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Resistance profiling of *Phthorimaea absoluta* (Meyrick) from tomato fields of Belagavi, Karnataka

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ABSTRACT: South American tomato pinworm, *Phthorimaea absoluta* (Meyrick), poses a major threat to tomato production in India, with insecticide resistance becoming a key challenge for its effective management. The present study assessed the resistance status of *P. absoluta* and surveyed insecticide use patterns in tomato fields of Belagavi district, Karnataka. Field populations were collected and leaf dip bioassays were conducted using eight insecticides. Probit analysis revealed moderate resistance to chlorantraniliprole, with an LC_{50} of 60.631 ppm and a resistance ratio of 19.24 fold compared to the susceptible strain. While, lambda-cyhalothrin (LC_{50}: 56.294 ppm; RR: 7.36), profenofos (LC_{50}: 1350.221 ppm; RR: 7.35) and emamectin benzoate (LC_{50}: 46.821 ppm; RR: 6.83) showed low levels of resistance. However, cyantraniliprole (LC_{50}: 39.987 ppm; RR: 6.65), flubendiamide (LC_{50}: 32.378 ppm; RR: 4.96), spinosad (LC_{50}: 27.107 ppm; RR: 5.44) and indoxacarb (LC_{50}: 20.609 ppm; RR: 3.45) exhibited reduced susceptibility. However, wider LC_{50} – LC_{90} gaps indicated population heterogeneity and possible resistance build-up. The insecticide usage survey revealed indiscriminate use of chlorantraniliprole, adding selection pressure and cross resistance due to possible detoxifying enzymes activity.

Keywords: South American pin worm, field population, bioassay, insecticide resistance and spraying pattern

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is an economically important vegetable crop cultivated extensively across India for its nutritional value and market demand. With an annual production exceeding 20 million metric tons from more than 841,000 hectares, India ranks second in global tomato production (Anonymous, 2024). However, the productivity and profitability of tomato cultivation have come under significant threat due to the rapid spread of the South American tomato pinworm, *Phthorimaea* (*Tuta) absoluta* (Meyrick) (Lepidoptera: Gelechiidae).

Originally described from Peru in 1917, *P. absoluta* has emerged as one of the most invasive and damaging pests of tomato crops worldwide (Omandi, 2015). Its remarkable dispersal ability has facilitated its spread across Europe, North and East Africa, the Middle East and Asia since the early 2000s (Campos, 2017). The pest was first reported in India in 2014 at the Indian Institute of Horticultural Research, Bengaluru, Karnataka (Sridhar *et al.,* 2014) and has since rapidly expanded its presence to most major tomato-growing regions in the country. Several biological and behavioural traits make *P. absoluta* exceptionally difficult to manage. Its high reproductive capacity, concealed larval feeding habits, ability to infest all aerial parts of the tomato plant and oligophagous nature allow it to escape control measures and cause severe damage throughout the crop cycle (Ferracini *et al.*, 2012). Infestations can result in yield losses as high as 80–100 per cent under both greenhouse and open-field conditions, leading to significant economic losses for growers (Desneux *et al.*, 2010).

The predominant management approach for *P. absoluta* relies heavily on chemical insecticides. However, repeated and indiscriminate applications, often with limited awareness of integrated pest management (IPM) principles, have led to widespread resistance development and reduced control efficiency (Galdino *et al.*, 2011). Early evidence of insecticide resistance was reported in South America, where field populations showed reduced susceptibility to organophosphates and pyrethroids (Lietti *et al.*, 2005). Since then, resistance to multiple chemical classes, including diamides, oxadiazines and spinosyns, has been documented in several countries (Reyes *et al.*, 2011; Campos *et al.*, 2015; Melis *et al.*, 2015; Silva *et al.*, 2016; Roditakis *et al.*, 2018; Taleh *et al.*, 2021; Zhang *et al.*, 2022). In India, recent field-level observations and laboratory studies have confirmed resistance development against commonly used insecticides, with farmers frequently experiencing unexplained field failures despite repeated applications (Prasannakumar *et al.*, 2020).

However, regular monitoring of resistance through laboratory bioassays and probit analysis remains essential to quantify current susceptibility levels and detect changes over time. Bioassays provide reliable estimates of lethal concentrations and enable comparison with known susceptible baselines (Karuppaiah *et al.*, 2017), forming a scientific basis for selecting effective insecticides and designing rotation schedules. Understanding the local patterns of insecticide application is also crucial for analysing the influence of selection pressures on the development of resistance in *P. absoluta* populations. Documenting these application practices helps identify areas where misuse may be contributing to resistance, guiding recommendations for more judicious insecticide use. Together, insights into resistance levels and insecticide application patterns offer critical baseline information for developing robust, region-specific insecticide resistance management (IRM) strategies that can sustain the productivity and profitability of tomato cultivation. In this context, the present study was undertaken to assess the resistance status of *P. absoluta* and document insecticide use practices in tomato fields of Belagavi district, Karnataka, India to support informed decision making and promote sustainable pest management in the region.

MATERIALS AND METHODS

Field collection and rearing of *P. absoluta* population

The *P. absoluta* populations used in this study were sourced from tomato fields of Tigadi village (15.806˚ N, 74.722˚ E) from Belagavi district of Karnataka state during September 2023. Independent samples of leaves and fruits of tomatoes with *P. absoluta* larvae were collected. Approximately 1000 to 1200 larvae from five different tomato fields spanning 10 km^2 were collected and brought to the Toxicology laboratory, Department of Entomology, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka India. Larvae collected from field were reared separately in rearing cages with insect free tomato plants under controlled laboratory conditions (25 ± 2 °C, 75 ± 5% relative humidity and 12 h of light and 12 h of darkness photoperiod) up to adults. After adult emergence, 10 per cent honey solution with Vit E was provided for enhancement of reproduction efficiency and fresh tomato plant parts were provided for oviposition. Here, second instar larvae from the F_1 progeny were selected and employed for the bioassays to evaluate their response to insecticidal treatments.

The susceptible (SUS) *P. absoluta* population was developed using the larval population collected from unsprayed tomato fields from Belagavi district, Karnataka, India, during August 2023. The population was separately maintained in a controlled laboratory room following the steps and conditions described above without exposure to any insecticides up to 25 generations.

Survey for spraying pattern

A field survey was conducted alongside the collection of *P. absoluta* populations in Belagavi district during the 2023 cropping season. Farmers were asked about the

Table 1. Details of insecticides used in this study

Tr. No.	Treatment details	IRAC Groups	Trade Name	Manufacturers
T_1	Chlorantraniliprole 18.5 SC	28 / Diamide	Coragen	Du-Pont India, Ltd., Gurgaon, Haryana.
T_2	Cyantraniliprole 10.25 SC	28 / Diamide	Benallia	Du-Pont India, Ltd., Gurgaon, Haryana.
T_3	Flubendiamide 480 SC	28 / Diamide	Fame	Bayer Crop Science Ltd., Thane, Maharashtra
T_4	Indoxacarb 14.5 SC	22A / Oxadiazine	Advaunt	Kalyani Industries, Mumbai, Maharashtra.
T_5	Emamectin benzoate 5 SG	6 / Avermectins	Proclaim	Syngenta India Pvt. Ltd., Pune, Maharashtra.
T_6	Lambda-cyhalothrin 5 EC	3A / Synthetic Pyrethroid	Karate	Syngenta India Pvt. Ltd., Pune, Maharashtra.
T_7	Spinosad 45 SC	5 / Spinosyns	Badge	UPL Limited, Bengaluru, Karnataka.
T_8	Profenofos 50 EC	1B / Organophosphate	Curacron	Syngenta India Pvt. Ltd., Pune, Maharashtra
T_9	Control	-	-	

types of insecticides used and the total number of sprays applied during the tomato crop cycle. This information was used to assess spraying trends and possible selection pressure on local populations.

Bioassay

Bioassay was carried out using eight selected insecticides as furnished in Table 1., which are recommended for *P. absoluta* management and frequently used by tomato growers. Procedure of IRAC test method No. 022 was employed for bioassay to assess the level of toxicity to *P. absoluta* using leaf dip method. Prior to the finalization of five concentrations of each insecticide (in double distilled water) for bioassay, pilot study was made independently for each insecticide (commercial grade formulations) limiting mortality >20 to <80 per cent. Pest and disease free tomato seedlings were raised in the Department of Entomology, College of Agriculture, UAS, Dharwad. Uniform sized 30 days old seedlings leaves were dipped in different concentrations of insecticide solution separately, air dried and placed individually in labeled petri dishes lined with a wetted cotton layer and filter paper. Here, thirty second instar larvae were used for different concentration of each insecticide separately and replicated four times to assess the mortality at 24 h to 72 h. Moribund larvae despite co-ordinated prodding were considered as dead. Similarly a control was placed for every set of bioassay by dipping the leaf in double distilled water.

Statistical analysis

Mortality obtained from leaf dip bioassay was corrected using Abbott's formula (Abbott, 1925). The LC_{50} values were calculated by Probit analysis using Polo Plus 2.0 LeOra software (LeOra Software LLC, Parma, USA). Resistance ratios (RRs) were calculated by dividing the LC_{50} value of respective insecticide and LC_{50} value of the susceptible strain of *P. absoluta*. According to the RR value obtained, the tested insect populations were categorized as susceptible (<3.0), decreased susceptible (3.1–5.0), low resistance (5.1–10.0), moderate resistance (10.1–40.0), high resistance (40.1–160.0) and very high resistance (>160.0) (Jin *et al.,* 2016).

RESULTS AND DISCUSSION

Insecticides spraying pattern for management of *P. absoluta* in Belgavi location fields is given in Table 2. Use of chlorantraniliprole as single molecule and in combination with others was found to be highest in surveyed area. Furthermore, synthetic pyrethroids also having higher usage across area. However, 8 to 12 insecticidal sprays were operated during complete season of tomato cycle.

Relative toxicity results (Table 3.) revealed that Belgavi location field populations showed decreased susceptibility towards all the eight insecticides. Field populations showed highest resistance for chlorantraniliprole with LC_{50} value 60.631 ppm as compared to 3.152 ppm value for susceptible population with 19.24-fold resistance (Fig. 1). Next in line, lambda-cyhalothrin followed by profenofos showed 56.294 ppm and 1350.221 ppm LC_{50} values, respectively for field population with 7.36 and 7.35-fold resistance ratio, respectively. Lowest resistance development was showcased in indoxacarb treated field collected insects with 3.45-fold resistance ratio trailed by spinosad (RR 5.44-fold) with LC_{50} 27.107 ppm. Among remaining insecticides, decreasing resistance order was observed as emamectin benzoate (LC_{50} 46.821 ppm) > cyantraniliprole (LC_{50} 39.987 ppm) > flubendiamide (LC_{50} 33.378 ppm) with resistance ratio 6.83-fold, 6.65-fold and 4.96-fond,

Table 2. Usage pattern of insecticides for management of *P. absoluta* in Belgavi, Karnataka

S. No.	Technical Name	Recommended dose (ml/L)	Farmers applied dose (ml/L)	No. of sprays / season
1	Chlorantraniliprole 18.5 SC	0.30	0.50	2-3
2	Chlorantraniliprole 8.8% + Thiamethoxam 17.5% SC	0.20	0.50	1
3	Imidacloprid 17.8 5 SL	0.30	0.50	1-2
4	Chlorantraniliprole 10% + Lambda-cyhalothrin 5% ZC	0.40	0.50	2-3
5	Fipronil 40% + Imidacloprid 40% WG	0.30	0.50	1
6	Unknown	-	5.00	1-2

respectively. Overall, the goodness-of-fit χ^2 statistics for all tested populations were consistently lower than the tabulated critical values, indicating an adequate probit model fit and strengthening the confidence in the derived toxicity estimates. Additionally, the substantial disparities in LC_{50} and LC_{90} metrics across different field populations highlight the likely coexistence of resistant individuals within these groups, reaffirming the heterogeneous nature of resistance development.

Assessment of field-evolved resistance indicated the development of moderate resistance in the population for chlorantraniliprole, whereas lambda-cyhalothrin, profenofos, and emamectin benzoate showed low levels of resistance, and the remaining insecticides exhibited reduced susceptibility. The frequent and repeated use of chlorantraniliprole without proper rotation with insecticides of different modes of action appears to have exerted strong selection pressure on *P. absoluta* populations. This is consistent with the findings of Silva *et al.,* (2019), who demonstrated that continuous selection of a susceptible *P. absoluta* population with chlorantraniliprole for over 15 generations resulted in a resistance increase of 10,76,955-fold compared with the initial level, clearly showing how selection pressure can accelerate resistance development. In addition, the role of detoxification enzymes cannot be overlooked, as these enzymes are not specific to a single insecticide group but act on structural similarities among molecules, thereby increasing the chances of cross-resistance. Future studies are needed to quantify the contribution of detoxifying enzymes in elevating resistance levels.

However, there is no any resistance level assessment study previously on *P. absoluta* from Belagavi location of Karnataka. Hence, present study results are compared with other field locations from South India. Mohan *et al.* (2025) revealed that Coimbatore (Tamil Nadu) and Kolar (Karnataka) showed LC_{50} values as 28.38 ppm and 45.66 ppm, respectively for flubendiamide. Whereas, chlorantraniliprole showed 61.73 ppm and 66.50 ppm LC_{50} values for Bengaluru and Kolar location field population, respectively. Similarly, Coimbatore and Dharmapuri from Tamil Nadu showed LC_{50} value as 27.87 ppm and 33.82 ppm, respectively. These results are very closely aligned with present study showing similar trend in resistance development. Prasannakumar *et al.* (2021) conducted bioassay to assess resistance levels from 6 locations of South India and found that Anantapur field location from Andhra Pradesh showed LC_{50} values as 33.216 ppm for indoxacarb, 32.343 ppm for flubendiamide, 29.270 ppm for emamectin benzoate and 29.495 ppm for cyantraniliprole, which were highest among all locations. However, other locations showcased low resistance level indicating less selection pressure. Certainly, few studies exhibited very less resistance among

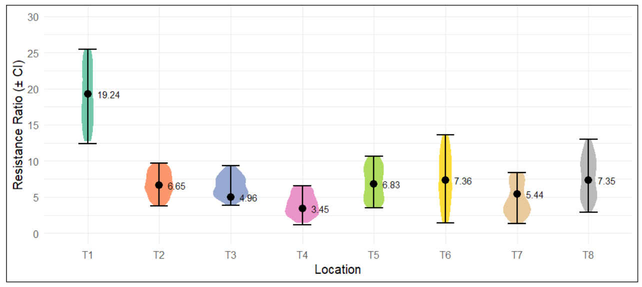

Fig. 1. Resistance ratios for different insecticides in field collected *P. absoluta* population

South Indian field population denoting the correct spraying pattern and negligible selection pressure. Study conducted in 2017-18 from 5 field collected *P. absoluta* population from Tamilnadu state emphasized less than 2-fold resistance for Chlorantraniliprole, Chlorpyriphos, Flubendiamide, Imidacloprid, Indoxacarb and Spinosad (Kumar *et al.*, 2020). Pavithra *et al.* (2024) unveiled that field collected *P. absoluta* population from 10 south Indian locations exhibited less than 5-fold resistance ratio for chlorantraniliprole, cyantraniliprole, spinosad, indoxacarb, flubendiamide, acetamiprid and imidacloprid.

Apart from India, worldwide researches also accentuated the escalation of insecticide resistance in *P. absoluta*. In Chile, field-collected populations of *P. absoluta* exhibited reduced susceptibility to spinosad, showing significantly lower mortality than the susceptible strain (Reyes *et al.,* 2011).

Between 2010 and 2011, Brazilian populations demonstrated resistance levels of 8- to 93-fold for spinosad and 1.5- to 7-fold for spinetoram (Campos *et al.,* 2015). In Greece, field populations showed 2- to 14-fold resistance to chlorantraniliprole and 2- to 11-fold resistance to flubendiamide and indoxacarb (Roditakis *et al.,* 2012; Roditakis *et al.,* 2015). Brazilian, Spanish, and Italian populations also reported low levels of resistance to diamide insecticides (Roditakis *et al.,* 2013). A study from Turkey revealed that the *P. absoluta* population from Aydın had higher resistance to indoxacarb, metaflumizone,

Table 3. Relative toxicity of different insecticides on *P. absoluta*

S. No.	Location	LC_{50} (ppm)	Fiducial limits (95 %)		LC_{90} (ppm)	Fiducial limits (95 %)		Slope function (± SD)	Chi-square (df:13)	Ht	RR
			Lower	Upper		Lower	Upper				
A.) Susceptible strain											
1	Chlorantraniliprole 18.5 SC	3.152	1.398	5.964	16.446	13.261	20.338	2.884 ± 0.344	3.265	1.011	-
2	Cyantraniliprole 10.25 SC	6.015	4.087	8.625	20.232	17.212	23.648	2.999 ± 0.242	3.827	0.294	-
3	Flubendiamide 480 SC	6.502	5.615	8.340	26.645	20.259	40.275	3.194 ± 0.271	12.891	0.992	-
4	Indoxacarb 14.5 SC	5.980	4.226	4.226	25.127	20.687	31.364	2.325 ± 0.277	7.319	0.746	-
5	Emamectin benzoate 5 SG	6.851	5.577	8.175	24.433	18.723	36.790	2.310 ± 0.298	9.573	0.736	-
6	Lambda-cyhalothrin 5 EC	7.650	6.396	9.862	33.126	25.129	49.437	3.199 ± 0.248	6.215	0.342	-
7	Spinosad 45 SC	4.981	4.620	6.839	21.002	15.684	31.768	3.250 ± 0.281	4.126	0.317	-
8	Profenofos 50 EC	183.800	153.593	211.885	451.611	369.985	541.978	4.282 ± 0.480	12.335	0.449	-
B.) Belagavi field population											
1	Chlorantraniliprole 18.5 SC	60.631	41.123	74.507	357.662	243.407	678.772	1.543 ± 0.482	8.647	0.906	19.24
2	Cyantraniliprole 10.25 SC	39.987	32.691	47.179	112.800	88.301	170.058	2.145 ± 0.371	14.504	1.116	6.65
3	Flubendiamide 480 SC	32.378	25.457	41.651	196.521	134.472	246.087	1.468 ± 0.214	7.468	0.688	4.96
4	Indoxacarb 14.5 SC	20.609	13.768	27.824	112.079	91.805	140.306	1.717 ± 0.196	4.240	0.326	3.45
5	Emamectin benzoate 5 SG	46.821	36.192	58.729	211.925	181.487	365.488	1.714 ± 0.223	5.549	0.427	6.83
6	Lambda-cyhalothrin 5 EC	56.294	46.448	66.202	164.687	133.431	222.370	2.749 ± 0.323	10.298	0.792	7.36
7	Spinosad 45 SC	27.107	21.600	32.341	90.583	78.482	129.331	2.151 ± 0.294	5.240	0.403	5.44
8	Profenofos 50 EC	1350.22	1252.49	1617.99	2456.89	2580.58	3675.83	3.847 ± 0.690	8.977	0.921	7.35

Note: ppm- Parts per million, SD- Standard deviation, df- Degrees of freedom, Ht- Heterogeneity, RR- Resistance ratio
RR- LC_{50} of field population / LC_{50} of susceptible population

spinosad, and chlorantraniliprole compared to the Urla population (Yalcin *et al.,* 2015). In Kuwait, resistance to flubendiamide and chlorantraniliprole initially appeared at 3- and 4-fold levels, which later increased to 750- and 860-fold after 34 generations of selection (Jallow *et al.,* 2019). Likewise, a field-collected and laboratory-selected population in Pakistan exhibited high resistance to flubendiamide, with resistance ratios between 38- and 550-fold, while LC_{50} values for chlorantraniliprole, thiamethoxam, permethrin, abamectin, and tebufenozide were higher than those of the susceptible strain (Zhang *et al.,* 2022).

The overall findings of this study are in line with earlier reports worldwide, where increased resistance in *P. absoluta* has been attributed to elevated detoxification enzyme activity. Several studies have shown that metabolic enzymes like esterases, monooxygenases and glutathione S-transferases play a key role in resistance development. This indicates that the resistance levels observed here may similarly be linked to such enzyme-mediated mechanisms, as supported by previous research.

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