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Persisting Resistance of *Helicoverpa armigera* (Lepidoptera: Noctuidae) to Pyrethroid, Organophosphate and Carbamate Insecticides

Honnakerappa S. Ballari[1] and Shashikant S. Udikeri[2]*

[1]*Department of Agricultural Entomology, College of Agriculture, Dharwad 580005, Karnataka, India.*

[2]*Agricultural Research Station, Dharwad Farm, Dharwad 580007, Karnataka, India.*

ABSTRACT

Insecticide resistance in polyphagous pest *Helicoverpa armigera* is important in any agroecosystem. The resistance to classical insecticides *viz*., synthetic pyrethroids, organophosphates and carbamates was global issue in early nineties. Hence many new generation pesticides are in use widely. To know the status of different insecticides belonging pyrethroid, ogranophaopsahte and carbamate molecules monitoring was exercised using populations of *H. armigera* collected from different agroclimatic situations in Karnataka state, India. An abstinent to tremendous resistance was documented for synthetic pyrethroids, carbamates and organphosphates insecticide despite under use of these molecules over decades. Raichur populations comprehend high level of resistance to Pyrethroids with LC_{50} 121.63 ppm to cypermenthrin which indicated 23.21fold of resistance with respect to a laboratory susceptible strain. Similarly, there was 24.95 folds of resistance to deltamethrin in same population with LC_{50} 128.47 ppm. Among organophosphates a high level of resistance was recorded against monochrotophos with LC_{50} 160.94 ppm and 18.23 resistance ratio in Rachur population itself. The same population exhibited 9.24 resistance ratio towards thiodicarb a carbamate insecticide. Kalaburagi population indicated resistance close to Raichur population against all insecticides both being high selection pressures areas. On the contrary resistance to each insecticide tested was low in Vijayapur population, a low rainfall area. The cross resistance was significant amongst similar groups and negative in a selective pattern. Quinolphos, lambda cyhalothrin and profenphos with high r = -8 to -9 appeared to be choice for rotation a resistance management strategy.

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HSB conducted entire experiment as PG student, analysed the data and wrote the manuscript. SSU concept development and facilitation of this experiment as guide, writing the manuscript.

Key words
***Helicoverpa armigera*, Insecticide, Resistance, Pyrethroids, Organophosphates, Carbamates**

INTRODUCTION

Gram podborer, *Helicoverpa armigera* (Hubner) is a cosmopolitan and widely distributed insect pest of global importance. It has host range of >360 plant species including the crop plants *viz*., cotton, maize, sorghum, sunflower, tomato, okra, pulses and legumes (Singh and Singh, 1975). About 182 plant species have been reported as hosts of *H. armigera* by Pawar *et al*. (1986) amongst which 56 are heavily damaged. Worldwide, losses due to this pest in cotton, legumes, vegetables, cereals, exceeded US$2 billion and the cost of insecticides used to control was over US$1 billion annually (Reed and Pawar, 1982) when insecticide resistance issues started underpinning. In India, a yield loss caused by *H. armigera* in different crops ranged between 20 to 30 per cent and sometimes rose to 75 % in chickpea (Rahman, 1989). Further the loss ranged from 70 to 95% (Prakash *et al*., 2007) indicating persisting resistance. In cotton alone 35-38 % of insecticide was used to manage *H. armigera* the American bollworm by Tamil Nadu and Karnataka state farmers as per Rai *et al*. (2009).

H. armigera is able to endorse various cropping systems due to its high polyphagy, wide geographical range; mobility, migratory potential, facultative diapause, high fecundity (Fitt, 1989). Propensities to progress insecticides resistance are physiological, ethological and ecological factors that have robustly subsidized to its pest stature. However, with the extensive use of chemicals, a widespread of resistance to pyrethroids, organophosphates and carbamates insecticides cropped up in *H. armigera* in India and other countries in 1990s. Pest has been wreaked to heavy selection pressure and the development of resistance to the major chemical families of insecticides has been recorded, including carbamates (methomyl, thiodicarb, carbaryl), organophosphates (monocrotophos, quinalphos and phoxim, and to a lesser extent profenofos, methyl-parathion, phosalone and chlorpyrifos) and especially pyrethroids (*i.e.* permethrin, fenvalerate, cypermethrin, deltamethrin, lambda-cyhalothrin) as

* Corresponding author: ssudikeri@gmail.com
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reported by (Gunning *et al.*, 1984; Armes *et al.*, 1996; McCaffery, 1998). Over dependence on a particular group of chemical is one of the important reasons for rapid development of resistance. With this development of insecticide resistance, the control of *H. armigera* has become critical in many regions worldwide (Tabashnik *et al.*, 2014). Increased resistance of *H. armigera* in Pakistan (Ahmad *et al.*, 1995), South India (Ramasubramanian and Regupathy, 2004; IndraChaturvedi, 2013), Spain (Torres *et al.*, 2002) and West Africa (Brun *et al.*, 2010). With advent of insecticides belonging newer groups and awareness of IPM practices usage of pyrethoides, organophospahates (OPs) and carbamates has been reduced. Further adaption of Bt transgenic cotton hybrids synthetic insecticide usage in cotton ecosystem reduced significantly targeting bollworm *H. armigera*.

However, information about *H. armigera* resistance to different insecticides in different locations of Karnataka state of India (Fig. 1) representing major cropping systems is limited. Field control failures of *H. armigera* have been reported in Karnataka by pest control advisors as well as in the technical literature about crop protection. Thus it was essential to understand status of resistance to selected organophospahate, carbamate and pyrethroid insecticide which are still in use in different crops to know their contribution to control failures. Hence resistance was monitored in different field populations of *H. armigera* during 2016-17. The locations repreneted different agro-climatic zones, cultivated host crop dominance as well as insecticide pressures area with respect to *H. armigera*.

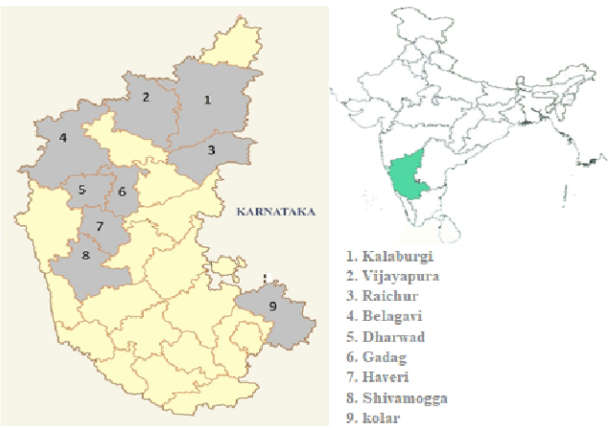

Fig. 1. Locations selected for data collection on *Helicoverpa armigera* management practices in Karnataka (India).

MATERIALS AND METHODS

The experiment was conducted at the Agriculture Research Station, Dharwad (Hebballi) Farm of University of Agricultural Sciences, Dharwad during 2016-17 in laboratory. The *H. armigera* larvae were collected from different locations of Karnataka (Fig. 1), representing different cropping patterns and agro-ecosystems which are dominating host crops of *H. armigera* (Honnakerappa and Udikeri, 2018).

Test insect rearing

The field collected late instar larvae of *H. armigera* were brought to the laboratory, kept individually in 5cm diameter Petri dishes and fed with artificial diet as described by Kranthi (2005). The culture was maintained location wise separately. Then pupae were transferred into petridishes having moist sawdust (5 pupae/Petri dish) and placed in separate adult cages. The adults were fed with 10% honey solution and allowed for mating. Five mating pairs were maintained in each adult cages and provision oviposition was done with black cloth. After hatching first instar larvae were reared in large Petri plates provided with thin layer artificial diet. While larvae reached late second instar status they were reared individually in TNAU model and/or 50 well larval trays. The laboratory condition during experiment was maintained at 27$\pm$1 ^{0}C with photo-period of 14D: 10L, while the relative humidity was maintained at 65$\pm$5%.

Establishment of reference strain

A laboratory susceptible strain of *H. armigera* provided by Dr. Vinay Kalai Principal Scientist, Division of Entomology, Indian Agricultural Research Institute, New Delhi was rused as reference strain (LAB-S) in this study. This strain was maintained as per rearing procedure followed for field test strains.

Test insecticides

The insecticides used in the study and formulations are shown in Table I. All insecticides were obtained as commercial formulations available in market during 2016. The required concentrations of test insecticides were prepared from the formulated products by dissolving the required quantities in double distilled water after accurate weighments. The solutions thus prepared were preserved in refrigerator for further use. Concentrations limiting the mortality between 10-90% were used for probit, log dose mortality analysis. To arrive at five test concentrations couple of round pilot tests were carried out.

Bio-assays for resistance studies

Bioassays were conducted using third instar (1d old) larvae of *H. armigera* from F_1 generation cultures of each location and SUS-L strain. Residual toxicity method (Rafiee *et al.*, 2008) was followed for bio-assays. Fully expanded DCH-32 non Bt cotton leaf discs (5cm diameter) were dipped in the insecticide solutions for 10s, and allowed to dry for 30 min. These leaf discs were placed into plastic Petri dishes lined with moistened filter paper to avoid desiccation. Ten larvae were used in each concentration of every insecticide and replicated four times. A distilled water dipped and dried set with 10 larvae replicated four times served as control to correct the mortality.

Table I. Insecticides used for the determination of resistance in *Helicoverpa armigera.*

Chemicals	Formu-lations	Trade name	Manufactures
Synthetic pyrethroids			
Cypermethrin	10 EC	Hycyper	Hyderabad Chem. Ltd.
Lambda cyhalo-thrin	5 EC	Karate	Syngenta India Ltd.
Deltamethrin	11 EC	Decis	Bayer Crop Sciences
Bifenthrin	10 EC	Talstar	FMC India Pvt. Ltd.
Organophosphates			
Profenphos	50 EC	Curecron	Syngenta India Ltd.
Quinolphos	25 EC	Celquin	Excel Crop Care Ltd.
Monocrotophos	36 SL	Monostar	UPL Ltd.
Chlorpyriphos	20 EC	Dursban	Dow Agro Sciences
Carbamates			
Thiodicarb	75 WP	Larvin	Bayer Crop Sciences

Data analysis and interpretation of resistance levels

Larval mortality was recorded at 24, 48 and 72 h after treatment. The mortality was determined based on the failure of insect to move upon coordinated pronding. The corrected mortality (%) as per Abbott's formula at 72 h after treatment was considered as end point for the assessment of toxicity of test insecticides (Fisk and Wright, 1992). Data were subjected for probit analysis (Finney, 1971) with SPSS statistical computer programme and R Studio to find out lethal concentrations. Cross-resistance among the insecticides was determined through pair wise correlation coefficients of log LC_{50} values of the common populations for each insecticide. Resistance ratio (RR) was worked based on ratio between LC_{50} of test strain and LC_{50} of SUS-L strain for each location and insecticide.

RESULTS AND DISCUSSION

Synthetic pyrethroids resistance in H. armigera

The RCR strain recorded highest resistance with LC_{50} value of 121.63 ppm followed by KBG (102.73 ppm) and HVR (79.72 ppm) strains (Table II). The lowest resistance was observed in SMG (55.89 ppm). Hence resistance ratio was maximal for RCR (23.21 fold), KBG (19.60 fold) and HVR (17.87 fold) strains. Least resistance ratio was for SMG (10.65 fold) strain in cypermethrin. Similarly, in lambda cyhalothrin, deltamethrin and bifenthrin, the ultimate lethal concentration resistance ratio level was recorded for RCR (69.35, 128.47, 97.23 ppm and 14.18,24.95, and 26.12 fold), KBG (60.23, 106.46, 89.68 ppm and12.32,20.67,19.08 fold) strains respectively followed by HVR (45.77, 76.08 ppm and 9.3614.77 fold) in lambda cyhalothrin and deltamrthrin except bifenthrin in strain of GDG having lethal concentration 73.89 ppm and resistance ratio of 15.72 fold which has been noticed after the RCR and KBG strains and also the lethal concentration and resistance ratio was paramount in SMG strain 55.89, 25.29, 53.50, 57.8 ppm and 10.67, 5.17, 10.39, 12.30 fold respectively in lambda cyhalothrin, deltamethrin and bifenthrin (Table II).

Organophosphate resistance in H. armigera

The high resistance level was found with lethal concentration and resistance ratio in RCR strain (178.46 ppm and 14.05 fold) followed by KBG (156.80 ppm and 12.35 fold) and HVR (64.73 ppm and 5.10 fold) strains and the lowest resistance level was recorded in SMG (41.14 ppm and 3.24 fold) strain was noticed in profenphos as presented in Table III. Accordingly, monocrotophos and quinolphos showed resistance level of 18.23 fold and 12.05 fold with lethal concentration 160.94 and 138.00ppm, respectively observed in RCR strain followed by KBG strain 16.12 fold and 10.45 fold with the lethal concentration of 142.32 and 119.61 ppm, respectively, also SMG strain having resistance ratio of 5.22 fold and 2.86 fold with the lethal concentration of 32.76 and 46.10 ppm respect to both chemicals was significantly subordinate.

But in case of chloropyrphos DWD strain noticed surpassing resistance with the LC_{50} value 74.03 ppm and resistance ratio and 6.69 fold followed by HVR strain 69.66 ppm and 6.30 fold, respective lethal concentration and resistance level and significant inferior resistance ratio was found in KBG strain (5.07 fold) with the lethal concentration.

Carbamate resistance in H. armigera

Lethal concentration and resistance ratio for carbamate insecticide (Table IV) i.e. thiodicarb was maximum with the LC_{50} value 194.55 ppm in RCR strain followed by KBG (167.97 ppm) and HVR (94.17 ppm) strains. Least resistance was shown in KLR strain (33.28 ppm). Consequently, resistance ratio was highest for RCR (9.20 fold), KBG (7.94 fold) and HVR (3.15 fold) strains. Lowest resistance ratio was noticed for KLR (1.57 fold) strain.

Table II. Toxicity of synthetic pyrethroids insecticides against different strains of *Helicoverpa armigera* from various localities in Karnataka during 2016-17.

Places	LC50 (PPM)	FL 95%	LC90 (PPM)	SLOPE ± SE	RR
Cypermetrin					
SUS-L	4.46	2.6-6.59	66.91	1.01 ± 0.16	-
HVR	79.72	65.99-97.67	280.73	2.34 ± 0.35	17.87
VJP	69.15	55.61-85.53	281.82	2.1 ± 0.33	13.20
DWD	70.92	57.65-86.89	269.47	2.21 ± 0.34	13.53
BLG	69.18	55.69-85.5	280.21	2.10 ± 0.33	13.20
SMG	55.89	43.2-69.23	237.16	2.04 ± 0.33	10.67
KLR	72.91	60.35-88.16	248.05	2.41 ± 0.35	13.91
RCR	121.63	100.87-148.93	430.56	2.14 ± 0.31	23.21
KBG	102.73	84.83-122.63	338.12	2.47 ± 0.31	19.60
GDG	67.01	53.76-82.63	271.34	2.11 ± 0.33	12.79
Lambda cyhalothrin					
SUS-L	4.89	3.24-6.44	30.37	1.61 ± 0.25	-
HVR	45.77	37.76-57.59	167.83	2.27 ± 0.35	9.36
VJP	40.48	33.41-49.96	146.34	2.20 ± 0.34	8.28
DWD	39.76	32.16-49.75	186.71	2.09 ± 0.34	8.13
BLG	37.54	30.28-46.96	156.93	2.06 ± 0.33	7.68
SMG	25.29	19.05-31.35	108.26	2.029 ± 0.34	5.17
KLR	29.78	23.08-36.99	132.18	1.98 ± 0.33	6.09
RCR	69.35	56.88-88.36	272.85	2.15 ± 0.36	14.18
KBG	60.23	49.27-74.54	232.85	2.18 ± 0.37	12.32
GDG	38.77	31.36-48.67	161.61	2.06 ± 0.33	7.93
Deltamethrin					
SUS-L	5.15	2.96-7.67	87.62	1.04 ± 0.16	-
HVR	76.08	60.22-95.44	343.02	1.65 ± 0.33	14.77
VJP	71.32	56.34-88.53	308.19	2.016 ± 0.33	13.85
DWD	73.97	59.62-90.79	289.88	2.16 ± 0.34	14.36
BLG	69.63	56.05-84.81	262.91	2.22 ± 0.34	13.52
SMG	53.50	39.78-66.57	233.04	2.00 ± 0.33	10.39
KLR	55.22	14.9-93.09	248.92	1.96 ± 0.33	10.72
RCR	128.47	105.44-157.92	481.61	2.23 ± 0.36	24.95
KBG	106.46	87.12-127.39	359.2	2.42 ± 0.37	20.67
GDG	69.52	55.67-85.06	270.43	2.17 ± 0.34	13.50
Bifenthrin					
SUS-L	4.7	2.74-6.93	67.39	1.10 ± 0.16	-
HVR	78.89	63.7-99.54	334.67	2.04 ± 0.33	16.79
VJP	70.41	56.64-87.26	288.77	2.09 ± 0.33	14.98
DWD	72.72	58.55-90.59	302.63	2.06 ± 0.33	15.47
BLG	67.32	54.07-82.86	269.66	2.12 ± 0.33	14.32
SMG	57.81	44.69-71.65	251.85	2.00 ± 0.33	12.30
KLR	59.39	45.97-73.87	266.32	1.96 ± 0.33	12.64
RCR	97.23	77.21-118.55	381.54	2.15 ± 0.37	20.69
KBG	89.68	69.81-109.50	358.03	2.13 ± 0.37	19.08
GDG	73.89	59.73-91.93	301.36	2.09 ± 0.34	15.72

SUS-L, Lab Susceptible; HVR, Haveri; VJP, Vijayapur; DWD, Dharwad; BLG, Belagavi; SMG, Shivamoga; KLR, Kolar; RCR, Raichur; KBG, Kalburgi; GDG, Gadag.

Table III. Toxicity of organophosphates insecticides against different strains of *H. armigera* from various localities in Karnataka during 2016-17.

Places	LC50 (PPM)	FL 95%	LC90 (PPM)	SLOPE ± SE	RR
Profenphos					
SUS-L	12.7	8.08-17.42	105.57	1.39 ± 0.20	-
HVR	64.73	37.01-97.34	951.25	1.09 ± 0.17	5.10
VJP	47.58	24.65-75.43	969.49	0.97 ± 0.16	3.75
DWD	57.83	33.34-87.84	930.55	1.06 ± 0.16	4.55
BLG	55.44	31.36-84.84	928.34	1.04 ± 0.16	4.37
SMG	41.14	21.58-65.30	810.26	0.99 ± 0.15	3.24
KLR	44.96	24.51-70.29	828.04	1.01 ± 0.15	3.54
RCR	178.46	110.88-252.58	1712.29	1.30 ± 0.20	14.05
KBG	156.8	95.22-223.30	1448.09	1.32 ± 0.20	12.35
GDG	54.73	30.44-84.42	971.87	1.02 ± 0.16	4.31
Chlorpyriphos					
SUS-L	11.06	8.37-13.63	43.42	2.15 ± 0.33	-
HVR	69.66	42.75.-98.99	675.14	1.29 ± 0.20	6.30
VJP	67.95	41.54-96.63	651.65	1.30 ± 0.20	6.14
DWD	74.03	47.37-102.63	653.71	1.35 ± 0.21	6.69
BLG	64.26	39.26-90.75	589.99	1.33 ± 0.21	5.81
SMG	62.93	39.09-7.87.98	522.41	1.39 ± 0.22	5.69
KLR	61.11	37.57-85.79	512.56	1.38 ± 0.22	5.53
RCR	60.49	38.55-83.03	445.98	1.47 ± 0.23	5.47
KBG	56.06	35.31-77.25	406.23	1.49 ± 0.23	5.07
GDG	58.36	37.28-83.15	651.67	1.22 ± 0.20	5.28
Monocrotophos					
SUS-L	8.83	5.41-12.32	81.91	1.32 ± 0.20	-
HVR	60.52	42.08-81.91	490.02	1.41 ± 0.24	6.85
VJP	47.26	32.47-62.8	313.71	1.55 ± 0.24	5.35
DWD	48.96	33.49-65.38	343.19	1.51 ± 0.24	5.54
BLG	46.78	31.7-62.57	326.12	1.52 ± 0.24	5.30
SMG	46.10	30.59-62.27	345.44	1.46 ± 0.24	5.22
KLR	73.94	55.59-96.91	448.17	1.60 ± 0.24	8.37
RCR	160.94	122.39-213.88	992.82	1.62 ± 0.27	18.23
KBG	142.32	106.49-187.45	895.32	1.60 ± 0.27	16.12
GDG	50.78	34.61-68.16	376.13	1.47 ± 0.24	5.75
Quinolphos					
SUS-L	11.47	7.43-16.02	112.83	1.29 ± 0.21	-
HVR	75.57	50.59-102.95	607.38	1.41 ± 0.22	6.60
VJP	37.79	21.23-56.94	551.54	1.10 ± 0.18	3.30
DWD	39.90	22.47-60.24	612.09	1.08 ± 0.18	3.48
BLG	35.21	19.24-53.53	526.52	1.09 ± 0.18	3.08
SMG	32.76	18.51-48.56	390.35	1.19 ± 0.19	2.86
KLR	33.96	19.5-50.04	396.92	1.20 ± 0.19	2.97
RCR	138.00	164.43-250.93	728.05	2.36 ± 0.38	12.05
KBG	119.61	83.94-155.84	653.70	1.73 ± 0.26	10.45
GDG	36.06	20.38-54.03	488.71	1.13 ± 0.18	3.15

For abbreviations, see Table II.

Table IV. Toxicity of carbamate insecticides (Thiodicarb) against different strains of *H. armigera* from various localities in Karnataka during 2016-17.

Strain	LC50 (PPM)	FL 95%	LC90 (PPM)	Slope ± SE	RR
SUS-L	21.15	13.54-29.66	232.21	1.23 ± 0.17	-
HVR	94.17	61.06-133.03	965.29	1.26 ± 0.19	4.45
VJP	66.66	38.39-100.33	967.4	1.10 ± 0.17	3.15
DWD	62.43	35.4-94.42	906.29	1.10 ± 0.17	2.95
BLG	53.61	28-83.90	928.58	1.03 ± 0.17	2.53
SMG	49.08	26.63-75.11	673.08	1.12 ± 0.17	2.32
KLR	33.28	18.17-52.52	664.74	0.98 ± 0.15	1.57
RCR	194.55	136.22-256.31	1288.04	1.56 ± 0.40	9.20
KBG	167.97	118.05-217.89	942.04	1.71 ± 0.26	7.94
GDG	61.55	34.29-93.84	946.13	1.08 ± 0.17	2.91

For abbreviations, see Table II.

Cross resistance pattern

Pair-wise correlation comparisons of the log LC_{50}s for the same insecticide across populations (Table V) could show positive significant correlations between each group of insecticides and all other group of insecticides except quinolphos. Positive correlation exists between cypermethrin to bifenthrin, monocrotopho, chlorpyriphos, thiodicarb. Significant positive correlation found between all group chemicals except quinolphos and cypermethrin. Thus each insecticide could have a cross-resistance to chemicals belonging to same group as well as other groups. However, the level of cross resistance was more prominent in OP, synthetic pyrethroids and carbamates. Concurrently negative correlation appeared between quinolphos and all other group of insecticides except monocrotophos.

DISCUSSION

Among nine strains the peak resistance level was noticed in RCR strain against cypermethrin (23.21fold), lambda cyhalothrin (14.18 fold), deltamethrin (24.95 fold) and bifenthrin (20.69 fold), it was followed by KBG and HVR strains. The least resistance was recorded in SMG, GDG, VJP and KLR strains to different pyrethroids. Likewise Basavangoud (1994) observed the highest level of cypermethrin (15.76 times) resistance was noticed in Sindhanur strain followed by Saundatti, Bijapur (presently called Vijayapur) and Mundagod. Even after two decades the resistance to cypermethrin has not declined clearly indicating its continued selection pressure. Hence same group of chemicals usage may cause the problem of cross resistance (Honnakerappa and Udikeri, 2018) on those locations where there was maximum resistance detected. Nonetheless the pattern of resistance was found varying much amongst high (Sindhanur/Raichur/Kalaburgi) and low (Mundagoda/ Shivamoga) pesticide usage. Upendhar (2012), Fakruddin *et al.* (2004) and Indira-Chaturvedi (2013) specifically perceived highest resistance in Raichur when they collected strains from Karntataka during their collections.

The ultimate resistance ratio was found to be in RCR strain against OPs *viz.*, profenphos (14.05 fold), monocrotophos, (18.23 fold) and quinolphos (12.05 fold) due to higher lethal concentration values and it was followed by KBG and HVR strains. In such a way Patil (1993) study was evident long back in Karnataka to OPs sensitivity. Where there is a high pesticide pressure area required higher concentrations to kill both early and late instars of *H. armigera* like in pyrethroids.

Table V. Pairwise correlation coefficient comparisons of log LC_{50} values *Helicoverpa armigera* for different insecticides.

Insecticides	Cypermethrin	Lambda Cyhalothrin	Deltamethrin	Bifenthrin	Profenphos	Quinolphos	Monocrotophos	Chlorpyriphos	Thiodicarb
Cypermethrin	1								
Lambda cyhalothrin	.211	1							
Deltamethrin	-.073	.911**	1						
Bifenthrin	.033	.934**	.934**	1					
Profenphos	.283	.947**	.922**	.893**	1				
Quinolphos	-.472	-.482	-.405	-.366	-.648	1			
Monocrotophos	.216	.878**	.859**	.869**	.945**	-.771*	1		
Chlorpyriphos	.012	.913**	.886**	.908**	.811**	-.186	.695*	1	
Thiodicarb	-.041	.838**	.886**	.819**	.799**	-.089	.610	.883**	1

* Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Further, Basavangoud (1994) also recorded highest level of resistance against monocrotophos (6.78 times) in Sindhanur strain. After couple of years again Kranthi *et al*. (2002) and Fakruddin *et al*. (2004) observed maximum resistance in the strain collected from south India.Thus a selection pressure based dynamics in resistance was evident through this study. The present finding is evident with observations of Indira-Chaturvedi (2013) for monocrotophos resistance where in his inference Raichur strain had high degree of resistance compared to Dharwad strain. Hence a gradual decrease in the levels of resistance to OPs and pyrethroids in *H. armigera* noticed in the present study in contrast to arecent reports (Indira-Chaturvedi, 2013) which may be probably due to minimized selection pressure with significant less in the use of organophosphates in the view of increase in area under Bt cotton and usage of newer chemicals which replaced conventional insecticides like OP and pyrethroids.

Thiodicarb resistance in RCR strain (9.20 fold) was highest followed by KBG (7.94 fold) and HVR (4.45 fold) strain (Fig. 2). The present finding is proximity with Fakrudin *et al*. (2004) who observed higher carbamate resistance (carbaryl) in Raichur populations recorded a maximum LD50 value to carbaryl (13.36 µg/µL) followed by Nalgonda, Guntur, Mysore and Dharwad populations. Further mythomyl resistance (Upendhar, 2012) was also high in Raichur than Nagpur which is another carbamate. The declining trend in carbamate resistance as observed in present study compared to previous reports may be due to decrease in their usage of this group of chemicals (Honnkaerappa and Udikeri, 2018) owing to newer chemicals and increased planting of Bt cottons.

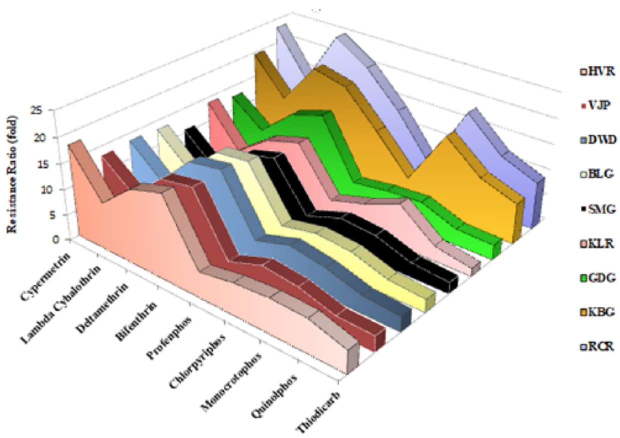

Fig. 2: Resistance level of selected insecticides against field populations of Karnataka during 2016-17.

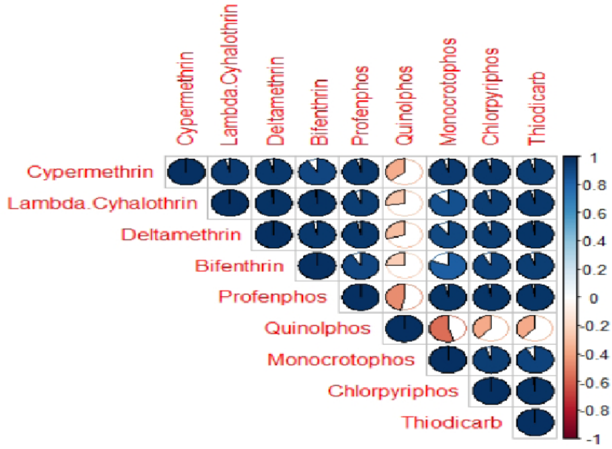

Fig. 3. Pairwise correlation coefficient comparisons between log LC_{50} values of field populations of *Helicoverpa armigera* for different insecticides.

The correlation analysis among different insecticides it clearly depicting cross resistance between intra group as well as intergroup insecticides (Fig. 2), however, the insecticides exclusively in synthetic pyrethroids, OP and carbamates showing high bright colour in pie chart implying significant cross resistance but most interestingly if we observed Figure 3 notably in quinolphos insecticide showing series of L shape light brown colourpies with little disparity exhibiting negative significant correlation in most of insecticides exclusively in OP, synthetic pyrethroid, carbamates. It clearly deciphers that can be explored in management of resistance. Insecticides betraying cross resistance in *H. armigera* were fetched from different parts of Karnataka may be dependence of farmers on similar group of insecticides especially in OP and synthetic pyrethroids among these group exclusively OPs (Honnkaerappa and Udikeri, 2018) because of cheaper cost and availability in local areas where the peak resistance noticed in locations under this study. So, comprehensibly stipulating that we should steer clear of using intra group as well as inter group of insecticides *viz*, pyrethroid, OP and carbamtes except quinolphos.

CONCLUSION

The resistance in gram podborer *H. armigera* to conventionally used synthetic pyrethroides, OPs and carbamates is still persisting and alarming especially in high pesticide usage areas. Due to existence of cross resistance careful selection of insecticides is essential in pulses, vegetables and conventional cotton to manage this pest.

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Statement of conflict of interest

The authors have declared no conflict of interest.

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