppers over control and were followed by Pymetrozine 50 WG @ 0.6 g l^{-1} and Imidacloprid 17.8 SL @ 0.3 ml l^{-1}. The results of the present study are parallel to that of Sharanabasappa *et al.* (2018) [32] reported dinotefuron 20 SG @ 0.3 g l^{-1} as the best treatment which recorded a significantly lowest number of nymphs and adults of mango leafhoppers, followed by imidacloprid 70 WG @ 0.25 g l^{-1}, buprofezin 25 SC @ 2 ml l^{-1}, thiamethoxam 25 WG @ 0.24 g l^{-1}, and imdidacloprid 17.8 SL @ 0.5 ml l^{-1}. Efficacy of Buprofezin was also reported by Manjunatha *et al.* (2017) who revealed that application of Buprofezin 25 SC @ 1.25 ml l^{-1} was the most effective in reduction of population of mango leafhopper followed by combined application of Yellow sticky tarp (YST) @ 2 traps per tree + azadirachtin 10,000 ppm @ 1 ml l^{-1} - *Lecancillium lecanii* @ 2 g l^{-1} – azadirachtin@ 1 ml l^{-1}. Chaudhary *et al.* (2017) [27] reported that imidacloprid 17.8 SL @ 0.4 ml l^{-1}, thiomethoxam 25 WG @ 0.1 g l^{-1} and acephate 75 SP @ 1 g l^{-1} 95.35, 93.99 and 73.66 per cent mean mortality of mango leafhoppers after the second spray, respectively. The present study is also in concordance with Mohapatra *et al.* (2019) [23] according to whom thiamethoxam 12.6% + lambda-cyhalothrin 9.5% ZC, thiamethoxam 25 WG and acephate

50% + imidacloprid 1.8% SP were the most effective treatments in reducing the incidence of *A. atkinsoni* and were followed by buprofezin 15% + acephate 35% WP, acetamiprid 20 SP and buprofezin 25 SC after three sprays. Jhansi *et al.* (2010) [14] reported that Ethiprole + imidacloprid and thiamethoxam + lambdacyhalothrin exhibited excellent initial and persistent toxicity against brown plant hopper, white backed plant hopper and green leaf hopper in rice.

The present study is also in close conformity with Ferdous and Jahan (2020) [9] who reported 100 and 90.45 per cent mortality of mango leafhoppers (*I. clypealis*) by application of pymetrozine and spinosad at registered doses, respectively. The results were also in concordance with Sarode and Mohite (2016) [31] who revealed that imidacloprid 17.8 SL @ 0.004% was found to be most effective in reducing mango hopper which was on par with thiamethoxam 25 WG @ 0.01% and lambda cyhalothrin 5 EC @ 0.004% indicating that they are equally effective in reducing the survival population of mango hopper. Efficacy of imidacloprid against mango leafhoppers was also reported by Samanta *et al.* (2009), and Murthy *et al.* (2019). Pashi *et al.* (2019) [30, 24, 26] reported that Flonicamid 50%WG @ 25 g a.i. ha^{-1} as the best treatment with highest mortality (88.77 %) of mango leafhoppers and were followed by Flonicamid 50%WG @ 15 and 20 g a.i. ha^{-1}, Imidacloprid 17.8 % SL @ 25 g a.i. ha^{-1}, Lambda cyhalothrin 5% EC @ 5 g a.i. ha^{-1} and Dimethoate 30%EC @ 50 g a.i. ha^{-1}.

The enhanced efficacy of combination insecticides might be due to various factors of individual insecticides present in the formulation which are discussed here in brief. Neonicotinoids and phenyl pyrazoles are insecticides with systemic properties. Neonicotinoids are reported for their effective translocation along various parts of the plant including the apices of new vegetation enhancing their efficacy against sucking pests, both above ground and below. Neonicotinoids have multiple target/binding sites *i.e.*, they acts as agonists on nAChRs opening cation channels (Casida and Durkin 2013) [4] and on voltage-gated calcium channels (Jepson *et al*., 2006) [13]. Thiamethoxam, a second generation neonicotinoid is a poor agonist of insect nAChRs (Nauen *et al.,* 2003; Tan *et al*., 2007; Benzidane *et al.,* 2010) [25, 1] but is able to bind to mixed nicotinic/muscarinic receptors (Lapied *et al*., 1990) [19]. Synergism in the toxicity of neonicotinoids through the production of metabolites may be another contributing factor further enhancing the toxic action of the insecticide. The metabolite of thiamethoxam, clothianidin, can act on imidacloprid-sensitive nAChR1 and imidacloprid-insensitive nAChR2 subtypes (Thany 2009, 2011) [36, 37]. Neonicotinoids are also reported to stimulate defense mechanisms of plant. They induce salicylic acid, an inducer of systemic acquired resistance can modulate (a)biotic stress responses (Kevin *et al*., 2010). Thus, combining these neonicotinoids with insecticides belonging to other chemical groups like phenyl pyrazoles or synthetic pyrethroids with further diverse target sites and modes of action reduces the risk of development of resistance and also decreases the need for over use of insecticides at field level.

Ethiprole is a new non-systemic 1-phenylpyrazole insecticide differs from fipronil, the major phenylpyrazole insecticide, only in an ethylsulfinyl substituent replacing the trifluoromethylsulfinyl moiety. The toxicity of phenylpyrazoles to insects and mammals is attributable to their action at the GABA receptor as noncompetitive blockers of the GABA-gated chloride channel (Caboni *et al.*, 2003) [3]. Lambda-cyhalothrin is a third generation photostable pyrethroid insecticide, one of the most potent insecticidal compounds. Pyrethroids are sodium channel modulators, interfering with the central nervous system of insects. Lambda-cyhalothrin kills insects by contact, ingestion and ovicidal action, and is not locally systemic in plants. It offers rapid knockdown and residual control while anti-feeding and repellency properties extend the biological effect against some pests (Syngenta, 2018) [34]. In the current study, these insecticides have performed better when combined with other chemicals of different modes of action rather than solo applications.

Another combination insecticide used in the current study is Buprofezin (15%) + Acephate (35%) WP whose efficacy, during earlier days of observation, was at par with earlier mentioned combination insecticides. Acephate is a systemic insecticide used to control sucking and biting insects by direct contact or ingestion (Tomlin, 2006; Thomson, 1989) [39, 38]. Organophosphates such as acephate bind to and inhibit the enzyme acetylcholinesterase (AChE) in nervous system tissues resulting the accumulation of acetylcholine and repeated activation of cholinergic receptors (Klaassen, 2001; Reigart and Roberts, 1999) [18, 29] leading to over-excitation of nerves, muscles or tissues (Reigart and Roberts, 1999) [29]. Insects metabolize acephate into methamidophos by hydrolysis accounting for acephate's relatively high selectivity against insects (Farag *et al*., 2000; Mahajna *et al*., 2007) [8, 20]. It can be assumed that Acephate, an insecticide of moderate persistence with residual systemic activity of about 10-15 days at the recommended use rate when used with chitin synthesis and prostaglandin inhibitor insecticide, Buprofezin having hormonal disturbing effect, leading to suppression of ecdysis can effectively exert a good control against planthoppers with two different mode of action (Ghoshal *et al*., 2018) [10].

Amongst solo insecticides, Pymetrozine has registered higher per cent reduction than other chemicals along with another selective feeding blocker *i.e*., Flonicamid. Pymetrozine acts through a novel mechanism that is linked to the signaling pathway of serotonin which strongly enhanced the action of the insecticide (Kaufmann *et al*., 2004) [16]. Flonicamid was found to be active on the A-type potassium channel currents. It was hypothesized that blockade of the A-type potassium channel in the pre-synaptic terminal underlies its lethal effect in insects. The loss of the A-type potassium rectifying current would lead to the disruption of controlled neurotransmitter release (Hayashi *et al*., 2006; Hancock, 2004) [12, 11]. Dinotefuran has displayed lesser efficacy than Imidacloprid in the current experiment. It is reported that Dinotefuran can exhibit a nerve-excitatory activity, which is lower than that of imidacloprid and a nerve-blocking activity which is comparable with that of imidacloprid (Kiriyama and Nishimura, 2002) [17].

Table 1: Overall efficacy of different insecticides against leafhoppers under mango ecosystem during first season, 2019-20

S. No.	Treatment	Dose	PTC	Per cent reduction of leafhopper population over control after first season								Over-all ROC (%)
				1 DAT		7 DAT		15 DAT		21 DAT		
				Mean	ROC (%)	Mean	ROC (%)	Mean	ROC (%)	Mean	ROC (%)	
T_1	Dinotefuron 20 SG	0.3 g l^{-1}	26.88	2.62	91.13^{d} (72.79)	7.11	78.15^{d} (62.35)	12.06	56.71^{e} (48.90)	16.80	39.66^{e} (39.03)	67.41^{f} (55.22)
T_2	Buprofezin (15%) + Acephate (35%) WP	2.5 g l^{-1}	30.58	0.00	100.00^{a} (90.05)	0.20	99.35^{a} (87.37)	0.96	96.50^{b} (81.22)	6.55	76.43^{b} (61.10)	93.49^{b} (75.28)
T_3	Flonicamid 50 WG	0.4 g l^{-1}	30.81	2.42	91.92^{c} (73.56)	6.93	78.77^{d} (62.68)	11.54	58.51^{e} (49.96)	15.85	43.18^{de} (41.09)	68.98^{f} (56.18)
T_4	Imidacloprid (40%) + Ethiprole (40%) 80 WG	0.6 g l^{-1}	26.83	0.00	100.00^{a} (90.05)	0.00	100.00^{a} (90.05)	0.00	100.00^{a} (90.05)	3.95	85.90^{a} (68.06)	96.67^{a} (79.58)
T_5	Lambda Cyhalothrin 5 EC	2.0 ml l^{-1}	31.27	2.06	92.96^{c} (74.87)	5.62	83.10^{cd} (65.85)	10.17	63.43^{de} (52.82)	15.13	45.59^{de} (42.48)	72.15^{e} (58.18)
T_6	Spinosad 480 SC	0.3 ml l^{-1}	26.90	4.17	85.95^{e} (68.06)	12.02	63.35^{e} (52.79)	16.59	40.25^{f} (39.39)	23.21	16.80^{f} (24.09)	52.72^{g} (46.58)
T_7	Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC	1.0 ml l^{-1}	32.81	0.00	100.00^{a} (90.05)	0.00	100.00^{a} (90.05)	0.31	98.90^{ab} (85.19)	4.82	82.77^{ab} (65.63)	95.68^{a} (78.14)
T_8	Pymetrozine 50 WG	0.6 g l^{-1}	29.31	0.62	97.94^{b} (81.96)	1.62	94.97^{b} (77.42)	5.20	81.31^{c} (64.44)	11.86	57.43^{c} (49.30)	83.71^{c} (66.24)
T_9	Imidacloprid 17.8 SL (Check)	0.3 ml l^{-1}	30.73	1.70	94.23^{c} (76.35)	3.95	87.83^{c} (69.75)	8.21	70.34^{d} (57.06)	14.18	49.08^{cd} (44.49)	76.29^{d} (60.90)
T_{10}	Control	water	26.88	29.73	-	32.96	-	27.79	-	27.88	-	-
SEm±		-	-	-	1.08	-	1.46	-	1.90	-	1.75	0.53
CD (5%)		-	NS	-	3.23	-	4.38	-	5.70	-	5.26	1.59
CV (%)		-	-	-	2.34	-	3.46	-	5.21	-	6.28	1.43

*Figures in parenthesis are angular transformed values, PTC: Pre treatment count, ROC: Reduction Over Control

Table 2: Overall efficacy of different insecticides against leafhoppers under mango ecosystem during second season, 2020-21

S. No.	Treatment	Dose	PTC	Per cent reduction of leafhopper population over control after second season								Over-all ROC (%)
				1 DAT		7 DAT		15 DAT		21 DAT		
				Mean	ROC (%)	Mean	ROC (%)	Mean	ROC (%)	Mean	ROC (%)	
T_1	Dinotefuron 20 SG	0.3 g l^{-1}	31.96	3.29	90.94^{cd} (73.12)	9.00	77.44^{f} (61.70)	13.25	62.91^{c} (52.58)	19.91	40.56^{f} (39.49)	68.67^{f} (56.00)
T_2	Buprofezin (15%) + Acephate (35%) WP	2.5 g l^{-1}	31.58	0.00	100.00^{a} (90.05)	0.53	98.66^{b} (83.44)	2.26	93.69^{a} (75.59)	9.15	72.78^{bc} (58.63)	91.77^{b} (73.40)
T_3	Flonicamid 50 WG	0.4 g l^{-1}	31.39	3.17	91.21^{cd} (72.98)	7.58	80.95^{ef} (64.20)	12.51	64.77^{c} (53.63)	19.54	41.94^{f} (40.26)	70.49^{ef} (57.15)
T_4	Imidacloprid (40%) + Ethiprole (40%) 80 WG	0.6 g l^{-1}	35.48	0.00	100.00^{a} (90.05)	0.00	100.00^{a} (90.05)	1.07	97.00^{a} (80.31)	6.38	80.99^{a} (64.21)	94.87^{a} (76.95)
T_5	Lambda Cyhalothrin 5 EC	2.0 ml l^{-1}	31.42	2.38	93.39^{c} (75.27)	5.91	85.22^{de} (67.59)	11.01	68.91^{c} (56.16)	17.14	49.08^{ef} (44.49)	74.87^{de} (59.95)
T_6	Spinosad 480 SC	0.3 ml l^{-1}	32.81	5.36	85.08^{d} (67.61)	14.75	63.02^{g} (52.58)	19.20	45.35^{d} (42.26)	26.29	22.07^{g} (27.91)	54.76^{g} (47.76)
T_7	Thiamethoxam (12.6%) + Lambda Cyhalothrin (9.5%) 247 ZC	1.0 ml l^{-1}	31.15	0.00	100.00^{a} (90.05)	0.00	100.00^{a} (90.05)	1.29	96.36^{a} (79.19)	7.07	79.19^{ab} (63.04)	94.25^{a} (76.22)
T_8	Pymetrozine 50 WG	0.6 g l^{-1}	30.65	0.64	98.23^{b} (82.47)	2.70	93.21^{c} (75.17)	6.03	82.57^{b} (65.88)	11.30	66.34^{cd} (54.59)	85.70^{c} (67.88)
T_9	Imidacloprid 17.8 SL (Check)	0.3 ml l^{-1}	38.02	2.24	93.85^{c} (76.34)	5.29	86.69^{d} (68.86)	9.10	74.43^{bc} (59.67)	14.77	56.11^{de} (48.54)	78.39^{d} (62.34)
T_{10}	Control	water	34.92	36.04	-	39.86	-	35.47	-	33.73	-	-
SEm±		-	-	-	2.03	-	1.51	-	2.53	-	2.19	0.82
CD (5%)		-	NS	-	6.09	-	4.54	-	7.57	-	6.58	2.46
CV (%)		-	-	-	4.41	-	3.61	-	6.96	-	7.75	2.22

*Figures in parenthesis are angular transformed values, PTC: Pre treatment count, ROC: Reduction Over Control

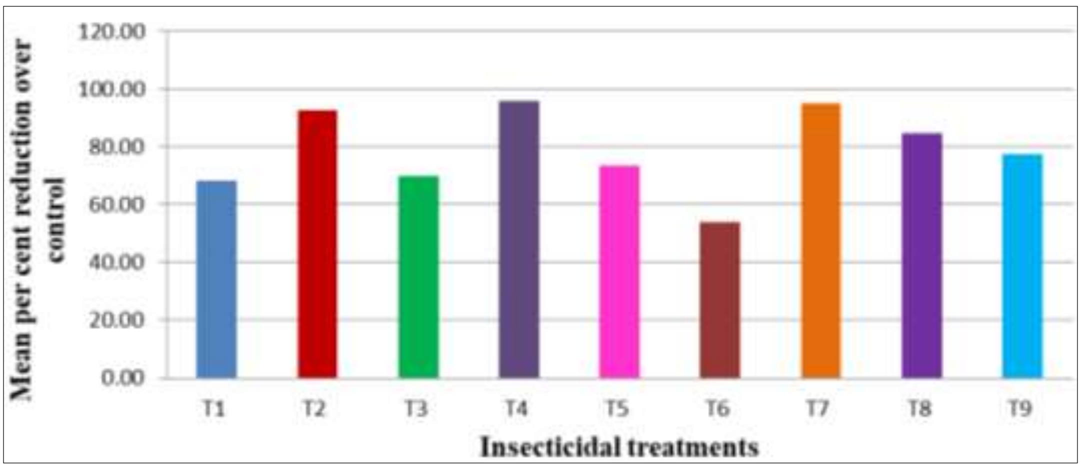

Fig 1: Pooled efficacy of different insecticides against leafhoppers after first and second season, 2019-20 & 2020-21

Conclusion
Combining insecticides with multiple active substances may enhance the toxicity against insects by synergism, acting on multiple target sites, different modes of action, *etc.* Besides, combination insecticides provide rapid and long lasting management of different developmental stages of same insect at the same time and also different insects feeding on different plant parts above and below the ground. Hence, combination insecticides may effectively be included in Integrated Pest Management strategies of insect pests under orchard ecosystems.

Acknowledgement
The authors are thankful to Sri. A. Nagendra Naidu, farmer, who has provided orchard for the conductance of experiment.

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