Susceptibility of Different Populations of *Nilaparvata lugens* from Major Rice Growing Areas of Karnataka, India to Different Groups of Insecticides

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Abstract: Susceptibility to insecticides was investigated by collecting field populations of brown planthopper from different locations of southern Karnataka, India (Gangavati, Kathalagere, Kollegala, Soraba and Mandya). All the field populations differed in their susceptibility to insecticides. In general, Soraba and Mandya populations were more susceptible to insecticides compared to Gangavati and Kathalagere populations. The resistance ratios varied greatly among the populations viz., chlorpyriphos (1.13 to 16.82), imidacloprid (0.53 to 13.50), acephate (1.34 to 5.32), fipronil (1.13 to 4.06), thiamethoxam (1.01 to 2.19), clothianidin (1.92 to 4.86), dinotefuran (0.82 to 2.22), buprofezin (1.06 to 5.43) and carbofuran (0.41 to 2.17). The populations from Gangavati, Kathalagere and Kollegala exhibited higher resistance to some of the older insecticides and low resistance to newer molecules.

Key words: *Nilaparvata lugens*; insecticide; susceptibility; resistance

The brown planthopper (BPH), *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) is widely distributed throughout Asia. It was first reported as a sporadic pest of rice (Tirumalarao, 1950) in 1927 around Tenali in Guntur district of Andhra Pradesh. Heavy infestation of this pest occurred in tracts of Tamil Nadu and Kerala during 1972 and 1973 (Das et al, 1973). Heavy attacks of BPH on rice in India were also reported in West Bengal (Chatterjee, 1978), Uttar Pradesh (Verma et al, 1979a; Rizvi and Singh, 1983) and Punjab (Dhaliwal and Singh, 1983). In Karnataka of India, BPH is an endemic pest of rice in all the major command areas, particularly in Tungabhadra and Cauvery command areas (Channabasavanna et al, 1976). Severe outbreaks of this pest were noticed in Chamarajanagar district in 2007 and in Haveri, Shimoga, Mandya, Mysore and Chamarajanagar districts in 2009 (Siddegowda and Gubbaiah, 2011) in India. *N. lugens* damages by sucking sap directly from the growing plants, the affected plants become chlorotic, and the leaves dry up gradually, resulting in the death of plants. This feeding damage is commonly referred as ‘hopper burn’, which begins in patches, but spreads rapidly as the hoppers move from dying plants to adjacent plants. In addition to direct feeding damage, *N. lugens* also serves as the vector of rice grassy stunt virus and rice ragged stunt virus (Ling, 1977). Outbreak of this pest often leads to total loss of the rice crop, if no effective control measures are taken up. Several cultural practices such as planting of rice with wider spacing, nutrient and water management and conservation of natural enemies, etc., have been suggested in the effective BPH management. However, the intensive and continuous cultivation of rice with excessive use of nitrogenous fertilizers has compelled the 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 development of resistance and resurgence of the pest (Nagata et al, 1979; Nagata, 1982; Gao et al, 1987).

During the past three decades, BPH has become a threat to rice production not only in India, but also in South East Asian countries due to insecticide resistance. A few studies have been conducted in developing methodologies and detecting insecticide resistance in case of BPH in countries like Japan and China (Nagata et al, 1979; Wang et al, 2008b). However, there are hardly few attempts made to detect insecticide resistance in any of the rice pests in Indian subcontinent. In 1969, Nagata and Moriya reported
the first documented case of insecticide resistance in BPH to BHC (Benzene hexa chloride (gamma-hexachlorocyclohexane HCH)). Later, the insecticide resistance in populations of the BPH was reported from Japan, China, the Philipines, Soloman islands, Sri Lanka, Taiwan and India (Hasui and Ozaki, 1984; Tranter and Emden, 1984; Sarupa et al, 1998; Krishnaiah et al, 2006). In many rice growing areas of India, insecticides failed to give the desired level of control of the pest because of the development of resistance to insecticides. The pest has become unmanageable in several districts of Karnataka in India, viz., Davanagere, Raichur and Chamarajanagar districts. However, few studies have been done in India to assess the level of resistance to different insecticides in BPH populations at present.

The first ever report on insecticide resistance in BPH in India was from Godavari delta of Andhra Pradesh. The Godavari population showed very low levels of resistance to BPMC (2-sec-butylphenyl methylcarbamate (fenobucarb)) (2.30), followed by chlorpyriphos (2.20), phosphamidon (1.89), phorate (1.54), carbaryl (1.50), monocrotophos (1.35), carbofuran (1.24) and quinalphos (1.24) (Sarupa et al, 1998). Krishnaiah et al (2002) investigated the resistance development in BPH under greenhouse conditions by continuously exposing the insects to LC70 to LC80 concentrations of monocrotophos and the most effective neem formulation (NG 4) once in each generation continuously for 26 generations. The selected population showed 1.98- to 2.15-fold resistance to NG 4 and low cross resistance (1.11- to 1.96-fold) to monocrotophos, ethofenprox, BPMC, cartap hydrochloride and imidacloprid. Selection with monocrotophos resulted in slight resistance (1.16- to 2.41-fold) to monocrotophos, BPMC and cartap, but slightly higher cross resistance to ethofenprox (2.04- to 3.97-fold), NG 4 (3.00- to 3.97-fold) and imidaclorpid (2.76- to 5.38-fold), thus indicating cross resistance from monocrotophos to ethofenprox and imidacloprid.

Padmakumari et al (2002) also reported very low levels of insecticide resistance in BPH populations from Godavari delta of Andhra Pradesh. In Tamil Nadu of India, Sujatha and Regupathy (2003) recorded the resistance ratios of 4.0, 2.3 and 1.4 for carbofuran and 2.2, 1.7 and 1.3 for phosphamidoan based on LD50, LD90 and LD99 values, respectively after nine generations of laboratory selection by topical application of LD50 doses. The population failed to acquire resistance to neem oil after nine generations of selection. In Andhra Pradesh of India, a BPH population collected from East Godavari district exhibited 5- to 35-fold resistance to neonicotinoid insecticides like imidacloprid, thiamethoxam and clothianidin, but had no cross-resistance to phenyl pyrazoles like fipronil and ethiprole (Krishnaiah et al, 2006a). Similarly, Krishnaiah et al (2006b) reported the resistance levels to imidacloprid (35.13-fold), thiamethoxam (10.78-fold) and clothianidin (4.98-fold) varied in a BPH population from the same location.

Based on the literature regarding pest outbreak and resistance to different group of insecticides, study to assess the susceptibility of different N. lugens populations to insecticides in southern Karnataka, India was undertaken. Reports regarding this aspect are few from southern Karnataka, India and rice being one of the staple foods of this country, there is a need to protect the crop. This study will be the basis for further investigation to tackle this pest.

**MATERIALS AND METHODS**

**Mass rearing of BPH**

The test insect BPH was reared on the 55- to 60-day-old rice seedlings in wooden cages covered by wire mesh (Heinrichs et al, 1981). The planthoppers collected in a rice field were formed as an initial population as the starting culture. They were cultured on the susceptible rice variety, Jaya. The wooden cages were placed in a shaded area. Cage stands were placed in trays with water to prevent ants from entering the cage. About 55–60-day-old plants were offered for feeding and oviposition by the hoppers. Six to ten seedlings were planted in plastic pots of 10-cm in diameter, which were then placed in a larger crate filled with puddled soil and water. The cages were examined periodically for the presence of predators and other insect species. Whenever the predators or other species of insects were observed in the cages, they were removed promptly to facilitate the development of BPH population.

**Susceptibility of different BPH populations to insecticides**

Base-line data for insecticide susceptibility is necessary to assess the level of resistance in the field populations of the pest. This data is obtained by establishing the sensitivity of a laboratory susceptible population which has not been exposed to any insecticide for a long period.
Susceptible population

The nucleus culture of susceptible BPH population was procured from Rice Entomology Section, Zonal Agricultural Research Station, V. C. Farm, Mandya, Karnataka, India where the population had been maintained for more than 10 years (approximately 60 generations) without exposure to any insecticides. This culture was maintained on rice seedlings by adopting the mass-rearing technique as described above.

Field populations

Field populations of *N. lugens* collected from different rice growing areas of Karnataka, India viz. Gangavati, Kathalagere, Kollegala, Soraba and Mandya were used to study the susceptibility to different insecticides. Insects were collected as nymphs and adults during rice growing seasons. The insects were reared to F₁ generation in the laboratory on rice seedlings.

Insecticides

The commercial formulations of the insecticides used in the bioassay studies belonging to different groups are listed in Table 1.

Bioassay

Bioassay was carried out by two methods. The liquid formulated insecticides were tested by rice-stem dipping method and granular form of insecticide was tested by dry residue film assay. Three replicates were maintained for each dose of insecticide with water treated control. The treated insects were maintained at room temperature and the mortality was recorded at 4 d after the treatment. The nymphs were considered dead if they were unable to show movement after gentle prodding with a fine brush. The data were subjected to probit analysis (Finney, 1971) after converting the observed mortality into corrected mortality by using Abbott’s formula (Abbott, 1925) for developing regression equations for dosage-mortality responses and to determine the LC₅₀ values. All the analyses were performed using SPSS (Version 10).

Procedure for rice-stem dipping method

The rice-stem dipping method (Zhuang et al, 1999) was employed for the determination of median lethal concentrations (*LC₅₀* values) of the insecticides viz., buprofezin, imidacloprid, thiamethoxam, chlorpyriphos, acephate, fipronil, dinotefuran and clothianidin. For each insecticide, bracketing was done to fix the appropriate dosage range giving different levels of mortality of test insects. At least eight concentrations of insecticides were used in each bioassay. The rice seedlings of susceptible variety were grown in cement tanks filled with puddled soil. The seedlings of 55 to 60 days age were pulled out with roots and washed thoroughly. The basal 10 cm long stems were cut and air-dried to remove excess water. Three rice stems were grouped and dipped into appropriate insecticide dilutions for 30 s. Three replicates were maintained for each dose of insecticide with water treated control. After the treated rice stems were air-dried for a few minutes, individual rice stems were placed in 500-mL plastic cups with root portion placed in a mixture of vermicompost, sand and water. Fifteen early fifth-instar nymphs were introduced into each plastic cup using an aspirator and retained in the cup using muslin cloth tied with rubber band.

Procedure for dry residue film assay

The response of BPH populations to carbofuran was investigated by employing the dry-residue-film assay method. Bioassay was conducted by using clean glass Petri plates of 6 cm in diameter and glass vials of 25 mL capacity for serial dilution. Glasswares were soaked in soap water for 12 h and then washed in running water followed by rinsing with distilled water and then with acetone. After air drying, they were autoclaved at 110 °C for 6 h. Early fifth instar nymphs

| Table 1. Details of insecticides used in resistance studies. |
|---|---|---|---|---|
| Sl. No. | Common name | Trade name and formulation | Chemical group | Manufacturing company |
| 1. | Chlorpyriphos | Dursban 20 EC | Organophosphates | Dow AgroScience Ltd. |
| 2. | Acephate | Asataf 75 SP | Organophosphates | Rallis India Ltd. |
| 3. | Carbofuran | Furadan 3G | Carbamates | FMC India Pvt. Ltd. |
| 4. | Imidacloprid | Confidor 17.8 SL | Neonicotinoids | Bayer crop science Ltd. |
| 5. | Clothianidin | Dantop 50 WDG | Neonicotinoids | Nagarjuna agrichem Ltd. |
| 6. | Thiamethoxam | Actara 25 WG | Neonicotinoids | Syngenta India Ltd. |
| 7. | Dinotefuran | Token 20 SG | Neonicotinoids | Indofo chemicals company |
| 8. | Fipronil | Regent 5 SC | Phenyl pyrazoles | Bayer crop science Ltd. |
| 9. | Buprofezin | Applaud 25 SC | Thiadiazines | Rallis India Ltd. |
were selected for conducting the bioassay. Each bioassay included eight concentrations of the insecticide. The Petri plates were labeled before treatment. Serial dilutions of insecticide were prepared using acetone. Inner surface of each Petri plate was coated with 0.5 mL of each insecticide dilution. After pouring the insecticide solution, the plates were swirled by tilting and rotating till the acetone evaporated for uniform coating of insecticide. Fifteen early fifth instar nymphs were introduced into each Petri plate by using an aspirator. No food was provided for 30 min. The nymphs were then transferred into the plastic cups containing rice stems with root portion placed in a mixture of vermicompost, sand and water as done in rice-stem dipping method.

RESULTS

Susceptibility of different BPH populations to insecticides

Bioassays with five field populations (Mandya, Gangavati, Kathalagere, Kollegala and Soraba) of BPH obtained from different rice growing areas of Karnataka revealed that all populations varied in their susceptibility to various insecticides compared to the susceptible laboratory population (Table 2). The Gangavati and Kathalagere populations exhibited higher levels of resistance to majority of the insecticides followed by Kollegala and Soraba populations. The field population of Mandya showed lower levels of resistance to insecticides compared to other populations (Table 2).

In general, Soraba and Mandya populations were more susceptible to insecticides compared to Gangavati and Kathalagere populations. The resistance ratios varied greatly among the populations viz., chlorpyriphos (1.13 to 16.82), imidacloprid (0.53 to 13.50), acephate (1.34 to 5.32), fipronil (1.13 to 4.06), thiamethoxam (1.01 to 2.19), clothianidin (1.92 to 4.86), dinotefuran (0.82 to 2.22), buprofezin (1.06 to 5.43) and carbofuran (0.41 to 2.17). The populations from Gangavati, Kathalagere and Kollegala exhibited higher resistance to some of the older insecticides and low resistance to newer molecules.

DISCUSSION

In view of the reports of failure in controlling BPH populations by conventional insecticides in different parts of southern Karnataka, the present study was undertaken to assess the susceptibility of different BPH populations to insecticides. A total of five BPH field populations collected from different locations of Karnataka (Gangavati, Kathalagere, Kollegala, Soraba and Mandya) were studied for their susceptibility or resistance to the insecticides. These locations were selected based on the occurrence of the pest and extent of use of insecticides to manage it. In Gangavati (Koppal district) and Kathalagere (Davanagere district), rice crop is grown all-year round using very high agronomic inputs. The use of pesticide is also much higher compared to the usage in other rice growing areas of Karnataka such as Kollegala (Chamarajanagar district), Soraba (Shimoga district) and Mandya. As

Table 2. The probit analysis of dosage-mortality responses of field populations N. lugens to different groups of insecticides.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Parameter</th>
<th>Gangavati</th>
<th>Kathalagere</th>
<th>Kollegala</th>
<th>Soraba</th>
<th>Mandya</th>
<th>Susceptible laboratory population (CK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorpyriphos</td>
<td>LC50 (mg/kg)</td>
<td>159.02</td>
<td>178.58</td>
<td>77.48</td>
<td>12.09</td>
<td>30.02</td>
<td>10.61</td>
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<tr>
<td></td>
<td>Resistance ratio</td>
<td>14.98</td>
<td>16.82</td>
<td>7.29</td>
<td>1.13</td>
<td>2.82</td>
<td></td>
</tr>
<tr>
<td>Acephate</td>
<td>LC50 (mg/kg)</td>
<td>135.10</td>
<td>112.62</td>
<td>173.74</td>
<td>43.94</td>
<td>71.26</td>
<td>32.60</td>
</tr>
<tr>
<td></td>
<td>Resistance ratio</td>
<td>4.14</td>
<td>3.45</td>
<td>5.32</td>
<td>1.34</td>
<td>2.18</td>
<td></td>
</tr>
<tr>
<td>Carbofuran</td>
<td>LC50 (mg/kg)</td>
<td>0.29</td>
<td>0.47</td>
<td>0.30</td>
<td>0.11</td>
<td>0.05</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>Resistance ratio</td>
<td>2.17</td>
<td>3.52</td>
<td>2.22</td>
<td>0.86</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>Imidacloprid</td>
<td>LC50 (mg/kg)</td>
<td>45.66</td>
<td>50.12</td>
<td>26.83</td>
<td>3.34</td>
<td>1.81</td>
<td>3.38</td>
</tr>
<tr>
<td></td>
<td>Resistance ratio</td>
<td>13.50</td>
<td>8.90</td>
<td>7.93</td>
<td>0.98</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>Clothianidin</td>
<td>LC50 (mg/kg)</td>
<td>7.38</td>
<td>4.84</td>
<td>5.56</td>
<td>2.92</td>
<td>3.43</td>
<td>1.51</td>
</tr>
<tr>
<td></td>
<td>Resistance ratio</td>
<td>7.38</td>
<td>3.19</td>
<td>3.66</td>
<td>1.92</td>
<td>2.26</td>
<td></td>
</tr>
<tr>
<td>Thiamethoxam</td>
<td>LC50 (mg/kg)</td>
<td>7.74</td>
<td>7.02</td>
<td>3.88</td>
<td>3.70</td>
<td>3.56</td>
<td>3.52</td>
</tr>
<tr>
<td></td>
<td>Resistance ratio</td>
<td>2.19</td>
<td>1.99</td>
<td>1.10</td>
<td>1.05</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Dinotefuran</td>
<td>LC50 (mg/kg)</td>
<td>3.49</td>
<td>5.83</td>
<td>3.49</td>
<td>2.16</td>
<td>2.66</td>
<td>2.62</td>
</tr>
<tr>
<td></td>
<td>Resistance ratio</td>
<td>1.33</td>
<td>2.22</td>
<td>1.33</td>
<td>0.82</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Fipronil</td>
<td>LC50 (mg/kg)</td>
<td>6.85</td>
<td>8.64</td>
<td>5.59</td>
<td>2.41</td>
<td>4.38</td>
<td>2.12</td>
</tr>
<tr>
<td></td>
<td>Resistance ratio</td>
<td>3.22</td>
<td>4.06</td>
<td>2.62</td>
<td>1.13</td>
<td>2.06</td>
<td></td>
</tr>
<tr>
<td>Buprofezin</td>
<td>LC50 (mg/kg)</td>
<td>3.11</td>
<td>4.29</td>
<td>3.51</td>
<td>1.45</td>
<td>0.84</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Resistance ratio</td>
<td>3.94</td>
<td>5.43</td>
<td>4.45</td>
<td>1.84</td>
<td>1.06</td>
<td></td>
</tr>
</tbody>
</table>

Resistance ratio = LC50 of field population / LC50 of susceptible population.
the insecticide resistance development is a selection process, the level and rate of development of resistance is determined by the frequency of application of insecticides. Therefore, BPH populations in areas around Gangavati and Kathalagere, which are subjected to greater selection pressure, were expected to possess higher levels of resistance to insecticides compared to the populations from Kollegala, Soraba and Mandya areas. It was evident from the results that BPH populations from different regions of southern Karnataka differed significantly in their response to different insecticides. For example, Gangavati and Kathalagere populations had greater levels of resistance to the insecticides compared to Kollegala, Soraba and Mandya populations. Apart from the frequency of applications, the insecticide usage pattern, cropping pattern in different regions, and even the genetic variation in populations which are widely separated might have contributed for the observed variations in responses of BPH populations to insecticides. The significant intra-regional variation in susceptibility of different populations has been reported in China and Taiwan (Chung et al, 1981a); Japan (Endo et al, 1988); Korea (Kim and Hwang, 1987); United Kingdom (Tranter and Emden, 1984) and India (Sarupa et al, 1998; Krishnaiah et al, 2002).

**Resistance to organophosphorous insecticides**

The BPH populations exhibited low to moderate levels of resistance to two organophosphorous insecticides with the exception of Soraba and Mandya populations. Gangavati and Kathalagere populations were more resistant to chloropyriphos (14.98- and 16.82-fold, respectively) compared to the population from Kollegala. It was interesting to note that Kathalagere population was slightly more resistant to chloropyriphos compared to the Gangavati population where the farmers use more chemicals (Fig. 1). This could be explained by the fact that the farmers in Gangavati area have switched over to the use of new insecticide molecules such as neonicotinoids and buprofezin in recent years and the use of organophosphorous compounds has come down drastically. Similarly, Kollegala population exhibited higher level of resistance to acephate (5.32-fold) compared to Gangavati population (4.14-fold) as the farmers in Kollegala area still use organophosphorous compounds to manage BPH. Mandya and Soraba populations had extremely low or no resistance to chloropyriphos and acephate as the pest outbreaks are not common and hence, not subjected to severe insecticide pressure. The variation in the BPH resistance to other organophosphorous compounds has been reported in China and Taiwan (malathion and monocrotophos ranging from 2.4- to 15.5-fold (Wang and Ku, 1984)), Japan (fenthion, fenitrothion, cyanophenophos and malathion ranging from 20- to 423-fold (Ozaki and Kassai, 1982), United Kingdom (malathion and monocrotophos ranging from 5- to 6-fold (Ghorpade 1990, 1993)) and India (chlorpyriphos, phosphamidan, phorate, monocrotophos and quinalphos ranging from 1.24- to 2.20-fold (Sarupa et al, 1998), monocrotophos ranging from 1.16- to 2.41-fold.

![Insecticide Resistance in Different Populations of N. lugens](image)
Resistance to carbamate insecticide

The BPH populations exhibited very low or no resistance to the soil insecticide, carbofuran. Only Kathalagere, Kollegala and Gangavati populations showed slight resistance to carbofuran (2.17- to 3.52-fold) (Fig. 1). Earlier, Sujatha and Regupathy (2003) had recorded only 4-fold resistance to carbofuran in Coimbatore population of the pest, which is almost similar to the level of Kathalagere population observed in the current study. Even though granular insecticides like carbofuran are easy to apply and give protection for a long period, its method of application and time is not properly followed by the farmers. However, the frequent application has resulted in slightly higher level of resistance in Kathalagere population. Such variation in susceptibility to other carbamates was reported in China and Taiwan (Propoxur, isopropcarb, MIPC and carbofuran ranging from 8- to 72-fold (Chung et al, 1981b, 1982, Wang et al, 1988b)), Japan (carbofuran ranging from 2- to 5-fold (Heinrichs and Tetangco, 1978), United Kingdom (metolcarb and carbofuran ranging from 2- to 9-fold (Ghorpade, 1990)) and India (fenobucarb, carbaryl and carbofuran ranging from 1.24- to 2.30 -fold (Sarupa et al, 1998), BPMC ranging from 1.61- to 2.41-fold (Krishnaiah et al, 2002)).

Resistance to neonicotinoid compounds

In early 1970s and 1980s, the organophosphates (monocrotophos and acephate), carbamates (carbaryl and BPMC) and ether derivatives including ethofenprox were extensively used in India and other countries to suppress BPH populations. As a result, the planthopper pest became resistant to these insecticides in many countries and regions including Japan, Taiwan, China and the Philippines, although the insecticide resistance has been reported to be at its incipient stage in India (Sarupa et al, 1998; Padmakumari et al, 2002). Since late 1990's, a new group of insecticides called neonicotinoids viz., imidacloprid, thiamethoxam and clothianidin are extensively utilized for suppressing the planthopper populations in China, India, Taiwan, Japan and Korea. Their application at low doses (20–25 g/hm²) and economical advantage worked very well in favour of these neonicotinoids. However, their continuous use resulted in development of resistance in planthoppers against this new group of insecticides in China, Taiwan, Japan and Korea and suspected resistance in several rice growing tracts in India as well (Krishnaiah et al, 2006).

In the current investigation, the field populations from Gangavati, Kathalagere and Kollegala were relatively more tolerant to imidacloprid (13.50-, 8.90- and 7.93-fold, respectively), whereas the Soraba and Mandya populations were highly susceptible (Resistance ratio: 0.98- and 0.53-fold, respectively) (Fig. 1). The observed variation in the resistance levels reflect upon the extent of use of imidacloprid in the respective areas. The Soraba and Mandya populations are highly susceptible because the severe outbreak of the planthopper in these areas is rare and the selection pressure by insecticides is also extremely low. The BPH populations showed either very low or no resistance to other neonicotinoid compounds like clothianidin, thiamethoxam, and dinotefuran. Only in the case of clothianidin, the populations from Gangavati, Kathalagere and Kollegala showed 3.19- to 4.86-fold resistance while Mandya and Soraba populations were more or less susceptible with resistance ratios of 2.26- and 1.92-fold, respectively. Though the neonicotinoid, clothianidin is a relatively new compound and it is not commonly used by the farmers even in Gangavati, Kathalagere and Kollegala areas, the observed resistance to this could be attributed to the cross resistance from imidacloprid which is extensively used in these areas. Resistance to thiamethoxam and dinotefuran is very low and negligible even in imidacloprid resistant BPH populations. Thiamethoxam is not frequently used by farmers and also there appears to be no cross-resistance from imidacloprid as suggested by Wen et al (2009). But some of the reports suggest that the resistant strain selected with imidacloprid showed substantial cross-resistance to imidaclothiz, thiacloprid, and acetamiprid, and slight levels of cross-resistance to dinotefuran and thiamethoxam, but no cross-resistance to nitenpyram, buprofezin, and fipronil (Wang et al, 2009). Even, Liu et al (2003) reported that imidacloprid selected resistant strain showed cross-resistance to all the acetylcholine receptor targeting insecticides such as monosultap, acetamiprid and imidacloprid homologues, JS599 and JS598. Similarly, variation in resistance of different BPH populations to neonicotinoids has been reported by several workers (Nagata et al, 2002; Liu et al, 2006; Chau, 2007; Wang et al, 2008a, b; Matsumura et al, 2009; Matsumura and Morimura, 2010) in the several East Asian countries. In India, Krishnaiah et al
Insecticides compared to Gangavati and Kathalagere populations were more susceptible to their susceptibility to insecticides. The Soraba and Mandya. All the field populations differed in a particular population in southern Karnataka, India. Field populations of N. lugens (Stål) to insecticides.

Resistance to phenyl pyrazole compound

Very low levels of resistance, ranging from 1.13- to 4.06-fold to fipronil were recorded in all the populations of BPH. Amongst the five populations, Kathalagere population was relatively more tolerant compared to the Gangavati, Kollegala, Mandya and Soraba populations (Fig. 1). Higher resistance to fipronil in the Kathalagere population might due to the extensive use of this insecticide in that area. Similar observation was also made by Wang et al (2008a), who reported a higher level of resistance (10.5-fold) in a particular population in China. Since it is not commonly employed in suppression of BPH, the level of resistance to BPH is low in many countries, though traces of resistance development have been reported from Mekong Delta, Vietnam (Chau, 2007).

Resistance to thiadiazine compound

Buprofezin, a chitin synthesis inhibitor, has been used continuously by the farmers in suppression of BPH for more than five years in areas around Gangavati, Kathalagere and Kollegala, due to its effectiveness. However, the present results indicated that the pest has acquired low levels of resistance in Kathalagere (5.43-fold), Kollegala (4.45-folds) and Gangavati (3.94-fold) areas (Fig. 1). The Soraba and Mandya populations were still susceptible to buprofezin (Resistance ratios: 1.84- and 1.06-fold, respectively). The observed variation in resistance levels could be due to the differences in the selection pressures in different locations. Resistance to buprofezin has been reported only from Mekong Delta, Vietnam (Chau, 2007).

CONCLUSIONS

The current investigation was undertaken to study the level of insecticide resistance in different BPH populations from different locations in southern Karnataka, India. Field populations of N. lugens was collected from different rice growing areas of southern Karnataka viz. Gangavati, Kathalagere, Kollegala, Soraba and Mandya. All the field populations differed in their susceptibility to insecticides. The Soraba and Mandya populations were more susceptible to insecticides compared to Gangavati and Kathalagere populations. The populations from Gangavati, Kathalagere and Kollegala exhibited higher resistance to some of the conventional insecticides and low resistance to newer molecules.

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