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Exploring the thermal dynamics of mango leaf hopper (Cicadellidae: Homoptera) populations and evaluating insecticide susceptibility

Sashanka Sekhar Dash[1,†,*], Manoj Kumar Tripathy[1,†], Susanta Kumar Das[2] and Pravasini Behera[1]

[1]Department of Entomology, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India; [2]Department of Forest Resource Management, College of Forestry, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India
†Both authors contributed equally
*Corresponding author's email: dash.sashank12@gmail.com

Effective pest management in agricultural systems requires understanding environmental conditions and chemical solutions. The efficacy of lambda cyhalothrin, imidacloprid, and acephate for mango leaf hopper control was examined in relation to temperature. A controlled laboratory setup with a Bio-Oxygen-Demand (B.O.D) incubator maintained temperatures of 25 °C, 22 °C, and 29 °C for the experiment. The investigated pesticides' toxicity varied with temperature. March 2022, October 2022, and July 2023 lambda cyhalothrin LD_{50} values were 0.524, 0.412, and 0.992 ppm at 25 °C. In the same timeframes, imidacloprid showed LD_{50} values of 0.797, 1.187, and 1.774 ppm. Acephate has 0.890, 1.572, and 1.927 ppm LD_{50}s. Piperonyl butoxide (PBO), N-(Propargyloxy) phthalimide (PP), diethyl maleate (DEM), and S,S,S-tributyl phosphorotrithioate (DEF) were also tested for synergy. DEM and the studied insecticides had synergistic ratios, suggesting improved pest control tactics. The data showed that temperature, pesticide effectiveness, and synergistic interactions promote sustainable mango pest management.

Keywords: Mango pest management, synergistic study, insecticides, temperature variations, resistance management.

INTRODUCTION

Mango cultivation, a cornerstone of tropical and subtropical economies, is no exception to this challenge. Production and quality of mango are mainly hampered by the incidence of about 400 insect pests (Thangam *et al.*, 2013). Among the mango pests, mango hoppers are most serious and widespread pests throughout the country (Verghese, 1999). *Amritodus atkinsoni* (Lethierry), *Idioscopus clypealis* (Lethierry) *I. niveosparsus* (Lethierry) and *I. nitidulus* (Walker), are the serious pests of mango at flowering and fruiting stages and could cause yield loss up to 100% (Rahman *et al.*, 2007, Prabhakara *et al.*, 2011). 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. In order to alleviate the losses due to this pest, farmers often resorted to chemical interventions involving conventional organophosphates, carbamates, synthetic pyrethroids and some selected new chemistry molecules resulted in development of resistance and subsequent control failures (Kranthi *et al.*, 2002; Abbas *et al.*, 2014; Saleem *et al.*, 2016). The infestation, abundance and severity of the pest are influenced by various environmental factors besides plant resistance or varietal characters (Dhaliwal and Singh, 2004; Kaushik *et al.*, 2014). Resistance within or between chemical classes of insecticides with similar mode of action is an ever increasing problem in sustainable pest control. Main mechanisms behind this phenomenon were reported to be biochemical where detoxifying enzymes play major role. In some cases it may also be due to certain physiological mechanisms or behavioural adaptations.

Given the remarkable difficulty and investment associated with development of new, cost-effective and safe insecticide molecules and to manage the field level resistance, there is a vital need to preserve the efficacy of current and future insecticides. Synergists are detoxification enzyme inhibitors whose main purpose is to restore the susceptibility of insects to the chemical, which would require higher levels of the toxicant for their control. Therefore synergists are considered as direct tools in resistance management for overcoming

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metabolic mechanisms and synergism is the best way to bring back vanished insecticides due to resistance development. Mechanisms of insecticide resistance can also be identified based on mortality count by combining various ratios of synergists with insecticides (Prabhaker *et al.*, 1988; Kaur and Kang 2015).

Detoxification enzymes such as mixed function oxidases and esterases are found to be most common mechanisms in biochemical resistance (Cheema 2013; Patil 2012). To investigate the role of detoxification enzymes in the ostensive resistant population of mango leaf hopper collected from different locations of Odisha, India, synergist's viz. PBO as a monooxygenase and esterase inhibitor, DEM as glutathione-S-transferase inhibitor, N-(propargyloxy) phthalimide, (PP) and S,S,S-tributyl phosphorotrithioate (DEF), are inhibitor of the enzyme acetylcholinesterase (AChE) were mixed with the test insecticides lambda cyhalothrin, imidacloprid and acephate at different ratios of 1:2, 1:4, 1:6 and 1:8 in the bioassay.

MATERIALS AND METHODS

Collection of Insects: The nymphs and adults of mango hopper population were collected from a high density (5.0 m × 5.0 m) mango orchard of OUAT located at Bhubaneswar, Odisha, during March 2022, October 2022 and July 2023. The insect collection was done by a sweeping net during the early morning hours of 6.0 A.M. and 8.0 A.M. Nymphs and adults were kept apart and delicate mango twigs were used for rearing of the insects inside a perforated plastic jar.

Rearing Container: One of the most important aspects of laboratory rearing is the proper container. The white round plastic jar with 12 cm diameter were chosen for rearing of the insects. After release of the adults and nymphs, each plastic container was covered with muslin cloth for proper aeration and preventing escape of the pest.

Substrate Preparation: Fresh mango leaves were collected from a pesticide-free source and thoroughly washed to remove contaminants. A layer of clean, moist sand was placed in the bottom of the rearing containers to provide humidity and prevent leaf desiccation.

Rearing Setup: Mango twigs were carefully placed in a bed of damp sand after washing. Mango hoppers, an insect found in mango orchards, were then released into a plastic container. A muslin cloth was then used to cover the container. Mango leaf hopper adults were purposefully introduced to shoots and flowers to study their infestation. In plant physiology, newly emerged nymphs take sap from plant shoots or inflorescences, desiccating the damaged plant parts. In the experiment, the branches or inflorescence base was removed before desiccation, conserving the hoppers. To permit further observations, the hoppers were moved to a new feeding habitat. The rearing process used a standard cage at ambient room temperature, a cage with two inches of dry sand, a cage with two inches of moist sand, and a cage in a B.O.D incubator set at four temperatures: 22°C, 25°C, 29°C, and 35°C, all of which maintained 75% relative humidity. Mango hoppers had a shorter survival duration at 35°C than at other temperatures.

Chemicals: Lambda cyhalothrin (98%), Imidacloprid (95%), and Acephate (99%) were purchased from Sigma Aldrich. Four synergists, namely Piperonyl butoxide (PBO) 98%, N-(Propargyloxy) phthalimide (PP) 99%, diethyl maleate (DEM) 99%, and S, S, S-tributyl phosphorotrithioate (DEF) 98% were purchased from Sigma Aldrich Chemicals Bangalore, Karnataka. The other chemicals were of analytical quality and purchased from commercial suppliers.

Bioassay: The determination of insecticide toxicity was done using the leaf-dipping method as outlined by Moores *et al.*, 1996. Stock solution of insecticides was meticulously prepared using acetone as the solvent. Subsequently, this was subjected to dilution, to a range of concentrations. By means of distilled water, with a little of 0.05% (v/v) Triton X-100 and 1% acetone. These meticulously prepared solutions were then employed for conducting bioassays with ensuring the utmost accuracy and precision in the procedures. In this study, we examined the effects of insecticide solutions on young mango leaves with diameter of 15 mm, which were carefully selected. The leaves dipped in the desired concentration for 5 seconds, after which they were positioned in a shaded area to undergo the natural process of air drying. Subsequently, the leaves were inverted and gently placed on small beakers filled with moist sand. This experimental setup aimed to investigate the potential impact of the insecticide treatments on subsequent behaviour and development of leaves. Bioassays were conducted in accordance with established protocols, wherein a total of 100 nymphs and adults were subjected to the insecticide-treated leaves as described above. To ensure the integrity of the experiment, a muslin cloth was meticulously fastened to the top of each beaker, effectively prevented the escape of any insects. In control conditions mango leaf hoppers was subjected to a treatment involving the application of distilled water containing 0.05% (v/v) Triton X-100 and 1% acetone. Each concentration was subjected to three replications, and the assessment of mortality was conducted after 24-hours interval. The LD_{50} values were determined through probit analysis utilizing the POLO-PC software, developed by LeOra Software Inc. in Berkeley, California. The bioassay method was performed on three separate occasions throughout the experimental period, specifically in March 2022, October 2022, and July 2023. The objective of these assessments was to investigate the varying levels of susceptibility and resistance exhibited by the mango leaf hopper across different seasons. In addition to the aforementioned details, it is noteworthy that the bioassay in question was meticulously carried out at three distinct temperatures, namely 25 °C, 22 °C, and 29 °C. The primary objective of this experimental endeavour was to comprehensively investigate the impact of insecticides on the post-treatment response in relation to temperature variations. Corrected mortality was computed by using Abbot's formula (Abbot, 1925).

Synergism bioassays: The evaluation of insecticide toxicity, both in the presence and absence of synergists PBO, DEM, PP and DEF, was conducted using the bioassay method as previously described. The non-toxic doses of each synergist were established according to the methodology outlined by Leong *et al.*, 2019. A minimum of five concentrations for each synergist, along with a control group treated with acetone-only, were employed in the study. The maximum sub lethal concentration utilized in our study was determined based on the dosage that resulted in no mortality within the mango hopper population. The adult mango leaf hoppers were subjected to an experimental setup wherein they were exposed to young, delicate mango leaves measuring 15 mm in diameter. These leaves were treated with a combination of PBO, DEM, PP, and DEF, thereby creating a conducive environment for the study. The mortality rate was assessed at 24-hours interval. The calculation of the synergistic ratio was performed utilizing the conventional methodology, which entails dividing the LD_{50} without the presence of a synergist by the LD_{50} with the inclusion of a synergist. Probit analysis was performed utilizing the POLO software, developed by LeOra Software Inc. based in Berkeley, California.

Statistical Analysis: Mortality was recorded after 24 hours of the treatment. Moribund insects were counted and considered dead if they failed to produce a coordinated movement on probe. Corrected percentage mortality was calculated using Abbot's formula (Abbot, 1925) and analysed by probit analysis using SPSS software. Median lethal dose were calculated and compared for their overlapped confidence limits. Values were said to be significantly different if there was overlapping in 95% confidence limits. The calculation of the synergistic ratio was performed utilizing the conventional methodology, which entails dividing the LD_{50} without the presence of a synergist by the LD_{50} with the inclusion of a synergist.

$$\text{Synergistic ratio} = \frac{\text{LD50 of insecticide}}{\text{LD50 of insecticide} + \text{Synergist}}$$

RESULTS

Bioassay: The result showing the response of the mix population of mango hopper collected from Bhubaneswar orchard, OUAT during three different months (March 2022, October 2022 and July 2023) of collection after 24 h of

Table 1. Effect of post exposure temperature on the efficacy of mango leaf hopper.

Month of observation	Insecticides	Temp °C)	n	LC_{50} (95 % FL) in ppm	Slope ± SE	χ^2
March, 2022	Lamda cyhalothrin	22 °C	200	1.715	2.183 ± 0.080	0.999
		25 °C	200	0.524	0.773 ± 0.226	0.982
		29 °C	200	1.618	2.200 ± 0.081	0.994
	Imidacloprid	22 °C	200	1.344	1.260 ± 0.142	0.986
		25 °C	200	0.797	0.767 ± 0.220	0.773
		29 °C	200	1.774	1.713 ± 0.106	0.995
	Acephate	22 °C	200	1.883	1.642 ± 0.109	0.998
		25 °C	200	0.890	1.421 ± 0.124	0.968
		29 °C	200	2.279	1.644 + 0.109	0.983
October, 2022	Lamda cyhalothrin	22 °C	200	1.558	1.167 ± 0.157	0.998
		25 °C	200	0.412	0.335 ± 0.508	0.920
		29 °C	200	1.307	1.644 ±0.109	0.934
	Imidacloprid	22 °C	200	1.187	1.054 ± 0.173	0.990
		25 °C	200	0.673	0.675 ± 0.260	0.993
		29 °C	200	1.398	3.172 ± 0.057	0.998
	Acephate	22 °C	200	1.716	1.087 ± 0.166	0.977
		25 °C	200	0.809	0.997 ± 0.185	0.997
		29 °C	200	2.361	1.479 ± 0.121	0.997
July, 2023	Lamda cyhalothrin	22 °C	200	1.594	1.785 ± 0.102	0.988
		25 °C	200	0.992	1.068 ± 0.162	0.998
		29 °C	200	1.233	1.010 ± 0.176	0.977
	Imidacloprid	22 °C	200	1.255	1.723 ± 0.105	0.997
		25 °C	200	0.795	1.017 ± 0.171	0.956
		29 °C	200	1.437	1.155 ± 0.155	0.998
	Acephate	22 °C	200	1.572	2.199 ± 0.084	0.987
		25 °C	200	0.682	0.994 ± 0.179	0.899
		29 °C	200	1.927	1.439 ± 0.124	0.993

treatment to selected test insecticides like lamda cyhalothrin, imidacloprid and acephate were presented under Table 1. In March 2022, each of the insecticides were tested in four different temperature regimes viz., 22 ºC, 25 ºC, 29 ºC and 35 ºC. At 35 ºC inside the B.O.D chamber we found all insects died within 6 h of insecticide treatments. In March 2022, the LD_{50} values of lambda cyhalothrin, imidacloprid, and acephate were assessed at various temperatures. At a temperature of 22 ºC, the LD_{50} values for lamda cyhaothrin, imidacloprid, and acephate were determined to be 1.715, 1.344, and 1.883 ppm, respectively. Likewise, the LD_{50} values for lamda cyhaothrin, imidacloprid, and acephate were determined to be 0.524, 0.797, and 0.890 ppm, respectively, at a temperature of 25 ºC. The LD_{50} values for lamda cyhaothrin, imidacloprid, and acephate were determined to be 1.618, 1.774, and 2.279 ppm, respectively, when exposed to a temperature of 29 ºC. In October 2022, the LD_{50} values of lambda cyhalothrin, imidacloprid, and acephate were assessed at various temperatures. At a temperature of 22 ºC, the LD_{50} values for lamda cyhaothrin, imidacloprid, and acephate were determined to be 1.558, 1.187, and 1.716 ppm, respectively. Likewise, at a temperature of 25 ºC, the LD_{50} values for the pesticides lamda cyhaothrin, imidacloprid, and acephate were determined to be 0.412, 0.673, and 0.809 ppm, respectively. The LD_{50} values for lamda cyhaothrin, imidacloprid, and acephate were determined to be 1.307, 1.398, and 2.361 ppm, respectively, at a temperature of 29 ºC. The LD_{50} values of lambda cyhalothrin, imidacloprid, and acephate were assessed at various temperatures throughout the month of July in the year 2023. At a temperature of 22 ºC, the LD_{50} values for lamda cyhaothrin, imidacloprid, and acephate were determined to be 1.594, 1.255, and 1.572 ppm, respectively. In a similar vein, the LD_{50} values for lamda cyhaothrin, imidacloprid, and acephate were determined to be 0.992, 0.795, and 0.682 ppm, respectively, at a temperature of 25 ºC. The LD_{50} values for lambda cyhalothrin, imidacloprid, and acephate were determined to be 1.233, 1.437, and 1.927 ppm, respectively, at a temperature of 29 ºC.

***Synergism assay*:** The result associated with synergism assay on resistant populations of mango leaf hopper to all the above-mentioned insecticides and their synergistic ratio are presented in Fig 1.

***Lamda cyhalothrin*:** In the conducted research investigating the phenomena of synergistic effects, a significant observation was recorded concerning the amalgamation of DEM and Lamda cyhalothrin at a temperature of 25°C. The results of the study indicate that the combination under investigation exhibited significantly higher synergistic ratios (8.18, 6.43, and 15.5) compared to the LD_{50} values of Lamda cyhalothrin used alone. The aforementioned findings were carefully recorded over the months of March 2022, October 2022, and July 2023. An in-depth investigation was

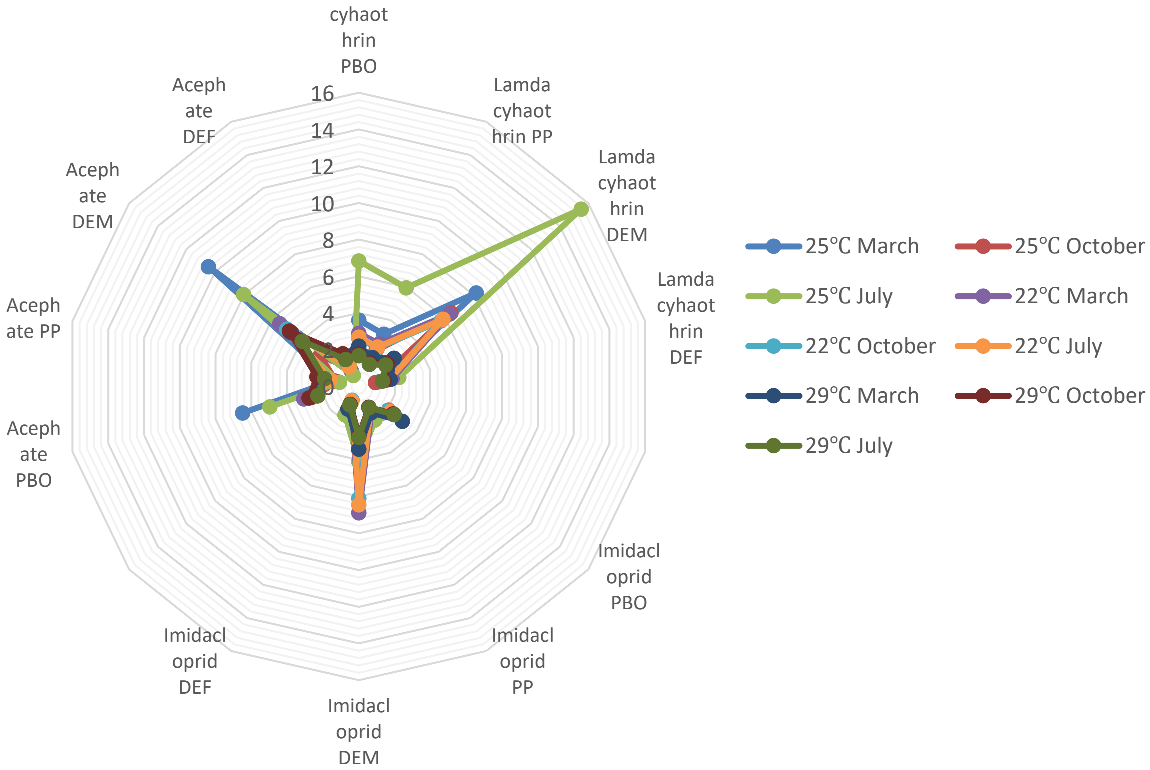

Figure 1. Synergistic ratio of insecticides and synergists in various temperatures regimes

conducted throughout the timeframes of March 2022, October 2022, and July 2023 to evaluate the possible synergistic outcomes arising from the amalgamation of DEM and Lamda cyhalothrin. The experiment was carried out at a temperature of 22 ºC. The study's results revealed that the synergistic ratios of DEM and Lamda cyhalothrin were very significant, with values of 6.32, 5.74, and 5.88, respectively. An experiment was conducted throughout the time periods of March 2022, October 2022, and July 2023 to assess the potential synergistic effects resulting from the simultaneous use of 29 ℃ DEM and lamda cyhalothrin. The experiment's results revealed that the combinations being examined demonstrated the highest levels of synergy, with respective ratios of 2.46, 1.99, and 1.87. The ratios given in this study were obtained by a rigorous research that involved a comparative evaluation of the LD_{50} values specifically related to lamda cyhalothrin. Based on the available data, it is apparent that the temperature of 25 ℃ exhibits the most favourable conditions for reaching the maximum level of synergistic action between lamda cyhalothrin and DEM, in contrast to the temperatures of 22 ℃ and 29 ℃.

Imidacloprid**:** In the study on imidacloprid, a significant observation was made about the temperature of 25 ℃. DEM had the highest synergistic ratio (4.10, 3.46, and 4.07 respectively) compared to imidacloprid LD_{50} values in solo. Results from March 2022, October 2022, and July 2023 are shown here. The DEM showed significant synergistic effects at 22 ℃, with high synergistic ratios of 6.89, 6.09, and 6.77. LD_{50} ratios of imidacloprid in isolation were carefully studied in March 2022, October 2022, and July 2023. Significant findings were found in the investigation on DEM compound performance at 29 ℃. In particular, the DEM compound's synergistic ratio exceeded imidacloprid's LD_{50} when taken alone. This suggests that the DEM component may improve imidacloprid efficacy at certain temperature conditions. March 2022, October 2022, and July 2023 had synergistic ratios of 3.42, 2.69, and 2.77. The present findings suggest that DEM may increase imidacloprid toxicity at different temperatures. Data suggests that imidacloprid has the highest SR value at 22 ℃, along with DEM.

Acephate**:** During the examination of the characteristics of acephate, a significant finding was made concerning the synergistic impacts demonstrated by DEM at a temperature of 25 ℃. The synergistic ratios, specifically 10.47, 2.69, and 8.02, were compared to the independent administration of acephate's LD_{50} values. The aforementioned findings were obtained throughout the months of March 2022, October 2022, and July 2023. At a temperature of 22 ℃, the combination of DEM exhibited significant synergistic effects, as indicated by the highest recorded synergistic ratios (5.49, 5.00, and 4.58) in comparison to the LD_{50} values of acephate administered alone. The data presented above demonstrated continuous patterns across the time period encompassing March 2022, October 2022, and July 2023. In the investigation that was conducted, a significant observation was discovered pertaining to the temperature of 29 ℃. The study revealed that the combination of DEM had significant synergistic effects, as evidenced by the computed synergistic ratios of 4.67, 4.84, and 3.95, respectively. The significant aspect of these findings is in their consistent observation across three unique time points: March 2022, October 2022, and July 2023. Based on the data provided, it can be deduced that acephate exhibited the highest SR value when exposed to a temperature of 25 ℃, in conjunction with DEM.

This figure displays all the synergistic ratio (SR) of insecticides and synergists from the centre towards the periphery. This experiment was conducted in three different months (March 2022, October 2022 and July 2023) in three different temperatures (22 ℃, 25 ℃ and 29 ℃). This figure depicts the SR as the extension of dots and straight line. For example, in the month of October 2022, the highest SR was observed against the combination of Lamda cyhalothrin with DEM. The SR value recorded was 15.5, where the grey colour line is indicating.

DISCUSSION

In the analysis of the present research, it was observed that among the various temperature conditions, a temperature of 25℃ exhibited the lowest LD_{50} values for lamda cyhalothrin, while a temperature of 22℃ yielded the highest LD_{50} values. Based on the data, it can be inferred that elevated temperatures enhance the efficacy of lamda cyhaothrin in controlling mango leaf hoppers. Conversely, lower temperatures diminish the effectiveness of the insecticides against the aforementioned pest which is the character of α cyanopyrethroids. Our findings are consistent with the results reported by Bandow *et al.*, 2014, indicating that elevated temperature (26 ℃) is associated with increased toxicity of *Folsomia candida*, a species of Collembola. In our findings indicate that lamda cyhalothrin exhibits optimal efficacy when used in conjunction with the synergist DEM. The observed trend indicates a decrease in the synergist ratio value from DEM to PBO. Notably, DEF exhibits the lowest synergistic ratio across various temperatures and months. The observed higher toxicity could potentially be attributed to the structural compatibility between lamda cyhalothrin and DEM and lambda cyhalothrin exhibited the highest synergistic ratio with PBO, followed by TPP and DEM in relation to *Spodoptera frugiperda*. Moreover, DEM is more active where glutathione-s-transferase is the principal enzyme for metabolism. This discrepancy may be attributed to the fact that we opted to utilize the mango hopper as our experimental insect specimen, while they chose the fall army worm as their experimental insect specimen. The study conducted by Morales and Romero (2019) demonstrates the remarkable synergistic efficacy of PBO and DEM in combination with synthetic pyrethroid insecticides against homopteran insects.

In the case of imidacloprid, it was observed that the LD_{50} values, which serve as indicators of toxicity, were lowest at a temperature of 25°C, suggesting the highest level of toxicity. Conversely, the highest LD_{50} values, indicating the lowest level of toxicity, were observed at a temperature of 29°C across various moth species. Based on the available evidence, it can be deduced that the efficacy of the detoxifying enzymes in the mango hopper is diminished under elevated temperatures. This observation is consistent with the discovery made by Bandeira *et al.* (2020), wherein they proposed that elevated temperatures resulted in reduced variability in imidacloprid toxicity towards Earthworms *Eisenia andrei* and collembolans *Folsomia candida* in different soils. This implies that the impact of soil properties on imidacloprid toxicity was less significant compared to the influence of temperature. In the investigation of the synergistic effects of Imidacloprid in combination with PBO, PP, DEM, and DEF, it was observed that the synergist DEM exhibited the greatest synergistic ratio, with PBO ranking second across various temperatures and months. The experimental results indicated that DEF exhibited the most minimal synergistic ratio. Our findings are inconsistent with the findings of Zewen *et al.*, 2003, who observed no synergistic effects of TPP and DEM on the efficacy of Imidacloprid against a specific population of brown planthoppers (*Nilaparvata lugens* Stål) in a field setting. The contradiction observed in this study can be primarily attributed to the contrasting characteristics of the strains investigated. Zewan *et al.* (2003) examined a resistant strain, whereas our study focused on a susceptible strain. Based on the study conducted by Wang *et al.* (2018) it was observed that the presence of piperonyl butoxide (PBO), an inhibitor of the P_{450}-monooxygenase oxidative metabolic system, exhibited a noteworthy synergistic effect on the toxicity of imidacloprid against *Rhopalosiphum padi*. These findings align with our own research outcomes. The present study's findings were substantiated by the research conducted by X. Qie *et al.*, 2020. In their investigation, the authors utilized a combination of PBO, TPP, and DEM as synergistic compounds and determined that PBO and DEM exhibited notable efficacy as synergists in regulating the population of *Mythimna separata*.

The present study investigates the effects of temperature on the toxicity of acephate, an insecticide commonly used in agricultural practices. The LD_{50} values, which represent the lethal dose required to cause mortality in 50% of the test subjects, were examined at various temperatures over a period of several months. The results of this study indicate that the LD50 values of acephate exhibit a temperature-dependent pattern. Specifically, at a temperature of 25°C, the insecticide demonstrated the lowest LD_{50} values, suggesting a higher toxicity level. Conversely, at a temperature of 29°C, the insecticide exhibited the highest LD_{50} values, indicating a lower toxicity level. These findings highlight the significance of temperature in influencing the toxicity of acephate. Further investigations are warranted to elucidate the underlying mechanisms responsible for this temperature-dependent effect. Such knowledge would contribute to the development of more effective strategies for the application and regulation of acephate in pest management practices. Based on the extant body of evidence, it can be inferred that elevated temperatures induce rapid degradation of acephate insecticide, thereby leading to a subsequent reduction in its toxicity. The present study provides further support for the observations made by Meena *et al.* (2021), wherein they demonstrated the superior efficacy of Acephate 75 SP within the temperature range of 25°C to 28°C. In the realm of synergistic interactions, acephate has demonstrated a similar trajectory to that of imidacloprid. In this study, we investigated the synergistic effects of two insecticides, DEM and PBO, on the efficacy of acephate against the mango hopper. Our experiments were conducted under varying temperature conditions and across different months. The results revealed that DEM and PBO exhibited the highest synergistic ratio when combined with acephate, indicating enhanced effectiveness in controlling the mango hopper. These findings highlight the importance of considering temperature variations and seasonal fluctuations when designing pest management strategies for mango crops. The findings presented in this study are consistent with the observations made by Venkatesan *et al.* (2017), wherein they documented a noteworthy augmentation in the synergistic ratio of acephate in combination with PBO and DEM against nine distinct populations of *Chrysoperla zastrowi sillemi* (Esben-Petersen), a crucial predator of sap-sucking insects found in India.

Conclusion**:** In the pursuit of effective pest management strategies for mango cultivation, this study has unveiled valuable insights into the temperature-dependent dynamics of insecticide efficacy and the potential for synergistic interactions to enhance pest control. The experiments conducted across varying temperature ranges have demonstrated that the toxicity of lambda cyhalothrin, imidacloprid, and acephate against the mango leaf hopper is significantly influenced by temperature fluctuations. The observed temperature-dependent variations in the LD_{50} values highlight the need for nuanced approaches to insecticide application based on the prevailing climatic conditions. The susceptibility of the mango leaf hopper to these insecticides exhibited distinct trends across different temperature intervals and time points. These findings underscore the significance of incorporating temperature considerations into pest management decisions, ensuring optimal effectiveness while minimizing the risk of resistance development. Furthermore, the exploration of synergistic interactions has shed light on the potential of combining insecticides with synergists like DEM to enhance their toxic effects. The consistent patterns of synergistic ratios observed across temperature ranges emphasize the relevance of synergists in augmenting insecticide potency. These insights contribute to the development of more sustainable and efficient pest control strategies, aligning with the principles of integrated pest management. In conclusion, this study serves as a pivotal step towards a more holistic understanding of the intricate interplay between temperature, insecticide efficacy, and synergistic effects in mango leaf hopper management. By recognizing the multifaceted nature of pest control, we can refine strategies that account for the dynamic environmental factors influencing pest behaviour, ultimately promoting more resilient and productive mango cultivation practices.

***Conflict of Interest*:** The Authors declare that there is no conflict of interest.

***Author's contributions*:** S.S. Dash and M.K. Tripathy conceived the study, designed the study, and helped to draft the manuscript. S. S. Dash, S. K Das and P. Behera performed the bioassay and drafted the manuscript. S.S. Dash and S.K. Das performed the statistical analysis and translated the manuscript. All authors read and approved the final manuscript.

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REFERENCES

Abbas, N., Samiullah, S. Shad, M. Aslam, M. Razaq and A. Waheed. 2014. Resistance of *Spodoptera litura* (Lepidoptera: Noctuidae) to profenofos: Relative fitness & cross resistance. Crop Protection 58:49-54.

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18:265-267.

Bandeira, F.O., P.R.L. Alves, T.B. Hennig, T. Toniolo, T. Natal-da-Luz and D. Baretta. 2020. Effect of temperature on the toxicity of imidacloprid to Eisenia andrei and Folsomia candida in tropical soils. Environmental Pollution 267:115565.

Bandow, C., A. Coors, N. Karau and J. Römbke. 2014. Interactive effects of lambda-cyhalothrin, soil moisture, and temperature on *Folsomia candida* and *Sinella curviseta* (Collembola). Environmental toxicology and chemistry 33:654-661.

Cheema, H.K. 2013. Evaluation of insecticide resistance profile in *Spodoptera litura* (Fabricius) populations through biological, biochemical & molecular diagnosis. Ph.D. dissertation. Punjab Agricultural University, Ludhiana, India.

Dhaliwal, G.S. and R. Singh. 2004. Host plant resistance to insects: concepts and applications, Panima Publishing Corporation, New Delhi. pp. 369.

Gonzalez-Morales, M.A. and Romero, A. 2019. Effect of synergists on deltamethrin resistance in the common bed bug (Hemiptera: Cimicidae). Journal of Economic Entomology 112:786-791.

Kaur, P. and B.K. Kang. 2015. Effect of selected synergists on insecticidal toxicity of deltamethrin and biochemical mechanisms on the field populations of tobacco caterpillar from Punjab, India. Phytoparasitica 43:565-575.

Kaushik, D.K., S. Sharma, D. Sharma, U. Baraiha. 2014. Efficacy of insecticides against hopper complex on langra mango in Chhattisgarh. Pesticide Research Journal 26:6-11.

Kranthi, K.R., D.R. Jadhav, S. Kranthi, R.R. Wanjari, S.S. Ali and D.A. Russel. 2002. Insecticide resistance in five major insect pests of cotton in India. Crop Protection 21: 449-460.

Leong, C.S., I. Vythilingam, J.W.K. Liew, M.L. Wong, W.S. Wan-Yusoff and Y.L. Lau. 2019. Enzymatic and molecular characterization of insecticide resistance mechanisms in field populations of *Aedes aegypti* from Selangor, Malaysia. Parasites & Vectors 12:1-17.

Meena, K.R., S.K. Khinchi, K.C. Kumawat, A. Hussain and A. Sharma. 2021. Bioefficacy of insecticides against major sucking insect pests of brinjal (*Solanum melongena* L.).

Patil, S.K. 2012. Assessment of insecticide resistance in Spodoptera litura (Fabricius) in Western Maharashtra. PhD thesis. Mahatma Phule Krishi Vidhyapeeth, Rahuri, India. pp. 248

Prabhakara M.S., S.K. Ghosh and M. Chaudhary. 2011. Field efficacy of Myco-jaal, an oil based commercial formulation of *Beauveria bassiana* (Deuteromycotina: Hyphomycetaceae) against mango inflorescence hopper, *Idioscopus nitidulus* (Walker). Pest Management in Horticulture Ecosystem 17:140-143.

Prabhaker, N., D.L. Coudrit and N.C. Toscano. 1988. Effects of synergists on organophosphate and permethrin resistance in sweet potato whitefly (Homoptera: Aleyrididae). Journal of Economic Entomology 81:34-39.

Qie, X., W. Lu, A.A. Aioub, Y. Li, W. Wu and Z. Hu. 2020. Insight into the detoxification of haedoxanA and the synergistic effects of phrymarolin I against *Mythimna separata*. Industrial Crops and Products 158:112967.

Rahman S.K. and M.A. Kuldeep. 2007. Mango hoppers: Bioecology and management. A Review. Agriculture Reviews 28:49-55.

Saleem, M., D. Hussain, G. Ghouse, M. Abbas and S.W. Fisher. 2016. Monitoring of insecticide resistance in *Spodoptera litura* (Lepidoptera: Noctuidae) from four districts of Punjab, Pakistan to conventional & new chemistry insecticides. Crop Protection 79: 177-184.

Thangam, S.D., A. Verghese, M.R. Dinesh, C. Vasugi and P.D. Jayanthi. 2013. Germplasm evaluation of mango for preference of the mango hopper, *Idioscopus nitidulus* (Walker) (Hemiptera: Cicadellidae): The first step in understanding the host plant resistance. Pest Management in Horticultural Ecosystems 19:10-16.

Venkatesan, T., S.H. Mahiba, S.K. Jalali, S.L. Ramya and M. Prathibha. 2017. Detection of insecticide resistance and mechanisms of resistance in field populations of *Chrysoperla zastrowi sillemi* (Neuroptera: Chrysopidae) collected from different geographical locations in India. Journal of Biological Control 159-167.

Verghese, A. 1999. Effect of imidacloprid, lambda cyhalothrin and azadirachtin on the mango hopper, *Idioscopus niveosparsus* (Leth.) (Homoptera: Cicadellidae). In VI International Symposium on Mango 509:733-736.

Wang, K., M. Zhang, Y. Huang, Z. Yang, S. Su and M. Chen. 2018. Characterisation of imidacloprid resistance in the bird cherry-oat aphid, *Rhopalosiphum padi*, a serious pest on wheat crops. Pest management science 74:1457-1465.

Zewen, L., H. Zhaojun, W. Yinchang, Z. Lingchun, Z. Hongwei and L. Chengjun. 2003. Selection for imidacloprid resistance in *Nilaparvata lugens*: cross-resistance patterns and possible mechanisms. Pest Management Science: formerly Pesticide Science 59:1355-1359.