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# Dynamics of resistance to organophosphate and carbamate insecticides in the cotton whitefly *Bemisia tabaci* (Hemiptera: Aleyrodidae) from Pakistan

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**Abstract** Field populations of adult whiteflies, *Bemisia tabaci,* from Pakistan were monitored from 1992 to 2007 for their susceptibility to seven organophosphate and three carbamate insecticides using a leaf-dip method. Malathion, quinalphos and chlorpyrifos generally exhibited no or a very low level of resistance in *B. tabaci* over a 16-year monitoring period. Resistance to profenofos, triazophos, parathion-methyl and ethion was usually low to high up to 1995, and then it dropped to very low levels during 1996–2004. Resistance levels again picked up from low to moderate levels for triazophos during 2005–2007, for parathion-methyl during 2003–2007, and for ethion in 2006. Among carbamates, thiodicarb resistance was high during 1994–1996, which dropped to moderate levels in 1997 and 1998 and to very low levels during 1999–2001, but again increased from low to high levels during 2002–2007. Methomyl resistance was moderate in 1994 and 1995, which dropped to very low levels during 1996–2002, and then increased to low levels during 2003–2007. Butocarboxim resistance remained very low during 1994–2003 and then increased from low to high levels during 2004–2007. The insecticides exhibiting no, very low or low resistance, and no cross-resistance among themselves can be exploited in devising an insecticide resistance management strategy to combat whitefly resistance in the field.

**Keywords** *Bemisia tabaci* · Insecticide resistance · Organophosphates · Carbamates · Pakistan

## Introduction

The cotton whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) has emerged as a major pest of cotton, vegetables and other crops in the tropical and sub-tropical regions of Asia, Africa, Australia, and Americas. It sucks plant sap and deposits sticky honeydew excretion, which promotes sooty mould that interferes with photosynthesis and reduces quality of the produce. Sticky cotton makes ginning and milling difficult. *B. tabaci* also transmits 111 virus diseases of plants worldwide, some of which are of high economic importance (Jones 2003). It is known to transmit >50 gemini viruses in South Asia. Cotton leaf curl, a devastating virus disease transmitted by *B. tabaci*, has plagued Pakistan and Western India for the last two decades.

The cotton whitefly is present throughout the year shifting from one crop to the other, and continually being subjected to selection pressure by insecticides used for its control. During early 1990s, its attack was phenomenal on cotton in Pakistan, mainly due to poor control with most conventional insecticides, which were used extensively during 1980s and 1990s for controlling sucking pests of cotton and vegetables, including whitefly. With the introduction of neonicotinoids like imidacloprid, acetamiprid and thiamethoxam, and insect growth regulators like buprofezin in mid 1990s, whitefly attacks subsided in the late

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1990s and early 2000s. However, its resurgence has now been witnessed in the provinces of Punjab and Sindh since mid 2000s. Monitoring of insecticide resistance revealed that this pest had developed a high level of resistance to organophosphates (OPs) like dimethoate, methamidophos and monocrotophos and to pyrethroids like cypermethrin and deltamethrin in Pakistan (Cahill et al. 1995; Ahmad et al. 2000, 2001, 2002). Concurrently, some commonly-used OPs and carbamates were still efficacious for whitefly control in the field. The studies reported herein were undertaken to assess the status of susceptibility/resistance of field populations of *B. tabaci* to the OPs (malathion, quinalphos, chlorpyrifos, profenofos, triazophos, methyl parathion, ethion) and carbamates (thiodicarb, methomyl, butocarboxim) during 1992–2007 to evolve an insecticide resistance management strategy.

## Materials and methods

### Whiteflies

Adult whiteflies were collected from different crops in southern Punjab within a radius of 50 km from Multan, Pakistan. Field populations were sampled from 8–10 random spots across a 2-ha block of a particular crop. Whiteflies were collected with a battery-operated aspirator in early hours of morning. Samples were pooled in wide-mouth jars ($11 \times 11 \times 19$ cm$^3$) and transferred to the laboratory in a cool-box to prevent mortality. The whiteflies were used for toxicity tests within 2 h of arrival in the laboratory. Before treatment, the jars were inverted (mouth down on a table), so that healthy individuals would climb to the top due to positive phototaxis. Disabled and dead individuals at the bottom were discarded.

### Insecticides

The commercial formulations of insecticides used for leaf-dip bioassays were: malathion 570 g/l EC (emulsifiable concentrate) (Fyfanon; Cheminova A/S, Lemvig, Denmark), quinalphos 250 g/l EC (Ekalux; Syngenta, Basle, Switzerland), chlorpyrifos 400 g/l EC (Lorsban; Dow AgroSciences, Indianapolis, IN, USA), profenofos 500 g/l EC (Curacron; Syngenta), triazophos 400 g/l EC (Hostathion; Bayer CropScience, Leverkusen, Germany), parathion-methyl 500 g/l EC (Folidol M; Bayer), ethion 468 g/l EC (FMC, Philadelphia, PA, USA), thiodicarb 800 g/kg DF (dry flowable) (Larvin; Bayer), methomyl 400 g/kg SP (water soluble powder) (Lannate; DuPont Agricultural Products, Wilmington, DE, USA), and butocarboxim 500 g/l EC (Drawin; Bayer).

### Bioassays

The bioassay technique was based on that described by Dittrich et al. (1985), in which whitefly adults of both sexes were exposed to treated leaf discs. The cotton leaf discs (38 mm diameter) were dipped into an ascending sequence of test concentrations of the respective insecticides for 10 s. After drying on a paper towel, the treated leaf discs were laid adaxial side down on a layer of 1% agar gel about 5 mm thick in the lids of plastic Petri dishes (39 mm diameter). Whiteflies were briefly immobilized with carbon dioxide and then transferred to the leaf discs in Petri dishes by tapping lightly with the forefinger to dispense 20–30 adults per lid of each dish. The other halves of the Petri dishes (39 mm diameter, 15 mm high), with mesh-covered holes on either side for ventilation, were used as lids. When adults recovered from narcosis, the dishes were inverted so that the leaf disc was adaxial side up and the adult whiteflies oriented normally. Treatment with each insecticide concentration was replicated four times alongside a similar untreated control. Serial dilutions of the test compounds at 0.4-fold intervals were prepared in distilled water on the basis of the percentage of active ingredient in the formulated insecticide. After treatment the laboratory temperature was maintained at 25 (±2)°C with a photoperiod of 14:10 h light:dark.

### Data analysis

Mortality was scored 24 h after the whiteflies were placed on treated leaf discs. Whiteflies were considered dead if they showed no sign of movement. Data were corrected for control mortality (Abbott 1925) and analyzed by probit analysis (Finney 1971) using Poloplus programme (LeOra Software 2003). The $LC_{50}$ and $LC_{90}$ values were calculated and any two values compared were considered significantly different if their respective 95% confidence limits (CLs) did not overlap. Resistance factors (RFs) were determined by dividing the lethal concentration (LC) values of each insecticide by the corresponding LC values for the T.S.Pur population, which generally showed reasonable lower LC values and thus served as a reference susceptible population. The 95% CLs for the RFs were determined according to Robertson and Preisler (1992). To interpret cross-resistance spectra among the insecticides tested, correlation coefficients for pairwise correlation of log $LC_{50}$s were calculated by the Pearson correlation formula according to Snedecor and Cockran (1989) using the MSTAT statistical computer programme (MSTAT-C 1989). As described previously (Ahmad and Arif 2009), resistance was generally classified as none (RF $\leq 1$), very low (RF = 2–10), low (RF = 11–20), moderate (RF = 21–50), high (RF = 51–100) and very high (RF >100).

## Results

### Baseline susceptibility

The LC values of chlorpyrifos and profenofos for the T.S.Pur reference population of *B. tabaci* were the same and lowest among the OPs (Table 1). The LC values of malathion and triazophos were slightly higher, but not different statistically, as compared with chlorpyrifos and profenofos. Quinalphos demonstrated a higher $LC_{50}$, but not the $LC_{90}$, than the above OPs. The LC values of parathion-methyl and ethion were the highest among the OPs tested.

The LC values of carbamates tested herein (Table 2) were not much different from some of the OPs (Table 1) for the reference population of *B. tabaci*. The LC values of thiodicarb and butocarboxim were similar, but higher than methomyl (Table 2). However, there were no statistical differences among LC values and slopes of the three carbamates. The LC values of all the OPs as well as carbamates for the T.S.Pur population were reasonably low, thus making it a good reference strain for using its baselines for resistance monitoring of *B. tabaci* in the future.

Except quinalphos, having a slope value of 2.7, all the OPs and carbamates had low slopes (<2) for the reference population of *B. tabaci*. The slopes of the regression lines for the other populations were generally low (<2) as well, which is typical for the field populations, showing a considerable heterogeneity.

### Organophosphates

From 1994 to 1998 and in 2000, no resistance was detected to malathion in the field populations of *B. tabaci* (Table 1). In the years 1999 and 2001–2007, a very low level of malathion resistance was found.

The Multan-3, Bosan-2, Lar-2 and Bosan-3 populations of *B. tabaci* tested in 1995, 1996, 1998 and 1999, respectively, were found to be susceptible to quinalphos (Table 1). Khanewal-1, Shershah-5, Lar-3 and Jehanian-3 populations tested in 1994, 2000–2003 and 2005 had a very low resistance at $LC_{50}$s but a low resistance at $LC_{90}$s. The rest of 10 populations exhibited a very low level of resistance to quinalphos.

Out of the 18 populations of *B. tabaci* monitored for resistance to chlorpyrifos, three populations viz. Shujabad-1, Khanewal-1 and Lar-2 populations tested in 1993, 1994, and 1998, respectively, exhibited a low resistance and the rest of 15 populations had a very low resistance, especially at $LC_{50}$s (Table 1).

There was no resistance to profenofos in Bosan-1 population of 1992 (Table 1). The Shujabad-1 and Khanewal-1 populations of 1993 and 1994, which had a low resistance to chlorpyrifos, showed a high level of resistance to profenofos. Multan-3 population tested in 1995 was moderately resistant and the Shershah-1 population, tested in 1993, had a low level of resistance to profenofos. The remaining 14 populations of *B. tabaci*, tested in 1992 and 1996–2007, demonstrated a very low level of profenofos resistance.

Like profenofos, there was no triazophos resistance in Bosan-1 population of 1992, but a low level of resistance in Shershah-1 population of 1993 (Table 1). Triazophos resistance in Shujabad-1 and Khanewal-1 populations, tested in 1993 and 1994, respectively, was moderate at $LC_{50}$s and high at $LC_{90}$s due to low slopes of regression lines. Resistance to triazophos in *B. tabaci* dropped to very low levels from 1995 to 2004. Triazophos resistance rose again to low to moderate levels during 2005–2007.

Khanewal-1 and Multan-3 populations of *B. tabaci,* tested in 1994 and 1995, respectively, showed a low resistance to parathion-methyl (Table 1). Parathion-methyl resistance then dropped to very low levels from 1996 to 2002. The resistance increased again from 2003 to 2007; it was low in 2004, moderate in 2003, 2005 and 2006, and moderate to high in 2007.

The resistance trend of ethion in *B. tabaci* was quite erratic during different years (Table 1). Bosan-1 population of 1992, Khanewal-2 of 1998 and Khokhran-3 of 2006 had moderate resistance whereas Shershah-1 of 1993 and Khanewal-1 of 1994 exhibited a high resistance. Bosan-2 population of 1996 had a low resistance whereas the populations tested in 1995 and 1999 displayed a very low resistance. Shujabad-1 population of 1993 and Kabirwala-1 population of 2001 showed a very low resistance at $LC_{50}$s but a low resistance at $LC_{90}$s. The LC values of Jehanian-2 population of 1997, Multan-4 of 2000 and Kabirwala-2 of 2004 were quite close to the susceptible reference population.

### Carbamates

Thiodicarb resistance was high in *B. tabaci* during 1994–1996. It dropped to moderate levels in 1997 and 1998, to very low levels in 1999 and 2001 and to low levels in 2002 and 2003 (Table 2). No resistance was found in the Multan-4 population tested in 2000. Thiodicarb resistance again rose to moderate to high levels during 2004–2007.

There was a moderate resistance to methomyl in the Khanewal-1 and Multan-3 populations of *B. tabaci* tested in 1994 and 1995, respectively (Table 2). The resistance reduced to very low levels during 1996–2002. Methomyl resistance again increased to low levels during 2003–2007.

Resistance to butocarboxim in the field populations of *B. tabaci* remained very low during 1994 to 2003 (Table 2). It then rose to low levels in 2004 and 2005, and to high levels in 2006 and 2007.

**Table 1** Toxicity of organophosphates against field populations of *Bemisia tabaci* collected from different locations of Punjab, Pakistan

| Insecticide | Location | Host | Date tested | No. tested | Fit of probit line | | | | $LC_{50}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{50}$ (95% CL) | $LC_{90}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{90}$ (95% CL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Slope ± SE | $\chi^2$ | df | *P* | | | | |
| Malathion | T.S.Pur | Cotton | Aug. 92 | 806 | 1.44 ± 0.11 | 5.31 | 5 | 0.38 | 2.01 (1.40–2.72) | 1.0 | 15.5 (10.9–24.6) | 1.0 |
| | Khanewal-1 | Brinjal | Mar. 94 | 911 | 1.24 ± 0.09 | 9.77 | 6 | 0.13 | 2.16 (1.36–3.17) | 1.1 (0.75–1.5) | 23.1 (14.5–43.9) | 1.5 (0.95–2.4) |
| | Multan-3 | Brinjal | Jul. 95 | 865 | 1.35 ± 0.09 | 5.72 | 6 | 0.46 | 1.59 (1.23–2.01) | 0.79 (0.56–1.1) | 14.2 (10.7–20.0) | 0.92 (0.59–1.4) |
| | Bosan-2 | Cotton | Aug. 96 | 877 | 1.38 ± 0.10 | 8.02 | 6 | 0.24 | 1.88 (1.25–2.64) | 0.94 (0.66–1.3) | 15.9 (10.8–26.7) | 1.0 (0.67–1.6) |
| | Jehanian-2 | Cotton | Sep. 97 | 818 | 1.33 ± 0.12 | 6.54 | 6 | 0.37 | 1.79 (1.11–2.60) | 0.89 (0.60–1.3) | 16.3 (11.0–27.5) | 1.1 (0.67–1.7) |
| | Lar-2 | Cotton | Sep. 98 | 888 | 1.20 ± 0.09 | 4.40 | 6 | 0.62 | 2.07 (1.54–2.70) | 1.0 (0.71–1.5) | 24.1 (17.5–35.7) | 1.6 (0.98–2.5) |
| | Bosan-3 | Brinjal | Mar. 99 | 632 | 1.17 ± 0.11 | 3.45 | 5 | 0.63 | 9.58 (6.68–13.1) | 4.8 (3.2–7.3) | 118 (80.3–197) | 7.6 (4.5–13) |
| | Multan-4 | Cotton | Sep. 00 | 692 | 1.26 ± 0.10 | 6.11 | 6 | 0.41 | 1.89 (1.29–2.65) | 0.94 (0.65–1.4) | 19.7 (12.9–34.5) | 1.3 (0.77–2.1) |
| | Kabirwala-1 | Cotton | Sep. 01 | 1255 | 1.38 ± 0.08 | 9.16 | 6 | 0.16 | 11.0 (8.04–14.5) | 5.5 (4.0–7.4) | 93.6 (66.1–147) | 6.0 (4.0–8.8) |
| | Khanewal-3 | Brinjal | Jun. 02 | 896 | 1.49 ± 0.12 | 2.55 | 6 | 0.86 | 14.2 (10.7–17.9) | 7.1 (5.0–10) | 102 (78.1–141) | 6.6 (4.4–10) |
| | Lar-3 | Cotton | Oct. 03 | 600 | 1.62 ± 0.15 | 3.95 | 4 | 0.41 | 16.4 (12.4–20.8) | 8.2 (5.7–12) | 101 (75.5–149) | 6.5 (4.1–10) |
| | Kabirwala-2 | Cotton | Sep. 04 | 855 | 1.47 ± 0.13 | 8.75 | 5 | 0.12 | 8.65 (4.36–14.0) | 4.4 (2.9–6.4) | 64.5 (41.4–120) | 4.2 (2.7–6.3) |
| | Jehanian-3 | Cotton | Oct. 05 | 547 | 1.54 ± 0.14 | 5.44 | 4 | 0.25 | 10.8 (6.50–16.2) | 5.4 (3.7–7.7) | 74.0 (46.0–155) | 4.8 (3.0–7.4) |
| | Khokhran-3 | Brinjal | Oct. 06 | 1251 | 1.13 ± 0.09 | 11.3 | 7 | 0.13 | 4.19 (2.35–6.44) | 2.1 (1.4-3.1) | 57.5 (36.3-109) | 3.7 (2.3-5.8) |
| | Shershah-6 | Cotton | Sep. 07 | 1899 | 1.27 ± 0.09 | 15.4 | 9 | 0.08 | 6.29 (4.40–8.44) | 3.1 (2.3–4.4) | 63.9 (43.8–107) | 4.1 (2.7–6.3) |
| Quinalphos | T.S.Pur | Cotton | Aug. 92 | 947 | 2.71 ± 0.23 | 3.63 | 5 | 0.60 | 2.75 (2.28–3.21) | 1.0 | 8.16 (6.99–9.81) | 1.0 |
| | Khanewal-1 | Brinjal | Mar. 94 | 1044 | 1.01 ± 0.07 | 12.3 | 7 | 0.09 | 8.63 (5.01–13.6) | 3.2 (2.2–4.4) | 162 (94.0–342) | 20 (13–30) |
| | Multan-2[a] | Cotton | Oct. 94 | 933 | 2.43 ± 0.19 | 3.52 | 4 | 0.47 | 10.3 (8.62–12.1) | 3.7 (2.9–4.8) | 34.9 (29.5–42.6) | 4.3 (3.3–5.4) |
| | Multan-3 | Brinjal | Jul. 95 | 852 | 1.44 ± 0.12 | 9.17 | 5 | 0.10 | 1.33 (0.74–2.03) | 0.48 (0.35–0.67) | 10.3 (6.53–20.1) | 1.3 (0.89–1.8) |
| | Bosan-2 | Cotton | Aug. 96 | 774 | 1.47 ± 0.12 | 4.68 | 5 | 0.46 | 2.05 (1.55–2.62) | 0.75 (0.55–1.0) | 15.2 (11.6–21.2) | 1.9 (1.3–2.7) |
| | Jehanian-2 | Cotton | Sep. 97 | 1194 | 1.67 ± 0.14 | 8.82 | 5 | 0.12 | 7.68 (4.59–11.0) | 2.8 (2.1–3.8) | 45.0 (31.2–76.2) | 5.5 (4.1–7.4) |
| | Khanewal-2[a] | Cotton | Jul. 98 | 878 | 1.82 ± 0.13 | 7.27 | 4 | 0.12 | 8.82 (5.88–12.2) | 3.2 (2.5–4.1) | 44.6 (30.7–76.6) | 5.5 (4.1–7.3) |
| | Lar-2 | Cotton | Sep. 98 | 791 | 1.31 ± 0.11 | 9.78 | 5 | 0.08 | 0.79 (0.39–1.27) | 0.29 (0.20–0.41) | 7.43 (4.46–16.2) | 0.91 (0.63–1.3) |
| | Bosan-3 | Brinjal | Mar. 99 | 863 | 1.14 ± 0.08 | 7.31 | 6 | 0.29 | 0.73 (0.51–1.01) | 0.27 (0.19–0.36) | 9.62 (6.17–17.3) | 1.2 (0.78–1.8) |
| | Shershah-5[a] | Brinjal | Jul. 00 | 708 | 1.52 ± 0.12 | 4.63 | 5 | 0.46 | 15.0 (11.4–18.9) | 5.5 (4.0–7.4) | 104 (79.0–146) | 13 (9.0–18) |
| | Multan-4 | Cotton | Sep. 00 | 500 | 2.55 ± 0.27 | 2.60 | 3 | 0.31 | 13.8 (11.2–16.4) | 5.0 (3.9–6.5) | 43.9 (36.1–57.1) | 5.4 (4.1–7.1) |
| | Bosan-4[a] | Squash | Dec. 00 | 771 | 1.48 ± 0.12 | 5.66 | 5 | 0.34 | 4.23 (2.89–5.79) | 1.5 (1.1–2.1) | 31.0 (21.2–52.6) | 3.8 (2.7–5.4) |
| | Kabirwala-1 | Cotton | Sep. 01 | 932 | 1.48 ± 0.12 | 9.95 | 6 | 0.13 | 10.9 (6.44–16.1) | 4.0 (2.9–5.5) | 79.7 (53.2–138) | 9.8 (7.1–14) |
| | Khanewal-3 | Brinjal | Jun. 02 | 896 | 1.21 ± 0.10 | 3.30 | 6 | 0.77 | 3.69 (2.73–4.81) | 1.3 (0.96–1.9) | 42.3 (30.2–65.0) | 5.2 (3.4–7.9) |
| | Lar-3 | Cotton | Oct. 03 | 731 | 1.41 ± 0.11 | 7.01 | 5 | 0.22 | 22.9 (14.6–33.1) | 8.3 (6.1–11) | 185 (119–349) | 23 (16–33) |
| | Kabirwala-2 | Cotton | Sep. 04 | 900 | 1.14 ± 0.06 | 11.6 | 7 | 0.11 | 2.89 (2.09–3.98) | 1.1 (0.80–1.4) | 38.8 (24.2–72.3) | 4.8 (3.2–6.9) |
| | Jehanian-3 | Cotton | Oct. 05 | 1058 | 1.49 ± 0.13 | 4.87 | 6 | 0.56 | 20.4 (14.9–26.3) | 7.4 (5.3–10) | 147 (114–201) | 18 (13–25) |
| | Khokhran-3 | Brinjal | Oct. 06 | 1084 | 1.26 ± 0.09 | 7.39 | 6 | 0.29 | 3.57 (2.34–5.07) | 1.3 (0.94–1.8) | 37.3 (25.3–61.3) | 4.6 (3.2–6.5) |
| | Shershah-6 | Cotton | Sep. 07 | 832 | 1.29 ± 0.09 | 6.97 | 6 | 0.32 | 5.32 (3.71–7.29) | 1.9 (1.4–2.6) | 51.9 (35.0–86.9) | 6.4 (4.4–9.4) |

**Table 1** continued

| Insecticide | Location | Host | Date tested | No. tested | Fit of probit line | | | | $LC_{50}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{50}$ (95% CL) | $LC_{90}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{90}$ (95% CL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Slope ± SE | $\chi^2$ | df | $P$ | | | | |
| Chlorpyrifos | T.S.Pur | Cotton | Aug. 92 | 801 | 1.51 ± 0.12 | 7.05 | 5 | 0.22 | 1.59 (1.06–2.22) | 1.0 | 11.2 (7.56–19.7) | 1.0 |
| | Bosan-1 | Squash | Dec. 92 | 642 | 1.43 ± 0.12 | 8.83 | 4 | 0.07 | 1.83 (0.99–2.97) | 1.2 (0.82–1.6) | 14.4 (8.00–39.7) | 1.3 (0.81–2.0) |
| | Shershah-1 | Brinjal | May 93 | 997 | 1.50 ± 0.09 | 6.63 | 5 | 0.25 | 6.66 (4.95–8.69) | 4.2 (3.1–5.7) | 47.7 (34.0–74.2) | 4.3 (2.9–6.3) |
| | Shujabad-1 | Cotton | Sep. 93 | 1056 | 1.43 ± 0.11 | 7.93 | 5 | 0.16 | 17.2 (10.9–24.6) | 11 (7.8–15) | 135 (90.7–235) | 12 (8.1–18) |
| | Khanewal-1 | Brinjal | Mar. 94 | 928 | 1.15 ± 0.09 | 4.51 | 6 | 0.61 | 17.2 (12.8–22.4) | 11 (7.6–16) | 221 (158–335) | 20 (12–33) |
| | Multan-3 | Brinjal | Jul. 95 | 670 | 1.76 ± 0.14 | 5.80 | 3 | 0.12 | 7.21 (4.39–10.7) | 4.5 (3.4–6.1) | 38.6 (23.7–89.4) | 3.4 (2.3–5.1) |
| | Bosan-2 | Cotton | Aug. 96 | 1019 | 1.47 ± 0.11 | 12.3 | 5 | 0.03 | 6.09 (3.46–9.33) | 3.8 (1.9–7.7) | 45.5 (28.1–94.7) | 4.1 (1.5–11) |
| | Jehanian-2 | Cotton | Sep. 97 | 957 | 1.21 ± 0.08 | 5.91 | 6 | 0.43 | 4.08 (3.04–5.28) | 2.6 (1.8–3.7) | 46.6 (34.8–66.1) | 4.2 (2.7–6.5) |
| | Lar-2[a] | Cotton | Sep. 98 | 1061 | 1.58 ± 0.10 | 7.58 | 5 | 0.18 | 22.1 (16.0–29.4) | 14 (10–19) | 143 (100–228) | 13 (8.7–19) |
| | Bosan-3[a] | Brinjal | Mar. 99 | 738 | 1.32 ± 0.10 | 5.62 | 5 | 0.34 | 6.50 (4.36–9.10) | 4.1 (2.9–5.8) | 60.9 (40.2–108) | 5.4 (3.4–8.5) |
| | Khokhran-2 | Cotton | Sep. 99 | 992 | 1.33 ± 0.10 | 7.56 | 6 | 0.27 | 10.8 (6.90–15.3) | 6.8 (4.7–9.7) | 99.7 (68.5–163) | 8.9 (5.7–13) |
| | Multan-4 | Cotton | Sep. 00 | 600 | 1.93 ± 0.19 | 4.46 | 4 | 0.35 | 14.8 (0.55–20.6) | 9.3 (6.6–13) | 68.5 (47.8–117) | 6.1 (4.0–9.2) |
| | Kabirwala-1 | Cotton | Sep. 01 | 1120 | 1.03 ± 0.09 | 11.8 | 8 | 0.16 | 12.2 (6.44–19.4) | 7.7 (4.9–12) | 216 (128–467) | 19 (11–32) |
| | Khanewal-3 | Brinjal | Jun. 02 | 896 | 1.18 ± 0.09 | 9.44 | 6 | 0.15 | 5.40 (3.17–8.26) | 3.4 (2.3–5.0) | 65.8 (40.2–131) | 5.9 (3.7–9.4) |
| | Lar-3 | Cotton | Oct. 03 | 600 | 2.10 ± 0.21 | 5.33 | 4 | 0.26 | 7.41 (4.86–10.1) | 4.7 (3.4–6.4) | 30.1 (21.0–53.3) | 2.7 (1.8–4.0) |
| | Kabirwala-2 | Cotton | Sep. 04 | 700 | 1.48 ± 0.12 | 9.28 | 5 | 0.10 | 4.38 (2.75–6.47) | 2.8 (2.0–3.8) | 32.2 (19.8–67.5) | 2.9 (1.8–4.5) |
| | Jehanian-3 | Cotton | Oct. 05 | 894 | 1.22 ± 0.09 | 7.60 | 6 | 7.60 | 12.3 (8.17–17.4) | 7.7 (5.5–11) | 137 (89.6–240) | 12 (7.8–20) |
| | Khokhran-3 | Brinjal | Oct. 06 | 717 | 1.22 ± 0.09 | 4.44 | 5 | 0.49 | 4.59 (3.58–5.82) | 2.9 (2.1–4.1) | 51.1 (36.0–79.7) | 4.6 (2.8–7.6) |
| | Shershah-6 | Cotton | Sep. 07 | 832 | 1.33 ± 0.10 | 7.44 | 6 | 0.26 | 2.29 (1.51–3.22) | 1.4 (1.0–2.1) | 20.9 (13.9–35.9) | 1.9 (1.2–3.0) |
| Profenofos | T.S.Pur | Cotton | Aug. 92 | 770 | 1.46 ± 0.11 | 4.72 | 5 | 0.45 | 1.60 (1.24–2.01) | 1.0 | 12.0 (9.06–17.1) | 1.0 |
| | Bosan-1 | Squash | Dec. 92 | 910 | 1.28 ± 0.11 | 8.20 | 6 | 0.22 | 2.04 (1.19–3.09) | 1.3 (0.85–1.9) | 20.6 (13.3–37.2) | 1.7 (1.1–2.7) |
| | Shershah-1 | Brinjal | May 93 | 987 | 1.91 ± 0.20 | 15.1 | 6 | 0.02 | 24.7 (12.1–36.6) | 15 (11–22) | 116 (78.9–227) | 9.7 (6.5–14) |
| | Shujabad-1 | Cotton | Sep. 93 | 976 | 1.38 ± 0.10 | 8.76 | 6 | 0.19 | 73.4 (49.2–103) | 46 (33–65) | 619 (413–1063) | 52 (33–81) |
| | Khanewal-1 | Brinjal | Mar. 94 | 700 | 1.34 ± 0.10 | 6.39 | 5 | 0.27 | 93.4 (61.6–133) | 58 (41–84) | 841 (546–1533) | 70 (44–112) |
| | Multan-3 | Brinjal | Jul. 95 | 600 | 1.64 ± 0.16 | 3.44 | 4 | 0.49 | 54.3 (41.4–68.5) | 34 (24–48) | 330 (244–494) | 27 (17–43) |
| | Bosan-2[a] | Cotton | Aug. 96 | 1195 | 1.43 ± 0.10 | 9.87 | 6 | 0.13 | 4.46 (2.87–6.31) | 2.8 (2.0–4.0) | 35.0 (24.1–57.4) | 2.9 (1.9–4.4) |
| | Jehanian-2 | Cotton | Sep. 97 | 1177 | 1.58 ± 0.11 | 7.37 | 7 | 0.39 | 2.49 (1.76–3.28) | 1.6 (1.1–2.2) | 16.2 (12.5–22.1) | 1.3 (0.90–2.0) |
| | Khanewal-2[a] | Cotton | Jul. 98 | 953 | 1.60 ± 0.09 | 6.77 | 5 | 0.24 | 7.23 (5.51–9.31) | 4.5 (3.4–6.1) | 45.7 (32.7–70.4) | 3.8 (2.5–5.7) |
| | Lar-2[a] | Cotton | Sep. 98 | 1074 | 1.38 ± 0.09 | 7.99 | 5 | 0.16 | 10.4 (7.28–14.2) | 6.5 (4.8–8.9) | 88.4 (59.0–154) | 7.4 (4.8–11) |
| | Bosan-3 | Brinjal | Mar. 99 | 725 | 1.40 ± 0.09 | 5.88 | 5 | 0.32 | 4.73 (3.54–6.26) | 3.0 (2.2–4.1) | 38.8 (25.9–67.1) | 3.2 (2.0–5.1) |
| | Multan-4 | Cotton | Sep. 00 | 1148 | 1.16 ± 0.08 | 8.81 | 7 | 0.27 | 2.15 (1.38–3.13) | 1.3 (0.91–2.0) | 27.2 (18.2–45.0) | 2.3 (1.4–3.6) |
| | Kabirwala-1 | Cotton | Sep. 01 | 756 | 1.41 ± 0.14 | 6.70 | 5 | 0.24 | 5.12 (2.97–7.64) | 3.2 (2.2–4.7) | 41.5 (26.2–83.7) | 3.5 (2.1–5.6) |
| | Khanewal-3 | Brinjal | Jun. 02 | 1008 | 1.09 ± 0.08 | 8.85 | 7 | 0.26 | 7.35 (4.68–10.7) | 4.6 (3.1–6.8) | 109 (70.4–191) | 9.1 (5.7–15) |
| | Lar-3 | Cotton | Oct. 03 | 801 | 1.18 ± 0.10 | 7.17 | 6 | 0.31 | 8.09 (5.16–11.8) | 5.1 (3.4–7.5) | 98.4 (61.5–189) | 8.2 (4.9–14) |

**Table 1** continued

| Insecticide | Location | Host | Date tested | No. tested | Fit of probit line | | | | LC$_{50}$ (mg l$^{-1}$) (95% CL) | RF at LC$_{50}$ (95% CL) | LC$_{90}$ (mg l$^{-1}$) (95% CL) | RF at LC$_{90}$ (95% CL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Slope ± SE | $\chi^2$ | df | *P* | | | | |
| | Kabirwala-2 | Cotton | Oct. 04 | 928 | 1.08 ± 0.08 | 7.12 | 6 | 0.31 | 5.87 (3.67–8.66) | 3.7 (2.5–5.5) | 90.2 (56.2–171) | 7.5 (4.5–12) |
| | Jehanian-3 | Cotton | Oct. 05 | 875 | 1.33 ± 0.11 | 5.36 | 6 | 0.50 | 4.38 (3.22–5.71) | 2.7 (1.9–4.0) | 40.0 (29.5–57.9) | 3.3 (2.1–5.3) |
| | Khokhran-3 | Brinjal | Oct. 06 | 734 | 1.32 ± 0.10 | 6.05 | 5 | 0.30 | 7.61 (5.16–10.7) | 4.8 (3.4–6.8) | 70.6 (46.1–127) | 5.9 (3.7–9.5) |
| | Shershah-6 | Cotton | Sep. 07 | 976 | 1.28 ± 0.09 | 5.10 | 6 | 0.53 | 10.9 (8.37–13.9) | 6.8 (4.8–9.7) | 109 (80.8–155) | 9.1 (5.8–14) |
| Triazophos | T.S.Pur | Cotton | Aug. 92 | 1091 | 1.97 ± 0.15 | 4.81 | 6 | 0.57 | 2.32 (1.85-2.79) | 1.0 | 10.4 (8.71–12.8) | 1.0 |
| | Bosan-1 | Squash | Dec. 92 | 506 | 1.71 ± 0.14 | 8.27 | 4 | 0.08 | 2.44 (1.51–3.73) | 1.1 (0.78–1.4) | 13.7 (8.04–34.3) | 1.3 (0.90–1.9) |
| | Shershah-1 | Brinjal | May 93 | 600 | 2.17 ± 0.20 | 1.89 | 4 | 0.76 | 36.5 (29.4–44.0) | 16 (12–21) | 142 (114–189) | 14 (10–19) |
| | Shujabad-1 | Cotton | Sep. 93 | 984 | 1.19 ± 0.08 | 6.46 | 5 | 0.26 | 57.9 (39.6–81.0) | 25 (18–34) | 692 (440–1289) | 67 (44–99) |
| | Khanewal-1 | Brinjal | Mar. 94 | 1044 | 0.98 ± 0.07 | 10.4 | 7 | 0.17 | 49.7 (29.0–77.5) | 21 (14–31) | 1021 (607–2057) | 98 (61–150) |
| | Multan-3 | Brinjal | Jul. 95 | 501 | 1.78 ± 0.18 | 6.94 | 3 | 0.07 | 8.79 (3.72–15.0) | 3.8 (2.7–5.2) | 46.1 (25.2–180) | 4.4 (3.0–6.5) |
| | Bosan-2[a] | Cotton | Aug. 96 | 751 | 1.30 ± 0.10 | 7.12 | 5 | 0.21 | 16.7 (10.4–24.7) | 7.2 (5.1–10) | 162 (101–317) | 16 (10–23) |
| | Jehanian-2 | Cotton | Sep. 97 | 915 | 1.62 ± 0.15 | 6.21 | 5 | 0.29 | 3.45 (2.14–4.87) | 1.5 (1.1–2.1) | 21.2 (15.0–34.1) | 2.0 (1.5–2.9) |
| | Khanewal-2[a] | Cotton | Jul. 98 | 847 | 1.57 ± 0.11 | 8.04 | 4 | 0.09 | 10.7 (6.98–15.3) | 4.6 (3.5–6.1) | 70.1 (44.9–137) | 6.7 (4.9–9.4) |
| | Lar-2 | Cotton | Sep. 98 | 700 | 1.48 ± 0.11 | 7.83 | 5 | 0.17 | 9.01 (6.12–12.7) | 3.9 (2.9–5.3) | 65.8 (42.3–124) | 6.3 (4.4–9.3) |
| | Bosan-3 | Brinjal | Mar. 99 | 1218 | 1.40 ± 0.10 | 7.57 | 6 | 0.27 | 10.3 (6.98–14.1) | 4.4 (3.2–6.1) | 84.5 (60.3–131) | 8.1 (5.9–11) |
| | Multan-4[a] | Cotton | Sep. 00 | 806 | 1.39 ± 0.11 | 8.89 | 5 | 0.11 | 9.23 (5.63–13.7) | 4.0 (2.9–5.5) | 77.6 (48.0–159) | 7.5 (5.1–11) |
| | Kabirwala-1 | Cotton | Sep. 01 | 864 | 1.24 ± 0.10 | 6.47 | 6 | 0.37 | 5.08 (3.29–7.26) | 2.2 (1.5–3.2) | 54.8 (36.6–93.1) | 5.3 (3.5–7.9) |
| | Khanewal-3 | Brinjal | Jun. 02 | 896 | 1.14 ± 0.09 | 7.26 | 6 | 0.30 | 6.94 (4.44–10.1) | 3.0 (2.1–4.3) | 91.6 (57.8–171) | 8.8 (5.8–14) |
| | Lar-3 | Cotton | Oct. 03 | 961 | 1.81 ± 0.20 | 14.3 | 5 | 0.01 | 12.4 (4.91–20.0) | 5.3 (3.8–7.4) | 63.0 (39.0–166) | 6.1 (4.3–8.4) |
| | Kabirwala-2 | Cotton | Oct. 04 | 854 | 1.21 ± 0.09 | 8.87 | 6 | 0.18 | 13.2 (8.53–19.1) | 5.7 (4.1–7.9) | 151 (94.5–286) | 15 (9.7–22) |
| | Jehanian-3 | Cotton | Oct. 05 | 967 | 1.20 ± 0.09 | 9.48 | 6 | 0.15 | 36.0 (22.8–53.2) | 16 (11–22) | 425 (261–836) | 41 (26–61) |
| | Khokhran-3 | Brinjal | Oct. 06 | 832 | 1.27 ± 0.09 | 7.53 | 6 | 0.27 | 32.3 (22.1–44.9) | 14 (10–19) | 327 (217–566) | 31 (22–47) |
| | Shershah-6 | Cotton | Sep. 07 | 600 | 1.87 ± 0.17 | 7.45 | 4 | 0.11 | 96.5 (55.3–145) | 42 (31–57) | 467 (295–996) | 45 (32–64) |
| Parathion-methyl | T.S.Pur | Cotton | Aug. 92 | 700 | 1.71 ± 0.16 | 3.48 | 5 | 0.63 | 3.27 (2.42–4.18) | 1.0 | 18.3 (14.1–25.6) | 1.0 |
| | Khanewal–1 | Brinjal | Mar. 94 | 890 | 1.39 ± 0.11 | 6.90 | 5 | 0.23 | 38.6 (23.7–56.7) | 12 (8.0–18) | 320 (208–582) | 17 (11–28) |
| | Multan-3 | Brinjal | Jul. 95 | 723 | 1.21 ± 0.10 | 7.29 | 5 | 0.20 | 40.2 (24.2–60.9) | 12 (8.2–18) | 462 (273–1004) | 25 (15–41) |
| | Bosan-2 | Cotton | Aug. 96 | 1139 | 1.30 ± 0.10 | 13.4 | 5 | 0.02 | 8.88 (4.60–14.3) | 2.7 (1.9–3.9) | 86.0 (49.5–209) | 4.7 (3.0–7.2) |
| | Jehanian-2 | Cotton | Sep. 97 | 765 | 1.33 ± 0.11 | 4.89 | 5 | 0.43 | 6.08 (4.56–7.82) | 1.9 (1.3–2.7) | 56.2 (41.5–82.2) | 3.1 (1.9–4.8) |
| | Lar-2 | Cotton | Sep. 98 | 1006 | 1.53 ± 0.09 | 10.5 | 5 | 0.6 | 9.73 (6.99–13.2) | 3.0 (2.2–4.1) | 67.0 (44.4–119) | 3.7 (2.5–5.4) |
| | Bosan-3 | Brinjal | Mar. 99 | 733 | 1.34 ± 0.10 | 7.70 | 5 | 0.17 | 19.1 (12.1–28.0) | 5.8 (4.0–8.4) | 174 (109–344) | 9.5 (5.9–15) |
| | Multan-4[a] | Cotton | Sep. 00 | 761 | 1.50 ± 0.11 | 9.73 | 5 | 0.08 | 20.1 (12.8–29.5) | 6.1 (4.3–8.8) | 144 (90.3–284) | 7.9 (5.1–12) |
| | Kabirwala-1 | Cotton | Sep. 01 | 1096 | 0.89 ± 0.07 | 12.7 | 8 | 0.12 | 17.3 (8.89–29.3) | 5.3 (3.3–8.5) | 480 (266–1080) | 26 (15–45) |
| | Khanewal-3 | Brinjal | Jun. 02 | 737 | 1.36 ± 0.12 | 6.87 | 5 | 0.23 | 16.9 (9.98–25.4) | 5.2 (3.5–7.7) | 149 (95.1–280) | 8.1 (5.1–13) |
| | Lar-3 | Cotton | Oct. 03 | 898 | 1.30 ± 0.09 | 6.41 | 5 | 0.27 | 94.0 (63.1–132) | 29 (20–41) | 917 (606–1603) | 50 (32–75) |

**Table 1** continued

| Insecticide | Location | Host | Date tested | No. tested | Fit of probit line |  |  |  | $LC_{50}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{50}$ (95% CL) | $LC_{90}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{90}$ (95% CL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Slope ± SE | $\chi^2$ | df | *P* |  |  |  |  |
|  | Kabirwala-2 | Cotton | Sep. 04 | 797 | 1.38 ± 0.10 | 6.02 | 5 | 0.30 | 45.1 (31.2–62.1) | 14 (9.5–20) | 384 (256–671) | 21 (13–32) |
|  | Jehanian-3 | Cotton | Oct. 05 | 755 | 1.23 ± 0.09 | 8.83 | 6 | 0.18 | 84.6 (54.6–123) | 26 (18–38) | 932 (589–1746) | 51 (32–81) |
|  | Khokhran-3 | Brinjal | Oct. 06 | 808 | 1.18 ± 0.08 | 9.67 | 6 | 0.14 | 79.4 (50.0–119) | 24 (16–35) | 975 (588–1969) | 53 (32–84) |
|  | Shershah-6 | Cotton | Sep. 07 | 936 | 1.14 ± 0.08 | 8.97 | 7 | 0.25 | 122 (81.3–175) | 37 (25–55) | 1630 (1060–2851) | 89 (56–141) |
| Ethion | T.S.Pur | Cotton | Aug. 92 | 600 | 1.59 ± 0.11 | 1.61 | 4 | 0.81 | 4.61 (3.85–5.50) | 1.0 | 29.6 (22.7–41.1) | 1.0 |
|  | Bosan-1[a] | Squash | Dec. 92 | 1058 | 1.32 ± 0.11 | 6.27 | 6 | 0.39 | 82.2 (53.9–115) | 18 (13–25) | 767 (538–1221) | 26 (17–40) |
|  | Shershah-1[a] | Brinjal | May 93 | 1634 | 1.22 ± 0.07 | 9.09 | 8 | 0.33 | 346 (256–448) | 75 (55–99) | 3919 (2905–5648) | 132 (86–193) |
|  | Shujabad-1[a] | Cotton | Sep. 93 | 1237 | 1.09 ± 0.08 | 4.13 | 8 | 0.85 | 30.7 (21.3–41.8) | 6.7 (4.6–9.8) | 458 (333–668) | 15 (10–25) |
|  | Khanewal-1 | Brinjal | Mar. 94 | 964 | 1.53 ± 0.10 | 8.59 | 5 | 0.13 | 314 (212–438) | 68 (52–90) | 2164 (1459–3730) | 73 (49–110) |
|  | Shershah-3[a] | Cotton | Sep. 95 | 896 | 1.39 ± 0.11 | 5.27 | 6 | 0.51 | 11.1 (7.90–14.7) | 2.4 (1.7–3.4) | 93.3 (70.1–132) | 3.2 (2.0–4.8) |
|  | Bosan-2[a] | Cotton | Aug. 96 | 1096 | 1.32 ± 0.10 | 7.68 | 6 | 0.26 | 54.0 (35.5–76.1) | 12 (8.5–16) | 504 (344–830) | 17 (11–27) |
|  | Jehanian-2 | Cotton | Sep. 97 | 1223 | 1.01 ± 0.07 | 9.93 | 7 | 0.19 | 6.11 (3.79–9.13) | 1.3 (0.93–1.9) | 113 (69.9–216) | 3.8 (2.4–6.3) |
|  | Khanewal-2 | Cotton | Jul. 98 | 965 | 1.51 ± 0.10 | 10.3 | 5 | 0.07 | 160 (106–226) | 35 (27–45) | 1126 (729–2111) | 38 (26–57) |
|  | Bosan-3[a] | Brinjal | Mar. 99 | 872 | 1.20 ± 0.09 | 13.4 | 5 | 0.02 | 21.5 (10.8–36.9) | 4.7 (3.4–6.5) | 251 (129–781) | 8.5 (5.2–14) |
|  | Khokhran-2[a] | Cotton | Sep. 99 | 613 | 1.56 ± 0.14 | 3.98 | 4 | 0.41 | 22.2 (16.8–28.2) | 4.8 (3.6–6.7) | 147 (111–209) | 5.0 (3.3–7.9) |
|  | Multan-4 | Cotton | Sep. 00 | 600 | 2.46 ± 0.27 | 3.93 | 4 | 0.42 | 10.4 (8.13–12.6) | 2.3 (1.7–3.0) | 34.4 (28.2–44.8) | 1.2 (0.81–1.7) |
|  | Kabirwala-1 | Cotton | Sep. 01 | 878 | 1.19 ± 0.08 | 9.82 | 6 | 0.13 | 34.8 (22.6–50.6) | 7.5 (5.6–10) | 412 (253–808) | 14 (8.9–23) |
|  | Kabirwala-2 | Cotton | Sep. 04 | 628 | 1.81 ± 0.19 | 8.63 | 4 | 0.07 | 6.96 (3.27–11.1) | 1.5 (1.1–2.1) | 35.5 (21.5–91.0) | 1.2 (0.79–1.9) |
|  | Khokhran-3 | Brinjal | Oct. 06 | 865 | 1.22 ± 0.10 | 7.76 | 7 | 0.35 | 98.8 (62.8–143) | 21 (15–31) | 1119 (749–1874) | 38 (23–59) |

[a] Data partially adapted from Ahmad (2007)

**Table 2** Toxicity of carbamates against field populations of *Bemisia tabaci* collected from different locations of Punjab, Pakistan

| Insecticide | Location | Host | Date tested | No. tested | Fit of probit line |  |  |  | $LC_{50}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{50}$ (95% CL) | $LC_{90}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{90}$ (95% CL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Slope ± SE | $\chi^2$ | df | *P* |  |  |  |  |
| Thiodicarb | T.S.Pur | Cotton | Aug. 92 | 808 | 1.57 ± 0.12 | 5.98 | 5 | 0.31 | 3.59 (2.56–4.81) | 1.0 | 23.6 (16.5–38.0) | 1.0 |
|  | Khanewal-1 | Brinjal | Mar. 94 | 500 | 1.74 ± 0.17 | 0.74 | 3 | 0.86 | 410 (318–511) | 114 (84–160) | 2224 (1658–3306) | 94 (62–151) |
|  | Multan-3 | Brinjal | Jul. 95 | 1008 | 1.30 ± 0.08 | 9.62 | 5 | 0.09 | 287 (187–413) | 80 (58–107) | 2789 (1754–5389) | 118 (77–176) |
|  | Bosan-2 | Cotton | Aug. 96 | 709 | 1.28 ± 0.11 | 6.40 | 5 | 0.27 | 235 (140–352) | 65 (45–94) | 2362 (1492–4516) | 100 (63–157) |
|  | Jehanian-2 | Cotton | Sep. 97 | 700 | 1.31 ± 0.13 | 14.3 | 5 | 0.01 | 83.3 (31.1–153) | 23 (16–34) | 789 (392–3315) | 33 (21–56) |
|  | Lar-2 | Cotton | Sep. 98 | 823 | 1.25 ± 0.10 | 6.50 | 6 | 0.37 | 77.5 (50.8–110) | 22 (15–31) | 824 (543–1435) | 35 (22–55) |
|  | Bosan-3 | Brinjal | Mar. 99 | 464 | 1.21 ± 0.11 | 2.17 | 6 | 0.90 | 20.6 (13.9–28.9) | 5.7 (3.7–8.8) | 235 (156–400) | 10 (5.8–17) |
|  | Multan-4 | Cotton | Sep. 00 | 1051 | 1.28 ± 0.10 | 4.12 | 6 | 0.66 | 2.99 (2.17–3.91) | 0.83 (0.58–1.2) | 29.8 (22.4–42.1) | 1.3 (0.83–2.0) |
|  | Kabirwala-1 | Cotton | Sep. 01 | 1215 | 1.69 ± 0.10 | 3.44 | 7 | 0.84 | 22.7 (19.2–26.4) | 6.3 (4.8–8.3) | 130 (107–162) | 5.5 (3.9–7.9) |
|  | Khanewal-3 | Brinjal | Jun. 02 | 928 | 1.15 ± 0.08 | 7.36 | 6 | 0.29 | 35.8 (23.3–51.4) | 10 (7.0–14) | 464 (299–837) | 20 (12–32) |
|  | Lar-3 | Cotton | Oct. 03 | 976 | 1.48 ± 0.15 | 8.02 | 6 | 0.24 | 50.2 (29.4–72.5) | 14 (9.6–20) | 370 (254–645) | 16 (10–24) |
|  | Kabirwala-2 | Cotton | Sep. 04 | 936 | 1.16 ± 0.08 | 6.67 | 7 | 0.46 | 125 (91.4–164) | 35 (24–50) | 1591 (1052–2717) | 67 (42–106) |
|  | Jehanian-3 | Cotton | Oct. 05 | 657 | 1.96 ± 0.16 | 3.88 | 4 | 0.42 | 201 (163–241) | 56 (41–74) | 907 (724–1199) | 38 (26–56) |
|  | Khokhran-3 | Brinjal | Oct. 06 | 960 | 1.40 ± 0.10 | 5.25 | 6 | 0.51 | 210 (162–265) | 58 (41–80) | 1740 (1313–2455) | 74 (47–111) |
|  | Shertshah-6 | Cotton | Sep. 07 | 704 | 1.15 ± 0.09 | 3.79 | 5 | 0.58 | 157 (117–206) | 44 (31–62) | 2052 (1399–3365) | 87 (52–146) |
| Methomyl | T.S.Pur | Cotton | Aug. 92 | 775 | 1.63 ± 0.12 | 2.95 | 5 | 0.71 | 2.46 (1.94–3.05) | 1.0 | 15.1 (11.7–20.4) | 1.0 |
|  | Bosan-1 | Squash | Dec. 92 | 936 | 2.25 ± 0.19 | 5.77 | 4 | 0.22 | 29.9 (20.7–39.2) | 12 (9.0–16) | 111 (83.2–169) | 7.4 (5.2–10) |
|  | Khanewal-1 | Brinjal | Mar. 94 | 928 | 1.07 ± 0.08 | 6.03 | 6 | 0.42 | 41.1 (26.7–59.0) | 17 (12–25) | 640 (409–1158) | 42 (27–72) |
|  | Multan-3 | Brinjal | Jul. 95 | 1345 | 1.07 ± 0.06 | 13.2 | 7 | 0.07 | 48.7 (30.7–72.2) | 20 (14–28) | 759 (472–1423) | 50 (34–80) |
|  | Bosan-2 | Cotton | Aug. 96 | 1034 | 1.41 ± 0.11 | 10.1 | 5 | 0.07 | 8.60 (4.99–13.0) | 3.5 (2.5–4.9) | 69.2 (43.5–139) | 4.6 (3.0–6.8) |
|  | Jehanian-2 | Cotton | Sep. 97 | 985 | 1.39 ± 0.12 | 8.06 | 6 | 0.23 | 12.5 (7.61–18.1) | 5.1 (3.5–7.4) | 104 (71.0–173) | 6.9 (4.6–11) |
|  | Lar-2 | Cotton | Sep. 98 | 847 | 1.84 ± 0.13 | 7.51 | 4 | 0.11 | 21.3 (14.3–29.4) | 8.7 (6.5–12) | 106 (73.0–180) | 7.0 (4.9–10) |
|  | Bosan-3 | Brinjal | Mar. 99 | 748 | 1.14 ± 0.08 | 4.12 | 5 | 0.53 | 8.47 (6.72–10.6) | 3.4 (2.5–4.7) | 113 (78.8–179) | 7.5 (4.5–12) |
|  | Multan-4 | Cotton | Sep. 00 | 602 | 1.54 ± 0.14 | 13.8 | 4 | 0.01 | 17.0 (7.01–31.3) | 6.9 (4.9–9.7) | 115 (56.9–536) | 7.6 (4.9–12) |
|  | Kabirwala-1 | Cotton | Sep. 01 | 864 | 1.27 ± 0.11 | 7.42 | 6 | 0.28 | 4.22 (2.51–6.33) | 1.7 (1.1–2.5) | 43.5 (28.4–76.7) | 2.9 (1.8–4.5) |
|  | Khanewal-3 | Brinjal | Jun. 02 | 896 | 1.19 ± 0.08 | 13.5 | 6 | 0.04 | 12.4 (6.91–19.9) | 5.0 (3.5–7.1) | 149 (84.7–338) | 9.9 (6.2–15) |
|  | Lar-3 | Cotton | Oct. 03 | 600 | 1.76 ± 0.19 | 4.51 | 4 | 0.34 | 26.9 (15.6–39.2) | 11 (7.5–16) | 145 (98.2–257) | 9.6 (6.3–14) |
|  | Kabirwala-2 | Cotton | Sep. 04 | 506 | 1.43 ± 0.12 | 3.88 | 5 | 0.57 | 35.1 (26.1–45.8) | 14 (9.8–20) | 278 (199–426) | 18 (11–29) |
|  | Jehanian-3 | Cotton | Oct. 05 | 754 | 1.30 ± 0.10 | 3.81 | 5 | 0.58 | 23.3 (17.9–29.6) | 9.5 (6.7–13) | 227 (164–339) | 15 (9.4–24) |
|  | Khokhran-3 | Brinjal | Oct. 06 | 930 | 2.35 ± 0.18 | 5.80 | 6 | 0.45 | 52.9 (44.3–61.8) | 22 (16–28) | 186 (156–229) | 12 (8.8–17) |
|  | Shershah-6 | Cotton | Sep. 07 | 990 | 1.07 ± 0.09 | 12.0 | 7 | 0.10 | 27.9 (14.8–45.0) | 11 (7.5–17) | 439 (259–933) | 29 (18–48) |

**Table 2** continued

| Insecticide | Location | Host | Date tested | No. tested | Fit of probit line | | | | $LC_{50}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{50}$ (95% CL) | $LC_{90}$ (mg $l^{-1}$) (95% CL) | RF at $LC_{90}$ (95% CL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Slope ± SE | $\chi^2$ | df | *P* | | | | |
| Butocarboxim | T.S.Pur | Cotton | Aug. 92 | 799 | 1.54 ± 0.12 | 7.04 | 5 | 0.22 | 3.15 (2.07–4.42) | 1.0 | 21.4 (14.5–37.1) | 1.0 |
| | Khanewal-1 | Brinjal | Mar. 94 | 928 | 1.11 ± 0.09 | 7.28 | 6 | 0.30 | 15.7 (9.96–23.0) | 5.0 (3.4–7.3) | 226 (142–424) | 11 (6.4–17) |
| | Multan-3 | Brinjal | Jul. 95 | 1061 | 1.31 ± 0.10 | 5.09 | 6 | 0.53 | 11.9 (9.00–15.1) | 3.8 (2.6–5.4) | 112 (84.2–160) | 5.2 (3.4–8.2) |
| | Bosan-2 | Cotton | Aug. 96 | 1115 | 1.26 ± 0.09 | 9.90 | 6 | 0.13 | 23.7 (14.6–34.8) | 7.5 (5.3–11) | 244 (161–424) | 11 (7.7–18) |
| | Jehanian-2 | Cotton | Sep. 97 | 885 | 1.73 ± 0.13 | 11.6 | 4 | 0.02 | 15.2 (8.68–23.3) | 4.8 (3.5–6.5) | 83.5 (50.5–195) | 3.9 (2.6–5.8) |
| | Lar–2 | Cotton | Sep. 98 | 840 | 1.66 ± 0.11 | 6.33 | 4 | 0.18 | 25.8 (18.5–34.5) | 8.2 (6.1–11) | 152 (105–260) | 7.1 (4.8–10) |
| | Bosan-3 | Brinjal | Mar. 99 | 820 | 1.43 ± 0.10 | 5.97 | 5 | 0.31 | 13.1 (9.19–17.7) | 4.2 (3.0–5.7) | 103 (70.8–170) | 4.8 (3.2–7.3) |
| | Multan-4 | Cotton | Sep. 00 | 787 | 1.23 ± 0.09 | 4.19 | 5 | 0.52 | 9.19 (7.07–11.7) | 2.9 (2.1–4.1) | 101 (73.2–152) | 4.7 (3.0–7.6) |
| | Kabirwala-1 | Cotton | Sep. 01 | 864 | 1.33 ± 0.11 | 5.95 | 6 | 0.43 | 3.29 (2.33–4.39) | 1.0 (0.70–1.6) | 30.0 (22.3–43.1) | 1.4 (0.91–2.2) |
| | Khanewal-3 | Brinjal | Jun. 02 | 896 | 1.16 ± 0.09 | 6.10 | 6 | 0.41 | 7.06 (4.63–10.0) | 2.2 (1.5–3.3) | 90.0 (59.0–158) | 4.2 (2.6–6.8) |
| | Lar-3 | Cotton | Oct. 03 | 1071 | 1.85 ± 0.17 | 10.3 | 5 | 0.07 | 20.7 (12.5–29.3) | 6.6 (4.8–9.1) | 102 (68.4–200) | 4.8 (3.2–7.1) |
| | Kabirwala-2 | Cotton | Sep. 04 | 600 | 1.55 ± 0.15 | 1.67 | 4 | 0.80 | 42.3 (31.3–54.4) | 13 (9.4–20) | 282 (207–425) | 13 (8.4–21) |
| | Jehanian-3 | Cotton | Oct. 05 | 832 | 1.14 ± 0.08 | 4.57 | 6 | 0.60 | 46.0 (34.8–59.5) | 15 (10–21) | 612 (431–948) | 29 (17–47) |
| | Khokhran-3 | Brinjal | Oct. 06 | 859 | 1.00 ± 0.07 | 7.47 | 6 | 0.28 | 107 (69.3–158) | 34 (23–49) | 2061 (1203–4331) | 96 (55–163) |
| | Shershah-6 | Cotton | Sep. 07 | 718 | 1.21 ± 0.09 | 11.8 | 6 | 0.07 | 220 (134–334) | 70 (49–99) | 2511 (1488–5351) | 117 (75–187) |

### Correlations between $LC_{50}$ values of insecticides

Paired comparisons of the log $LC_{50}$s of insecticides tested for the same populations showed no correlation among OPs malathion, quinalphos and chlorpyrifos, and between these OPs and carbamates thiodicarb, methomyl and butocarboxim (Table 3), implying no cross-resistance among these insecticides. The OPs and carbamates having no cross-resistance can be rotated to manage resistance to these insecticides in *B. tabaci*. There was some correlation (at 10% level of significance) between malathion and parathion-methyl, and among profenofos, triazophos and parathion-methyl. Except between profenofos and butocarboxim, and parathion-methyl and thiodicarb, which had no and slight correlation, respectively, the OPs profenofos, triazophos and parathion-methyl were highly correlated with the carbamates thiodicarb, methomyl and butocarboxim, indicating a cross-resistance between these OPs and carbamates. All the three carbamates also exhibited a positive correlation among themselves, demonstrating a cross-resistance among these carbamates.

## Discussion

In the present studies, T.S.Pur population was used as a reference strain to calculate baselines, because it usually produced the lowest LC values for the insecticides tested (Tables 1 and 2). Our profenofos baseline of 1.6 ppm at $LC_{50}$ was lower than those determined by Dittrich et al. (1985) (4.9 ppm) and Cahill et al. (1995) (6.1 ppm) on a susceptible Sudanese strain using similar leaf-dip bioassays. $LC_{50}$ of chlorpyrifos (1.59 ppm) for the T.S.Pur population was again lower than a baseline of 2.9 ppm reported by Cahill et al. (1995). The baseline $LC_{50}$s of other insecticides for the T.S.Pur population were also low and fell in the ranges of 2.0–4.6 ppm for OPs and 2.5–3.6 ppm for carbamates, thus making it a good reference population to determine resistance factors.

There was a low to high level of resistance to OPs profenofos, triazophos, parathion-methyl and ethion during 1992–1995 in the field populations of *B. tabaci* in our study. Concurrently, a very high resistance was observed to OPs methamidophos (Ahmad et al. 2001) and dimethoate (Ahmad et al. 2002) in the Pakistani populations of whitefly. A high resistance to triazophos was recorded in *B. tabaci* populations from north India (Sethi and Dilawari 2008). The Egyptian populations of *B. tabaci*, which had a moderate to high resistance to carbamates carbosulfan and aldicarb, displayed no resistance to OPs profenofos and pirimiphos-methyl (El-Kady and Devine 2003).

Compared with profenofos, triazophos, parathion-methyl and ethion, the OPs malathion, quinalphos and chlorpyrifos showed no or a very low resistance in the same populations of *B. tabaci* during the 16-year study period. Chlorpyrifos resistance in the Californian populations of *B. tabaci* also remained very low (<tenfold) (Prabhaker et al. 1988). Chlorpyrifos, profenofos and triazophos have been commonly used to control insect pests of cotton and other crops, whereas the use of malathion, quinalphos, parathion-methyl and ethion has been very limited in the Pakistani agriculture. Nevertheless, the differences within OPs towards the development of resistance found in our studies are very useful for the management of whitefly resistance to insecticides.

A moderate to high resistance was found to thiodicarb during 1994–1998 and 2004–2007, to methomyl during 1994–1995, and to butocarboxim during 2005–2007. A moderate to high level of methomyl resistance was also recorded in Indian populations of *B. tabaci* (Kranthi et al. 2001). Methomyl was not a popular insecticide for the control of whitefly and other sucking insect pests in Pakistan, and thiodicarb and butocarboxim were used very occasionally. A recent surge in resistance to these carbamates during 2004–2007 may be a consequence of cross-resistance from OPs profenofos, triazophos and parathion-methyl, the $LC_{50}$s of which have been found to be positively correlated with the carbamates in the current study (Table 3).

**Table 3** Pairwise correlation coefficient comparisons between log $LC_{50}$ values of the insecticides tested on field populations of *Bemisia tabaci*

| Insecticide | Malathion | Quinalphos | Chlorpyrifos | Profenofos | Triazophos | Parathion-methyl | Thiodicarb | Methomyl |
|---|---|---|---|---|---|---|---|---|
| Quinalphos | $0.308^{\mathrm{ns}}$ | | | | | | | |
| Chlorpyrifos | $-0.041^{\mathrm{ns}}$ | $0.149^{\mathrm{ns}}$ | | | | | | |
| Profenofos | $-0.111^{\mathrm{ns}}$ | $-0.132^{\mathrm{ns}}$ | $0.350^{\mathrm{ns}}$ | | | | | |
| Triazophos | $0.169^{\mathrm{ns}}$ | $0.184^{\mathrm{ns}}$ | $0.130^{\mathrm{ns}}$ | $0.492^{0.1}$ | | | | |
| Parathion-methyl | $0.493^{0.1}$ | $0.372^{\mathrm{ns}}$ | $0.111^{\mathrm{ns}}$ | $0.450^{0.1}$ | $0.788^{0.01}$ | | | |
| Thiodicarb | $-0.031^{\mathrm{ns}}$ | $-0.072^{\mathrm{ns}}$ | $0.134^{\mathrm{ns}}$ | $0.673^{0.01}$ | $0.634^{0.01}$ | $0.496^{0.1}$ | | |
| Methomyl | $-0.017^{\mathrm{ns}}$ | $0.077^{\mathrm{ns}}$ | $0.262^{\mathrm{ns}}$ | $0.648^{0.01}$ | $0.657^{0.01}$ | $0.747^{0.01}$ | $0.680^{0.01}$ | |
| Butocarboxim | $0.112^{\mathrm{ns}}$ | $0.008^{\mathrm{ns}}$ | $-0.138^{\mathrm{ns}}$ | $0.206^{\mathrm{ns}}$ | $0.811^{0.01}$ | $0.683^{0.01}$ | $0.622^{0.05}$ | $0.683^{0.01}$ |

Superscripts denote significance of the regression

The moderate to high resistance to OPs and carbamates in the present studies generally dropped to very low levels during 1996–2003, which was consistent with the decline of resistance to OPs and pyrethroids during 1997–2000 (Ahmad et al. 2000, 2001, 2002). This dramatic reduction in insecticide resistance in *B. tabaci* in Pakistan occurred due to introduction of new chemicals, particularly neonicotinoids, with novel modes of action that were supposed to have no cross-resistance to conventional insecticide classes. The new chemistries were efficacious and cost-effective, and therefore they quickly replaced conventional insecticides for whitefly control.

The present and earlier studies (Ahmad et al. 2000, 2001, 2002) have shown that Pakistani field populations of *B. tabaci* are resistant to conventional insecticide classes such as OPs, carbamates and pyrethroids, and this multiple resistance may therefore be due to more than one mechanism. However, the cross-resistance between OPs and carbamates in the same populations seems to be due to a common mechanism(s). Synergism studies indicate that both oxidative and hydrolytic detoxifications are responsible for partial resistance to OPs and pyrethroids in the Pakistani whiteflies (Ahmad et al. 1999). The mechanisms of OP- and carbamate-resistance in *B. tabaci* from different regions of the world have been found to be due to insensitive acetylcholinesterase (Dittrich et al. 1985, 1990; Byrne and Devonshire 1993, 1997; Byrne et al. 1994; Anthony et al. 1998; Erdogan et al. 2008) and metabolic detoxification by esterases (Dittrich et al. 1985, 1990; Horowitz et al. 1988; Prabhaker et al. 1988; Cahill et al. 1995; Ahmad 2007), monooxygenases (Prabhaker et al. 1988; Dittrich et al. 1990; Kang et al. 2006) and glutathione *S*-transferases (Kang et al. 2006). Over-expression of two acetylcholinesterase genes Ace1 and Ace2, and two carboxylesterase genes Coe1 and Coe2 was responsible for resistance in an OP-resistant strain of *B. tabaci* (Alon et al. 2008).

Owing to its short life cycle and high polyphagy, *B. tabaci* is a challenge for its management in hot climates like Pakistan's. It is notorious in developing resistance to insecticides (Brown et al. 1995; Denholm et al. 1996; Nauen and Denholm 2005). In Pakistan it is now resistant to OPs, carbamates and pyrethroids. The OPs showing no or a very low resistance in the present study can be a good fit in the insecticide resistance management strategy for the whitefly. Recently, new chemistries such as neonicotinoids (imidacloprid, acetamiprid, thiamethoxam, thiacloprid, nitenpyram), insect growth regulators (buprofezin, pyriproxyfen) and thiourea (diafenthiuron) have been introduced with great success. Judicious rotation of old and new chemistries can therefore prevent or delay the onset of resistance in whiteflies. Nevertheless, the chemical control should be a last resort for whitefly management. Its nymphs (except first instars) and pupae are sedentary, and thus highly vulnerable to attack by natural enemies. Predators and parasitoids should therefore be conserved by delaying the initial spray applications, using minimum and beneficial-friendly insecticides, and following other integrated pest management tactics.

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