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Insecticide resistance in the brown planthopper, *Nilaparvata lugens* Stål of different populations of Karnataka

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Abstract
The bioassay was carried out to know the insecticide resistance against acephate, monocrotophos and carbosulfan in the brown planthopper of different populations of Karnataka during *kharif* 2020-2021 using the seedling dip method. Results showed that higher levels of average resistance were recorded against acephate in populations of Cauvery command area (Mandya and Shivalli with LC_{50} of 199.5 and 197.6 mg/L, respectively), followed by TBP and UKP (Lingasugur) populations. Hilly and Coastal populations were highly susceptible to acephate. Significantly higher mean lethal concentrations against monocrotophos were recorded in populations representing the TBP area with 135.2 and 121.8 mg/L in Gangavathi and Sulekal, respectively, followed by UKP and TW populations. TBP, UKP and TW populations were more tolerant to carbosulfan compared to other field populations. Significantly lower resistance was noticed in Coastal and Hilly populations, as farmers in these areas were growing paddy for their daily use rather than commercial purpose, so farmers in these regions were rarely used insecticide.

Keywords: Brown planthopper, insecticide resistance, lethal concentrations

Introduction
The brown planthopper (BPH), *Nilaparvata lugens* Stål (Hemiptera: Delphacidae) is widely distributed throughout Asia. BPH is a primary insect pest of cultivated rice and effective control is essential for economical crop production. The outbreak of this pest often leads to the total loss of the rice crop, if no effective control measures were taken up. Several cultural practices such as planting of rice with wider spacing, nutrient and water management and conservation of natural enemies have been suggested in the effective BPH management. However, the intensive and continuous cultivation of rice with excessive use of nitrogenous fertilizers has compelled farmers to use insecticides for its suppression. Though insecticides did help in suppressing the pest initially, the indiscriminate use of chemicals has resulted in problems such as the development of resistance and the resurgence of the pest (Gao *et al*., 1987) [3].
The control of the BPH has relied on various insecticides throughout Asia. Initially, in 1950's it was started with conventional insecticides, which were highly persistent organochlorines such as DDT (dichlordiphenyltrichlorethan) and BHC (benzene hexachloride) but these insecticides have been banned since the 1970's due to environmental impact. Subsequently, the organophosphates and carbamates were widely used insecticides against BPH, but were replaced due to insecticide resistance (Zhu and Cheng, 2013) [7].

Materials and methods
Insecticide resistance
Bioassays were carried out using IRAC Susceptibility Test #05 with ten field populations of BPH obtained from six paddy growing regions of Karnataka (Table 1) against three insecticides. These locations were selected based on the source of irrigation to cultivate the paddy, irrespective of population dynamics and insecticide usage. Further data on the response of BPH populations of six major paddy growing regions of Karnataka were compared with the laboratory culture of BPH maintained for two years (more than 10 generations) at Agricultural Research Station, Gangavathi, UAS, Raichur.

Collection and rearing of *N. lugens*

Field populations of *N. lugens* collected from 10 locations representing six paddy growing regions of Karnataka. Insects collected at both nymphal and adult stage during rice growing seasons from different locations (Table 1) along with plant hill by covering polythene cover to the entire hill. The planthoppers adults, preferably short winged collected from the base of the rice plants using an aspirator and released into rice plant covered with polythene. The covered plants were brought back to research laboratory and transplanted into the empty pot kept in rearing cage along with pots containing 40 days old seedlings for rearing. Rearing cages were labelled with the respective collection dates, location names and geolocations. Later insects were reared to F_1 generation which was used for the bioassay studies. From F_1 generation, nymphs of similar age (approximately five days old) were used for bioassay studies.

Table 1: Details of different locations where samples of *N. lugens* populations were collected to study insecticide resistance

Sl. No.	Rice growing areas and specific collection locality		Latitude	Longitude
1.	Upper Krishna command area (UKP)	Lingasugur	16.1550°N	76.5199°E
		Malnoor	16.4501°N	76.4505°E
2.	Tungabhadra command area (TBP)	Gangavathi	15.4319°N	76.5281°E
		Sulekal	15.5689°N	76.4092°E
3.	Cauvery command area	Mandya	12.5870°N	76.8216°E
		Shivalli	12.5242°N	76.8957°E
4.	Coastal area	Karkala	13.2151°N	74.9962°E
5.	Hilly area	Mudigere	13.1365°N	75.6403°E
		Sirsi	14.5937°N	74.9476°E
6.	Tube well irrigated area (Kanakagiri)	Chikka Madinal	15.5021°N	76.3636°E

Bioassay

Susceptibility of target insect to different concentrations of various insecticides (Table 2) were analyzed by IRAC Susceptibility Test #05 (Heong *et al*., 2013) [4]. Ten rice seeds were sown in 5 centimeter diameter plastic cups containing soil with NPK nutrients. Germinated plants at four leaf stage were used to carry out bioassay study. Two per cent agar powder (HiMedia) was diluted according to the manufacturer's instruction and allowed to cool to 37 °C and then poured at the base of the rice seedling to cover the soil surface. Later, these rice seedlings were dipped into a different doses of insecticide solution for 30 seconds and air dried at room temperature for 15±1 min. After the drying, ten third instar uniform sized nymphs from pure culture were released on the treated seedlings and covered with a plastic tube with a muslin cloth above. Total of 30 nymphs were exposed for each concentration of an insecticide.

Number of dead nymphs were recorded at 24, 48 and 72 hours interval for acephate 75%, monocrotophos 36% SL and carbosulfan 25% EC.

Table 2: List of insecticides used for bioassay

Insecticide group	Insecticide	Classification	Mode of action
Organophosphates	Acephate	1B	Acetylcholine esterase inhibitors
	Monocrotophos	1B	
carbamate	carbosulfan	1A	

Statistical analysis

The percentage of mortality for each concentration of test insecticide along with the control were computed and corrected per cent mortality was worked out by Abbot's formula (Abbott 1925) [1]. Mortality data from the insecticide bioassays were subjected to probit analysis for the determination of lethal concentration values (LD_{50}) and their 95% confidential limits (CLs) by using the POLO plus program (LeOra software 2002, Berkeley, CA, USA). Later, the RR (Resistance ratio) for each insecticide was calculated using below formula.

$$RR = \frac{LC_{50} \text{ of Resistant population}}{LC_{50} \text{ of Susceptible population}}$$

Results and discussion

Resistance status of BPH against acephate 75% SP

The resistance level to acephate varied among populations collected from different regions during 2020 and 2021. Significantly higher resistance was recorded in Cauvery command area with LC_{50} of 198.44 and 197.77 mg/L for Mandya and Shivalli populations at 72 hrs of treatment during 2020. Whereas, populations of TBP were relatively less tolerable than the populations of Cauvery command area, with LC_{50} of 174.63 and 173.61 mg/L for Sulekal and Gangavathi populations, respectively. UKP (Lingasugur and Malnoor with LC_{50} of 166.58 and 148.05 mg/L) and TW (126.56 mg/L) populations showed moderate resistance compared to Cauvery command area and TBP. Lower LC_{50} was recorded in populations of Hilly area (25.54 and 28.68 mg/L Mudigere and Sirsi populations, respectively) indicating high susceptibility to acephate compared to Cauvery, TBP, UKP and TW field populations (Table 3). Resistance was decreasing on a gradient at 72 hrs during 2020-2021: Cauvery command area > TBP > UKP > TW > Hilly area > Coastal area.

Similar trend was observed during 2021 also wherein, populations of Cauvery command area recorded significantly highest LC_{50} (200.48 and 197.40 mg/L for Mandya and Shivalli populations, respectively) indicating resistant nature, followed by TBP population with LC_{50} of 194.38 and 189.33 mg/L for Sulekal and Gangavathi, respectively. Significantly lowest LC_{50} of 18.12 mg/L was recorded from Coastal region (Sangola population), followed by populations of Hilly regions (Mudigere and Sirsi populations with LC_{50} of 24.63 and 27.02 mg/L) (Table 4).

Higher mean LC_{50} of two years against acephate was observed in Mandya (199.5 mg/L) and Shivalli (197.6 mg/L) populations of Cauvery command area, followed by TBP populations (184.5 and 181.5 mg/L in Shivalli and Gangavathi populations, respectively). Significantly lower average LC_{50} was recorded in Coastal area (18.1 mg/L) population, followed by populations of Hilly region (25.1 and 27.9 mg/L in Mudigere and Sirsi populations, respectively) (Fig. 1).

The variation in the lethal concentrations obviously has direct relation with resistance ratios. It varied greatly from 1.24 to 9.67 among the different populations during 2020 (Table 3). The higher resistance ratio (RR) of 9.67 was recorded in Mandya population, followed by 9.63 in Shivalli populations from Cauvery command area. Whereas, lower RR were recorded in populations of Hilly area (1.24 and 1.40 folds in Mudigere and Sirsi populations, respectively). Similar trend was noticed during 2021 also with increasing to decreasing order of RR being, Mandya (11.77) > Shivalli (11.59) > Sulekal (11.41) > Gangavathi (11.12) > Lingasugur (10.42) > Malnoor (9.33) > Chikkamadinal (8.53) > Sirsi (1.59) > Mudigere (1.41) > Ranhola (1.06) (Table 4).

Average resistance ratio of two years was also indicating that higher in populations of Cauvery command area (10.72 and 10.61 folds in Mandya and Shivalli populations, respectively), followed by TBP populations. Significantly lower mean RR was observed in Ranhola (1.06 folds) population of Coastal area, followed by 1.33 folds in Mudigere population (Hilly area) (Fig. 1).

The higher levels of resistance against acephate is observed in Cauvery populations, slightly lower resistance is observed in TBP and UKP populations where lower per cent of farmers were spraying acephate, but along with this higher per cent of farmers of these command areas were using insecticide like monocrotophos belonging to OP group. The observed variations in the resistance levels reflect upon the extent of acephate usage in the respective areas. The BPH tolerance was varied to acephate within geographic region of different area populations were also reported by several authors like Mohan *et al*. (2019) [5] who found that RR varied from 0.28 to 2.02 folds in *N. lugens* populations of Nalgonda district, Telangana. Basanth *et al*. (2013) [2] found RR of 1.34 to 5.32 folds in field collected *N. lugens* population from Karnataka. Wen *et al*. (2009) [6] documented LC_{50} of 2.06 to 9.51 ppm with 1.8 to 8.3 folds of resistance in four *N. lugens* field populations of China.

Table 3: Resistance levels of *N. lugens* field populations to acephate 75% SP during 2020

Population		Slope (SE^a)	LC_{50}^{b} (mg/L)	Fiducial limit (95%)		X^2 (df)	RR^c
				Lower	Upper		
Susceptible		1.95 (±0.29)	20.53	15.55	27.19	0.39 (3)	-
TBP	Gangavathi	2.04 (±0.31)	173.61	131.83	226.19	2.26 (3)	8.46
	Sulekal	2.18 (±0.31)	174.63	134.67	224.51	2.38 (3)	8.51
TW	Chikkamadinal	1.56 (±0.29)	126.56	89.47	185.61	1.04 (3)	6.16
UKP	Lingasugur	1.50 (±0.28)	166.58	119.05	260.36	1.51 (3)	8.11
	Malnoor	1.40 (±0.27)	148.05	103.98	232.52	0.79 (3)	7.21
Cauvery	Mandya	2.10 (±0.31)	198.44	152.70	258.37	2.12 (3)	9.67
	Shivalli	2.21 (±0.31)	197.77	153.87	254.84	1.49 (3)	9.63
Hilly	Mudigere	1.81 (±0.29)	25.54	19.18	35.24	1.47 (3)	1.24
	Sirsi	1.62 (±0.28)	28.68	20.96	41.83	1.86 (3)	1.40

^{a}SE-standard error; ^{b}LC_{50} at 95% CI-confidence interval; df-degrees of freedom; ^{c}RR-resistance ratio.

Table 4: Resistance levels of *N. lugens* field populations to acephate 75% SP during 2021

Population		Slope (SE^a)	LC_{50}^{b} (mg/L)	Fiducial limit (95%)		X^2 (df)	RR^c
				Lower	Upper		
Susceptible		2.13 (±0.31)	17.03	13.43	22.62	0.15 (3)	-
TBP	Gangavathi	2.34 (±0.33)	189.33	148.49	240.86	0.54 (3)	11.12
	Sulekal	1.95 (±0.30)	194.38	146.81	256.72	1.59 (3)	11.41
TW	Chikkamadinal	1.48 (±0.27)	145.32	103.76	221.58	0.37 (3)	8.53
UKP	Lingasugur	1.78 (±0.30)	177.42	132.26	259.87	1.14 (3)	10.42
	Malnoor	1.69 (±0.29)	158.91	117.29	232.96	0.25 (3)	9.33
Cauvery	Mandya	2.00 (±0.30)	200.48	152.57	263.29	0.65 (3)	11.77
	Shivalli	2.26(±0.32)	197.40	154.29	253.31	2.56 (3)	11.59
Hilly	Mudigere	1.90 (±0.29)	24.63	18.70	33.40	2.36 (3)	1.41
	Sirsi	1.89 (±0.30)	27.02	20.48	37.03	0.89 (3)	1.59
Coastal	Ranhola	2.51 (±0.34)	18.12	14.36	22.74	0.88 (3)	1.06

^{a}SE-standard error; ^{b}LC_{50} at 95% CI-confidence interval; df-degrees of freedom; ^{c}RR-resistance ratio.

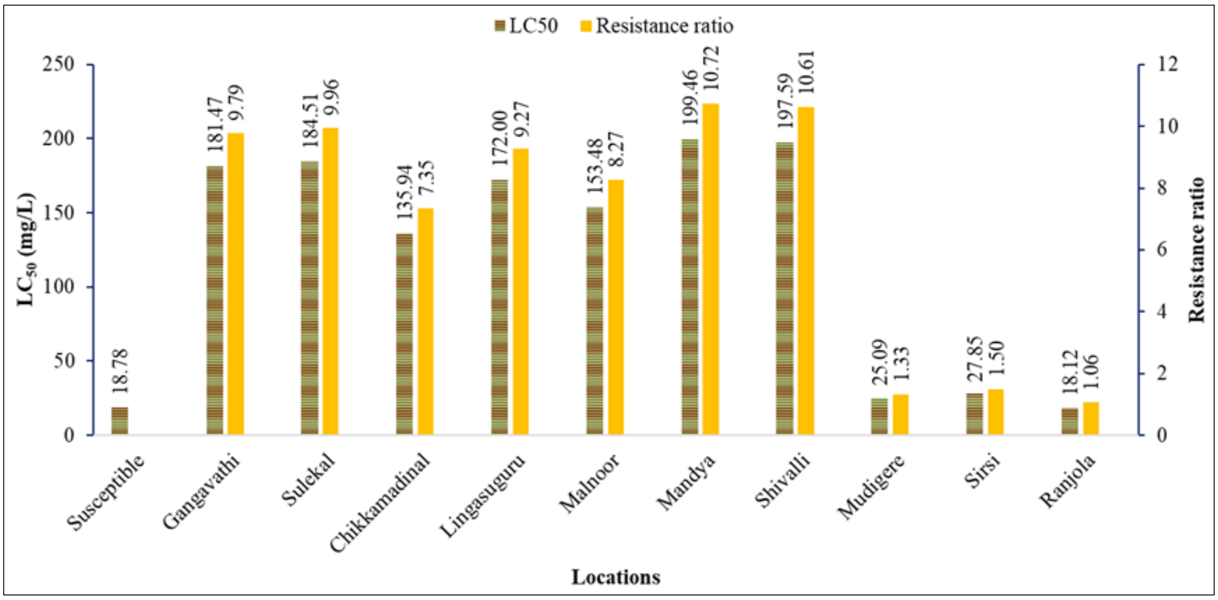

Fig 1: Mean of two years LC_{50} and resistance ratio values of *N. lugens* populations against acephate 75% SP

Resistance status of BPH against monocrotophos 36% SL

Resistance to monocrotophos varied among different populations of Karnataka during 2020 and 2021. The order of resistance was observed to be-TBP > UKP > TW > Cauvery command area > Hilly area. In 2020 monocrotophos resistance was higher in populations collected from TBP area with LC_{50} of 130.95 and 110.61 mg/L for Gangavathi and Sulekal, respectively at 72 hrs. Wherein, populations of UKP were relatively less tolerable than populations of TBP area, with LC_{50} of Lingasugur and Malnoor populations were 102.71 and 91.81 mg/L, respectively. Populations collected from TW (84.26 mg/L) irrigated area and Cauvery command area were showed a moderate resistance (LC_{50} of 86.43 and 80.38 mg/L for Mandya and Shivalli populations, respectively). Whereas, lower LC_{50} values of 21.59 and 22.34 mg/L were recorded in Mudigere and Sirsi populations, respectively representing Hilly area indicating higher susceptibility to monocrotophos compared to other field populations (Table 5). Significantly lower LC_{50} value of 11.37 mg/L was found in laboratory population.

Similar trend was observed during 2021 also wherein, populations of TBP region recorded significantly highest LC_{50} (139.37 and 132.95 mg/L for Gangavathi and Sulekal populations, respectively) indicating resistant nature, followed by UKP populations (109.21 and 90.94 mg/L Lingasugur and Malnoor populations, respectively). Whereas, populations representing Cauvery command area showed LC_{50} of 89.65 and 81.99 mg/L for Mandya and Shivalli, respectively. Significantly lower resistance (LC_{50} of 11.77 mg/L) was recorded in Coastal population, followed by Hilly populations (22.49 and 22.53 mg/L for Mudigere and Sirsi, respectively). Laboratory susceptible culture recorded significantly lowest resistance (10.53 mg/L) compared to field populations (Table 6).

Significantly higher mean lethal concentrations were recorded in populations representing the TBP area with 135.2 and 121.8 mg/L in Gangavathi and Sulekal, respectively, followed by Lingasugur population representing UKP area with 106.0 mg/L. Mean lower resistance was observed in Coastal population (Ranhola) with 11.8 mg/L, followed by populations of Hilly region (22.0 and 22.4 mg/L for Mudigere and Sirsi, respectively). Significantly lowest mean LC_{50} was recorded in susceptible population with 11.0 mg/L (Fig. 2).

The Resistance ratio for monocrotophos varied from 1.90 to 11.50 among the different field collected *N. lugens* populations during 2020 (Table 5). The higher resistance ratio (RR) was recorded in populations of TBP area, with 11.50 and 9.73 folds of resistance in Gangavathi and Sulekal populations, respectively, followed by populations from UKP area with RR of 9.03 and 8.07 folds for Lingasugur and Malnoor populations, respectively. Comparatively moderate RR was observed in population representing TW irrigation (7.41 folds) and Cauvery populations (7.60 and 7.07 folds in Mandya and Shivalli, respectively). Whereas, lower RR were recorded in populations from Hilly regions (1.90 and 1.96 folds in Mudigere and Sirsi population, respectively). Similar trend was noticed during 2021 also with increasing to decreasing order of RR being Gangavathi (13.24) > Sulekal (12.63) > Lingasugur (10.37) > Malnoor (8.64) > Mandya (8.51) > Chikkamadinal (7.94) > Shivalli (7.79) > Mudigere (2.14) > Sirsi (2.14) > Ranhola (1.12) (Table 6).

The average of two years resistance ratio was higher in Gangavathi (12.37 folds) and Sulekal (11.18 folds) populations of TBP area, followed by 9.70 folds in Lingasugur (UKP) population. Ranhola population of Coastal region recorded lower RR with 1.12 folds, followed by Hilly region populations (2.02 and 2.05 folds in Mudigere and Sirsi populations, respectively) (Fig. 2).

Resistance to monocrotophos is significantly higher in TBP populations, followed by UKP, Cauvery and TW populations, the higher resistance in these population might be due to the majority of the farmers spraying monocrotophos with higher than the recommended dose for managing the paddy insect pest. Significantly lower resistance is observed in Coastal and Hilly populations this might be because of these region farmers use insecticides rarely for control of insect pests. The varied responses of BPH populations to monocrotophos reflects the intensity and extent of use of the same insecticide or maybe use of insecticide belong to similar group or having similar mode of action. Mohan *et al.* (2019) [5] who found varied responses to monocrotophos in *N. lugens* of Nalgonda district of Telangana state.

Table 5: Resistance levels of *N. lugens* field populations to monocrotophos 36% SL during 2020

Population		Slope (SE^a)	LC_{50}^{b} (mg/L)	Fiducial limit (95%)		X^2 (df)	RR^c
				Lower	Upper		
Susceptible		1.87 (±0.29)	11.37	8.59	15.35	1.72 (3)	-
TBP	Gangavathi	1.86 (±0.32)	130.95	96.80	181.54	0.11 (3)	11.50
	Sulekal	2.06 (±0.30)	110.61	85.07	145.41	1.92 (3)	9.73
TW	Chikkamadinal	1.41 (±0.27)	84.26	59.07	137.93	1.57 (3)	7.41
UKP	Lingasugur	1.73 (±0.29)	102.71	75.59	140.23	0.51 (3)	9.03
	Malnoor	2.20 (±0.32)	91.81	56.11	147.96	3.44 (3)	8.07
Cauvery	Mandya	2.98 (±0.42)	86.43	50.69	141.03	5.62 (3)	7.60
	Shivalli	2.24 (±0.37)	80.38	49.59	123.96	3.24 (3)	7.07
Hilly	Mudigere	2.07 (±0.31)	21.59	16.60	28.29	0.51 (3)	1.90
	Sirsi	2.36 (±0.33)	22.34	14.21	36.67	3.61 (3)	1.96

^{a}SE-standard error; ^{b}LC_{50} at 95% CI-confidence interval; df-degrees of freedom; ^{c} RR-resistance ratio.

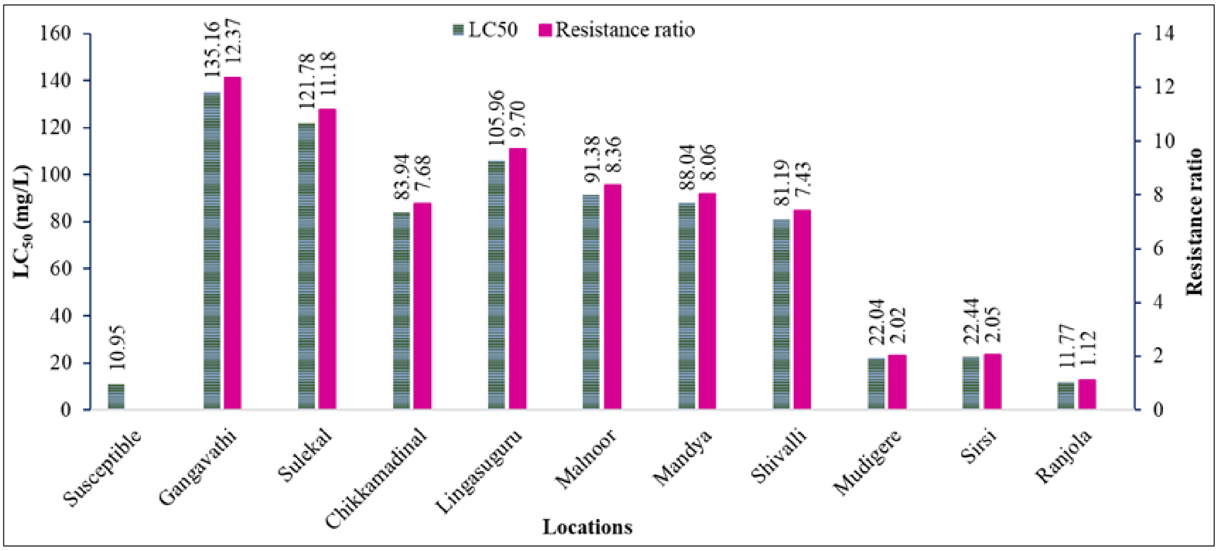

Fig 2: Mean of two years LC_{50} and resistance ratio values of *N. lugens* populations against monocrotophos 36% SL

Table 6: Resistance levels of *N. lugens* field populations to monocrotophos 36% SL during 2021

Population		Slope (SE[a])	LC_{50}[b] (mg/L)	Fiducial limit (95%)		X^2 (df)	RR[c]
				Lower	Upper		
Susceptible		1.69 (±0.28)	10.53	5.90	19.53	3.19 (3)	-
TBP	Gangavathi	1.82 (±0.32)	139.37	102.81	195.91	0.48 (3)	13.24
	Sulekal	1.72 (±0.29)	132.95	98.69	187.28	0.53 (3)	12.63
TW	Chikkamadinal	1.73 (±0.29)	83.61	61.99	122.87	2.02 (3)	7.94
UKP	Lingasugur	1.74 (±0.29)	109.21	80.67	149.62	0.76 (3)	10.37
	Malnoor	2.16 (±0.32)	90.94	38.46	209.41	6.79 (3)	8.64
Cauvery	Mandya	2.91 (±0.42)	89.65	54.88	144.21	5.07 (3)	8.51
	Shivalli	2.28 (±0.37)	81.99	64.49	103.28	2.27 (3)	7.79
Hilly	Mudigere	2.42 (±0.33)	22.49	17.83	28.61	0.42 (3)	2.14
	Sirsi	2.18 (±0.32)	22.53	17.55	29.28	1.79 (3)	2.14
Coastal	Ranhola	1.89 (±0.30)	11.77	8.89	15.88	1.12 (3)	1.12

[a]SE-standard error; [b]LC_{50} at 95% CI-confidence interval; df-degrees of freedom; [c]RR-resistance ratio.

Resistance status of BPH against carbosulfan 25% EC

Significant differences in resistance exist in the BPH population for carbosulfan among the populations of different regions during 2020 and 2021. Resistance was decreasing on a gradient at 72 hrs: TBP (Sulekal) > UKP (Lingasugur) > TBP (Gangavathi) > UKP (Malnoor) > TW (Tube well irrigated area) > Cauvery command area > Hilly region > Coastal region. Population of Sulekal region recorded highest lethal concentration in 2020 against carbosulfan with LC_{50} of 122.16 mg/L at 72 hrs, followed by Lingasugur population with LC_{50} of 114.94 mg/L. Gangavathi population recorded LC_{50} of 108.91 mg/L, followed by TW population with LC_{50} of 91.73 mg/L. Cauvery populations (52.05 and 41.16 mg/L for Mandya and Shivalli populations, respectively) showed relatively less resistance compared to TBP, TW and UKP populations. Whereas, lower LC_{50} was recorded in populations of Hilly regions (20.02 and 20.07 mg/L for Mudigere and Sirsi, respectively) indicating high susceptibility to carbosulfan (Table 7). Laboratory population recorded significantly lower LC_{50} (12.16 mg/L) compared to the field populations.

Pattern of resistance against carbosulfan was similar during 2021 wherein, Sulekal population recorded significantly highest LC_{50} of 118.62 mg/L indicating resistant nature, followed by Lingasugur population with LC_{50} of 115.79 mg/L. Gangavathi population showed slightly lower resistance with LC_{50} of 113.78 mg/L and Malnoor population recorded LC_{50} of 105.35 mg/L. TW populations showed LC_{50} of 99.37 mg/L. Lower resistance was noticed in Cauvery, Hilly and Coastal populations. Cauvery populations recorded the LC_{50} of 49.20 and 44.54 mg/L for Mandya and Shivalli populations, respectively. Whereas, significantly lower LC_{50} of 19.08 mg/L recorded in Ranhola population of Coastal region, followed by Hilly populations (19.49 and 22.61 mg/L for Mudigere and Sirsi populations, respectively) (Table 8).

The Sulekal population of TBP area recorded higher average lethal concentration with 120.39 mg/L indicating higher resistance, followed by 115.37 and 111.35 mg/L of LC_{50} in Lingasugur (UKP area) and Gangavathi (TBP area) populations, respectively. Slightly lower mean resistance was noticed in Malnoor (103.91 mg/L) and Chikkamadinal (TW irrigated) (95.55 mg/L) populations. Populations of Coastal region (19.08 mg/L) and Hilly area (19.76 and 21.34 mg/L for Mudigere and Sirsi populations, respectively) showed low resistance. 11.88 mg/L of LC_{50} was recorded in laboratory susceptible culture (Fig. 3).

The higher resistance ratio (RR) of 10.05 folds was recorded in Sulekal population, followed by 9.45 folds recorded in Lingasugur population. Gangavathi population showed RR of 8.96 folds. TW population recorded RR of 7.45 folds. Cauvery command area recorded relatively moderate resistance with RR of 4.28 and 3.38 folds for Mandya and Shivalli populations, respectively. Whereas, lower RR were recorded in populations of Hilly regions (1.65 and 1.65 folds in Mudigere and Sirsi population, respectively) (Table 7). Similar trend was noticed during 2021 also with increasing to decreasing order of RR being Sulekal (10.23) > Lingasugur (9.99) > Gangavathi (9.82) > Malnoor (9.09) > Chikkamadinal (8.57) > Mandya (4.25) > Shivalli (3.84) > Sirsi (1.95) > Mudigere (1.68) > Ranhola (1.65) (Table 8).

The average of two years resistance ratio was higher in Sulekal population (10.14 folds), followed by Lingasugur (9.72 folds) and Gangavathi (9.39 folds) populations. The lowest mean RR was recorded in Coastal area population (1.65 folds), followed by 1.67 and 1.80 folds of resistance in Mudigere and Sirsi populations, respectively (Fig. 3).

TBP, UKP and TW populations are more resistant to carbosulfan compared to Cauvery, Hilly and Coastal field populations. Whereas, comparatively moderate resistance is recorded in population of Cauvery command area. Significantly lower resistance is noticed in Coastal and Hilly populations. Results were partially in line with Wen *et al.* (2009) [6], who documented intra-regional variation in susceptibility to carbosulfan in field collected *N. lugens* populations from China.

Table 7: Resistance levels of *N. lugens* field populations to carbosulfan 25% EC during 2020

Population		Slope (SE^a)	LC_{50}^{b} (mg/L)	Fiducial limit (95%)		X^2 (df)	RR^c
				Lower	Upper		
Susceptible		1.74 (±0.29)	12.16	9.03	16.87	0.23 (3)	-
TBP	Gangavathi	1.95 (±0.30)	108.91	82.70	144.52	0.63 (3)	8.96
	Sulekal	2.04 (±0.31)	122.16	94.08	162.43	1.41 (3)	10.05
TW	Chikkamadinal	1.82 (±0.29)	91.73	67.89	122.73	0.37 (3)	7.45
UKP	Lingasugur	1.78 (±0.29)	114.94	85.61	157.43	0.18 (3)	9.45
	Malnoor	2.30 (±0.33)	102.47	80.31	131.01	0.75 (3)	8.43
Cauvery	Mandya	2.06 (±0.33)	52.05	39.09	68.75	0.31 (3)	4.28
	Shivalli	1.90 (±0.30)	41.16	30.51	54.34	0.71 (3)	3.38
Hilly	Mudigere	1.86 (±0.29)	20.02	14.97	26.77	0.22 (3)	1.65
	Sirsi	1.96 (±0.30)	20.07	15.19	26.49	0.25 (3)	1.65

^{a}SE-standard error; ^{b}LC_{50} at 95% CI-confidence interval; df-degrees of freedom; ^{c}RR-resistance ratio.

Table 8: Resistance levels of *N. lugens* field populations to carbosulfan 25% EC during 2021

Population		Slope (SE^a)	LC_{50}^{b} (mg/L)	Fiducial limit (95%)		X^2 (df)	RR^c
				Lower	Upper		
Susceptible		1.60 (±0.28)	11.59	8.40	16.43	0.51 (3)	-
TBP	Gangavathi	2.09 (±0.31)	113.78	87.86	149.18	1.15 (3)	9.82
	Sulekal	2.16 (±0.32)	118.62	92.36	155.09	2.85 (3)	10.23
TW	Chikkamadinal	1.82 (±0.29)	99.37	73.94	133.76	0.91 (3)	8.57
UKP	Lingasugur	2.09 (±0.31)	115.79	89.42	152.23	2.38 (3)	9.99
	Malnoor	2.07 (±0.31)	105.35	80.92	137.85	0.83 (3)	9.09
Cauvery	Mandya	2.19 (±0.34)	49.20	37.29	64.07	0.38 (3)	4.25
	Shivalli	1.60 (±0.28)	44.54	31.55	61.49	0.30 (3)	3.84
Hilly	Mudigere	1.93 (±0.30)	19.49	14.71	25.87	2.63 (3)	1.68
	Sirsi	1.75 (±0.29)	22.61	16.73	30.99	1.99 (3)	1.95
Coastal	Ranhola	2.08 (±0.31)	19.08	14.59	24.79	1.84 (3)	1.65

^{a}SE-standard error; ^{b}LC_{50} at 95% CI-confidence interval; df-degrees of freedom; ^{c}RR-resistance ratio.

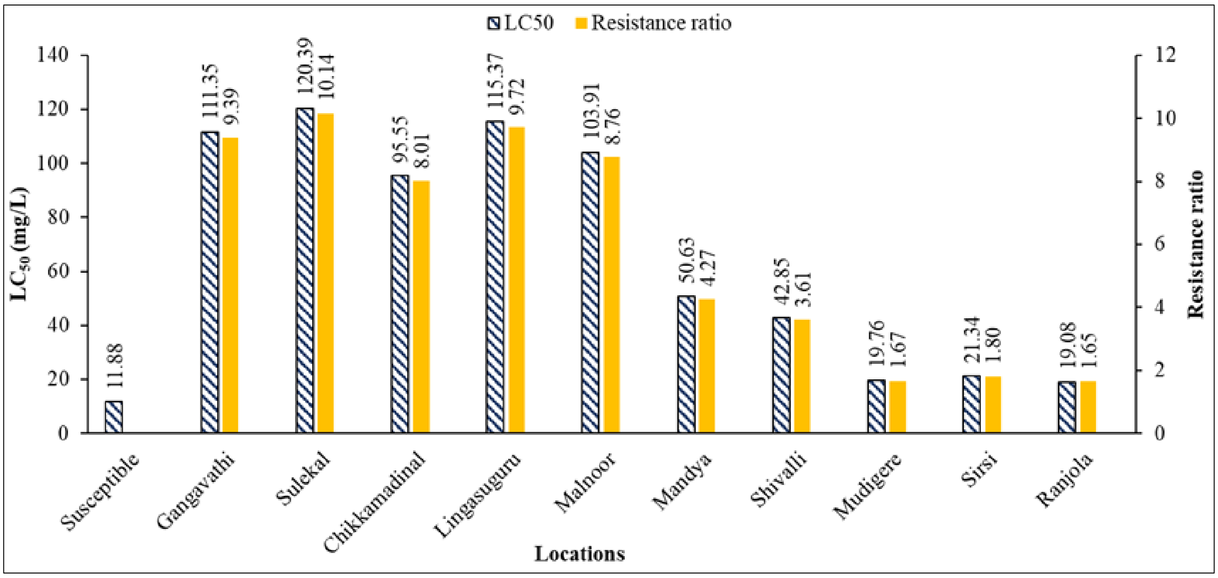

Fig 3: Mean of two years LC_{50} and resistance ratio values of *N. lugens* populations against carbosulfan 25% EC

Conclusion

The BPH populations exhibited varied levels of resistance to organo-phosphorous (acephate and monocrotophos) and carbamate (carbosulfan) insecticides. Higher levels of resistance were noticed to acephate in populations of Cauvery command area, followed by TBP and UKP (Lingasugur) populations. Hilly and Coastal populations were highly susceptible to acephate. Resistance to monocrotophos was significantly higher in TBP populations, followed by UKP and TW populations. TBP, UKP and TW populations were more tolerant to carbosulfan compared to other field populations. Significantly lower resistance was noticed in Coastal and Hilly populations, as farmers in these areas were growing paddy for their daily use rather than commercial purpose, so farmers in these regions were rarely use insecticide. The results will be beneficial for development of resistance management strategies to prevent and delay development of insecticide resistance in BPH.

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