Resistance of Cotton Aphid, *Aphis gossypii* Glover (Homoptera: aphididae) to Selected Insecticides in Major Cotton Growing Areas of Ethiopia

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Abstract

Resistance to insecticides in four populations of cotton aphids, *A. gossypii* Glover, collected from major cotton growing areas; (Arbaminch, Dubti, Goffa and Werer) were studied under laboratory conditions using a slide dip test. Mortality was recorded 24hrs after treatment and aphids were considered dead if do not respond to camel hair brush probing. Resistance ratios were determined by dividing LC_{50} values of the three field populations to LC_{50} of the susceptible Goffa population. Low to moderate level of resistance (12.14 to 22.2- fold) was detected for carbosulfan, furathiocarb and deltamethrin in all aphid populations. However, carbosulfan and furathiocarb gave 100% of aphid mortality at eight time's lower concentration than the recommended field rate. Dimethoate, endosulfan and pirimicarb have shown relatively low level of resistance (< 5.08-fold). But the mortality percentage of the cotton aphid obtained from pirimicarb at the field rate was very low (16.7- 56.7%) for all populations tested. Deltamethrin and pirimicarb yielded 100% mortality only at two and 32-times higher concentrations than the field rate, respectively. Generally, this study confirmed that, in Ethiopia resistance to insecticides by cotton aphid is at its initial stage and therefore, frequent monitoring and designing of resistance management strategy are at most urgent.

Introduction

The cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphididae) is one of the most important insect pests of cotton in all cotton growing areas of the world. In Ethiopia, it is important next to African bollworm, *Helicoverpa armigera* Hubner. It affects cotton yield by direct feeding as well as reducing the fiber quality by excreting honeydew, which causes "sticky cotton" (Ahmad *et al.* 2003). Alemayehu and Ababu (1986) reported 14% seed cotton yield loss to cotton aphid in irrigated cotton in Ethiopia. Over the years, a very wide range of insecticides have been used to control the pest including organophosphates, organochlorins, carbamates, synthetic pyrethroids, and more recently insect growth regulators, such as, bifenithrin, flucythrinate and insecticides like pirimicarb, methomyl, and carbosulfan (Shires 1991).

Some of the insecticides that are registered and are in use for aphid management in cotton include: dimethoate (Rogor), pirimiphos-methyl (Actellic), profenofos (Curacuron), deltamethrin (Decis), alphacypermethrin (Fastac), bromopropylate (Neoron), monocrotofos (Nuvacron), endosulfan (Ehtiosulfan, Thiodan and Thionex), phosphamidon (Dimecron), furathiocarb (Deltanate), carbosulfan (Marshal) and diafenthiuron (Polo) (Crowe and Shitaye 1972; Alemayehu and Ababu 1986; Abdurahman 1997). Among which carbosulfan, endosulfan and deltamethrin are widely used all over the cotton producing farms of Ethiopia.

When many generation of interbreeding population have been exposed to specific insecticides, the population commonly develops resistance to the insecticides and it is exhibited by a decrease in effectiveness (Georghiou 1980). Insecticide resistant biotypes of *A. gossypii* have been documented in many parts of the world, including Australia (Herron *et al.* 2001), China ((Jianguo *et al.* 1987, Jinliang *et al.* 1987), Israel (Ishaaya and Mendelson 1987), Pakistan (Ahmad *et al.* 2003), Sudan (Gubran *et al.* 1992) and United States of America (Kerns and Gaylor 1992).

Despite, the wide use of pesticides in cotton farms of Ethiopia, there was no information on pesticide resistance and its management strategy. Insecticides such as dimethoate, pirimiphos-methyl and phosphamidon failed to control the pest and are abandoned long ago. Moreover, the currently used insecticides, carbosulfan and furathiocarb have shown reduced efficacy in controlling cotton aphid in most of major cotton growing areas (Personal communication, 2006). This could probably be due to the development of resistance by cotton aphid to these insecticides. Hence, monitoring of resistance level of commonly used insecticides for cotton aphid management is very essential. Thus, the present study was executed to determine the level of insecticide resistance in cotton aphids collected from major cotton growing areas of Ethiopia.

Materials and Method

The experiments was conducted at Werer Agricultural Research Center (40°9'E 9° 60' N, 740 m a.s.l) in the Middle Awash.

Insecticides used

The insecticides evaluated in this study were representing commercial products of different generic groups such as, carbamates (carbosulfan 25% EC, furathiocarb 200 EC and pirimicarb 50% DP), organochlorins (endosulfan 35% EC), organophosphates (dimethoate 40% EC) and synthetic pyrethroids (deltamethrin 2.5% EC) which are recommended for the control of aphid and other pests in cotton (Alemayehu and Ababu 1986, Crow and Shitaye 1972 IAR 1969). These insecticides were obtained from FMC Europe, Brussels, Belgium; Syngenta Agro Service A.G. Ethiopia; Crop Care; Adamitulu Pesticide Processing and Packaging Share Company Ethiopia, and Aventis, respectively.

Aphid colonies establishment

Cotton aphids used in this experiment were offspring's of apterous parthenogenic females collected from cotton plants at Middle Awash (Melka-Sadi), Lower Awash (Dubti) and Arbaminch State farms where cotton is produced intensively and the listed insecticides are heavily applied to control cotton pests (Geremew 2005). The wild species or the expected susceptible population was collected from untreated fields of small-scale farms at Goffa (Selam Ber) area from southern region of Ethiopia. The insects were brought to Werer Research Center and each field population was maintained separately on pesticide-free cotton planted and monitored under mesh screen cages on natural light and temperature conditions.

Progeny uniformity was assured by maintaining populations in purposefully built aphid proof cages covered with mosquito net, having the size of 2m x 2m x 2m (h x l x w). The four ends of the mosquito net were stretched with fiber strings on wooden pole and no insect was allowed to inter. To maintain a homogenous population, each aphid population colony was started with a single apterous adult female.

Slide dip assay

The experiment was conducted from 16th July to 1st October, 2005. The FAO (1984) method for bioassay was used. Fresh dilutions of each treatment chemicals were made using tap water on each day of testing. A piece of adhesive tape (Scotch tape) was used and affixed to standard microscope slides, the sticky side placed up. Then ten fourth instar aphids were placed, on their back, on each slide with a fine brush, the aphid's legs were kept free from the tape as much as possible. Immediately after mounting, the slides were dipped in their respective treatment solutions so that the aphids were immersed completely and gently agitated for 30 seconds to ensure complete wetting. Similarly, control aphids were dipped in tap water in the same fashion. When withdrawn, slides were touch down on their edges on absorbent paper towel and to allow them to dry at room temperature for 15 minutes. These slides were held at 25± 1°C and 60% RH in a controlled environmental chamber for 24 hrs. Mortality was assessed under stereomicroscope after 24 hours of treatment. Every treated aphid was probed lightly with a fine camel hairbrush for 10 seconds. Those aphids, which moved at least one leg during probing, were considered alive. Aphids, which could not respond to brush probing or showed only very slight jerk, were considered dead. The experiment was replicated three times by considering one slide as a replication. A total of 648 slides (6 insecticides x 3 rep x 4 aphid populations x 9 concentrations (0-8)) were used. The data was subjected to probit analysis using SAS software version 8e, SAS (1999).

The daily minimum and maximum temperature of the laboratory and RH were recorded. The monthly average temperature and humidity of the laboratory were 30.5, 29, 29 °C and 59.5, 66.5 and 63% for the months of July, August and September, respectively.

Statistical analysis

Data from slide dip bioassay were corrected for control mortality with Abbotte's (1925) formula: Percent mortality = dead insects/total insects treated *100, Percent Corrected Mortality = % test mortality - % control mortality/100- % control mortality.

Dose-response regressions were estimated by probit analysis (Finney 1971) using the SAS software (SAS Institute 1999) from the data generated during the mortality observation. The LC_{50}, LC_{90}, upper and lower confidence limits (CL) values were determined. Failure of 95% CL to overlap at LC_{50} was used as the criterion for significant difference determination between LC_{50} values of the susceptible and the field populations (Kerns and Gaylor 1992). Resistance ratio (RR) was calculated by dividing LC_{50} of particular cotton aphid population with LC_{50} of the Goffa (susceptible) aphid population (Harlow and Lampert 1990). Aphid populations with RR value <20 were considered to have low resistance, while those with RR values of 20-50 were classified as moderately resistant, and those with RR value >50 were considered as highly resistant (Kerns and Gaylor 1992). The Chi square value greater than 7.8 (df =3, 0.05) confirms the best fit of the log dose probit regression line.

Results

Table 1 summarizes the mortality percentage of four cotton aphid populations in response to six insecticides commonly used on cotton. Table 2 shows the toxicological data of the four aphid populations responding to six insecticides tested, whereas, Table 3, describes the concentration levels of insecticides used in this study.

As to the mortality percentage, carbosulfan gave 100% mortality of all tested aphid populations at the concentration level of eight time's lower dose (1.1µl/ml) to the recommended field rate (8.8µl/ml). Further lowering of the dose of carbosulfan 16-times (0.55µl/ml) from the recommended field rate resulted in 96.7, 86.7, 98.3 and 96.7 % mortality for Arbaminch, Dubti, and Goffa and Werer populations, respectively. Similarly, furathiocarb caused 100% mortality at eight time's lower dose (1.25µl/ml) and lowering this dose by half (0.6252 µl/ml) resulted in 93.3, 76.7, 96.7 and 90% mortality for Arbaminch, Dubti, Goffa and Werer populations, respectively (Table 1).

Except for Dubti populations, the aphid mortality level obtained from endosulfan and dimethoate at the field rate (12.252 and 7.5µl/ml, respectively) was above 93%, where as dimethoate gave 83 % mortality for Dubti population. However, when dimethoate was further diluted by half (3.755µl/ml) the aphid mortality percentage was drastically reduced to 50, 46.7 and 60% for Arbaminch, Dubti and Goffa populations, respectively (Table 1).

In contrast, for deltamethrin to get the highest level of mortality (> 96.7%), it was required the double concentration (3.04µl/ml) than the field rate (1.52µl/ml). Whereas, with field rate the mortality percentage obtained from deltamethrin was very low (86.7 and 66.7%) especially for Arbaminch and Werer populations, respectively. Similarly, at the field rate, the efficacy of pirimicarb was very low and it resulted 16.7 – 56.7% mortality and it caused 100% mortality only at the rate 32-times higher (160µl/ml) than the recommended field rate (5µl/ml) (Table 1 cont'd).

Table 1. Percent mortality of cotton aphid, 24h after slide dip at different insecticides concentrations

Concentration levels	No. aphid tested	Carbosulfan 25% EC				Furathiocarb 200 EC				Endosulfan 35% EC				Dimethoate 25% EC			
		A*	D	G	W	A	D	G	W	A	D	G	W	A*	D	G	W
n**	30	100	100	100	100	100	100	100	100	96.7	96.7	93.3	100	96.7	83.3	96.7	96.7
n/2	30	100	100	100	100	100	100	100	100	83.3	90.0	76.7	93.3	50.0	46.7	60.0	93.3
n/4	30	100	100	100	100	100	100	100	100	73.3	83.3	50.0	73.3	30.0	30.0	43.3	86.7
n/8	30	100	100	100	100	100	100	100	96.7	60.0	60.0	46.7	66.7	20.0	16.7	30.0	56.7
n/16	30	96.7	86.7	98.3	96.7	93.3	76.7	96.7	90.0	46.7	46.7	23.3	46.7	10.0	10.0	6.7	20.0
n/32	30	60.0	70.0	85.3	73.3	86.7	66.7	86.7	83.3	-	-	-	-	-	-	-	-
n/64	30	53.3	53.3	70.0	53.3	50.0	53.3	73.3	53.3	-	-	-	-	-	-	-	-
n/128	30	20.0	43.3	46.7	43.3	13.3	10.0	20.0	13.3	-	-	-	-	-	-	-	-
Water (check)	30	12.2	10.0	10.0	7.4	12.2	10.0	10.0	7.4	12.2	10.0	10.0	7.4	12.2	10.0	10.0	7.4

*A= Arbaminch, D= Dubti, G = Goffa, W = Werer aphid populations, **concentration n refers field rate (See table 4)

Table 1 cont'd.

Concentration levels	No. aphid tested	deltamethrin 2.5% EC				Concentration levels	No. aphid tested	pirimicarb 50% DP			
		A*	D	G	W			A	D	G	W
2n	30	96.7	96.7	96.7	96.7	32n	30	100.	100	100	100
n**	30	86.7	93.3	93.3	66.7	16n	30	86.7	90.0	96.7	93.3
n/2	30	66.7	66.7	66.7	36.7	8n	30	60.0	83.3	90.0	73.3
n/4	30	53.3	43.3	43.3	16.7	4n	30	56.7	46.7	86.7	50.0
n/8	30	50	20.0	20.0	10.0	2n	30	36.7	40.0	63.3	33.3
n/16	30	26.7	6.7	6.7	3.3	n**	30	20.0	20.0	56.7	16.7
n/32	30	-	-	-	-	n/2	30	13.3	16.7	13.3	6.7
n/64	30	-	-	-	-	n/4	30	6.7	10.0	3.3	3.3
Water (check)	30	0.0	10	10	7.4	Water (check)	30	3.3	3.3	10.0	7.4

*A= Arbaminch, D= Dubti, G = Goffa, W = Werer aphid populations, **concentration n refers field rate (See table 4)

The LC_{50} values of carbosulfan for aphid populations of Arbaminch (0.133), Dubti (0.108), and Werer (0.112) µl/ml, and the RR values were 22.17, 18.0, and 18.67, respectively. This indicated that, the three field populations are 22, 18 and 19-fold more resistance to carbosulfan than the Goffa population (Table 2).

The level of resistance to furathiocarb in the Arbaminch, Dubti and Werer population as detected from slide dip test were 14.1, 16.9 and 13.5-fold higher than the susceptible Goffa population, respectively (Table 2). The highest LC_{50} value of 0.114, 0.136, and 0.11were recorded for Arbaminch, Dubti and Werer populations, respectively. Where as, the lowest LC_{50} value 0.0081 was recorded for Goffa population. The low LC_{50} (0.0081), the high slope of log dose probit (ldp) regression line (1.07) and the non-overlap of 95% CL confirms the susceptibility of the Goffa population to furathiocarb (Table 2).

The toxicity of endosulfan was not different among Arbaminch, Dubti and Werer populations, which has the LC_{50} values of 0.98, 0.92 and 0.94, respectively (Table 2). However, the populations were significantly different ($P<0.05$) from the Goffa population, which had the lowest LC_{50} value (0.268). Resistance ratio of 3.7, 3.4 and 3.5 were calculated for Arbaminch, Dubti and Werer populations, respectively (Table 2). This finding confirms that there is low level of resistance to endosulfan in among tested aphid populations.

For dimethoate, the highest LC_{50} values 3.18, 2.58 and 2.07 were recorded from Dubti, Arbaminch and Goffa populations, respectively. On the contrary to other insecticides, low LC_{50} (0.877) and LC_{90} (2.887) values were recorded from the Werer population (Table 2). The LC_{50} value of Werer population is significantly different from Arbaminch and Dubti populations, but not significantly different from the Goffa population. While, the calculated RR values were 3.62, 2.94 and 2.36 for Dubti Arbaminch and Goffa populations, respectively (Table 2).

The effect of deltamethrin is low especially on Arbaminch and Werer populations. The probit analysis showed that, the existence of significant level of resistance to Deltamethrin in all aphid populations tested. The resistance ratio (RR) obtained for Werer; Dubti and Arbaminch populations were 12.1, 17 and 17.4, respectively. This shows that, the Arbaminch, Dubti and Werer aphid populations are 17.14, 16.96 and 12.14-fold higher resistance to deltamethrin, respectively than the Goffa population (Table 2).

As compared to other tested insecticides, the highest LC_{50} values were recorded for pirimicarb, 16.7, 22.6, 4.446 and 19.4, for Arbaminch, Dubti, Goffa and Werer populations, respectively. Resistance ratio of 3.75, 5.08 and 4.41 were calculated for Arbaminch, Dubti and Werer populations, respectively. The three field populations were significantly different ($P<0.05$) from the Goffa population. The steep slope of ldp-line (5.51), low LC_{50} (4.45) and the lack of overlap of 95% CL confirm the susceptibility of Goffa population to pirimicarb (Table 2).

Discussions

The ULV formulation of carbosulfan is the most commonly used insecticide for cotton aphid management in Ethiopia. There were a lot of complaints made by users about its field control failure. Currently, the efficacy of carbosulfan was reduced not only in the large scale State farms, but also in small experimental plots of the research stations. Even though, the mortality percentage obtained from this study is not yet reduced and even at lower doses it can kill aphids, this may be due to the EC formulations used and complete immersion of the aphid in the test solution. Moreover, the probit analysis (RR values) showed that the three field populations of Arbaminch, Dubti and Werer were 22, 18 and 19 times more resistant to carbosulfan than the susceptible Goffa population. This indicates the presence of low to moderate level of aphid resistance to carbosulfan in Ethiopia. Similarly, Kai-Yun, *et al.* (2007) reported that the presence of resistance to carbosulfan in China on cotton aphids collected from four leading cotton producing regions. On the contrary, Ahmad M. and M. Iqbal Arif (2007) reported in Pakistan no resistance was found to carbamate aphidicides furathiocarb and carbosulfan. In Ethiopia, even though the mortality percentage is high, the LC_{50} value shows that the response of all populations to carbosulfan is significantly different from the unexposed Goffa population. The 95% CL of the three field populations does not overlap to the

Table 2. Toxicity of insecticides to Arbaminch, Dubti, Goffa and Werer cotton aphid populations in slide dip test

Locations	Insecticides	Parameters							
		N	LC_{50} µl/ml	95% CL	LC_{90} µl/ml	95% CL	Slope ±SE	χ^2	RR
Arbaminch	carbosulfan (Marshal) 25% EC	30	0.133	(0.104 - 0.164)**	0.363	(0.279 - 0.556)	1.27 ± 0.195	0.25	22.17
	furathiocarb (Deltanate) 200 EC	30	0.11363	(0.078 -0.148)**	0.401	(0.295 -0.679)	1.02± 0.18	3.29	14.081
	endosulfan (Thiodan) 35% EC	30	0.977	(0.441 -1.492)**	8.233	(5.001 -23.414)	0.60 ± 0.13	0.89	3.65
	dimethoate (Ethiothoate) 25% EC	30	2.576	(1.136 -10.505)**	10.074	(4.277 -2543)	0.94± 0.23	8.10	2.94
	deltamethrin (Decis) 2.5%	30	2.88	(1.76 -8.34)**	29.46	(9.58 – 558.53)	1.27 ± 0.3	1.17	17.14
	pirimicarb (pirimor) 50% DP	30	16.69	(10.84 – 37.94)**	137.56	(53.25 - 1280)	1.4 ± 0.3	0.32	3.75
Dubti	carbosulfan (Marshal) 25% EC	30	0.108	(0.065 - 0.15)**	0.604	(0.401 - 1.286)	0.74 ± 0.14	2.69	18.0
	furathiocarb (Deltanate) 200 EC	30	0.13670	(0.08 -0.194)**	0.931	(0.581 -2.348)	0.67± 0.13	4.20	16.94
	endosulfan (Thiodan) 35% EC	30	0.916	(0.461 -1.345)**	5.682	(3.768 -12.285)	0.70 ± 0.14	0.47	3.42
	dimethoate (Ethiothoate) 25% EC	30	3.176	(2.335 -4.581)**	15.947	(9.301 -43.07)	0.79 ±0.13	2.74	3.62
	deltamethrin (Decis) 2.5%	30	2.85	(1.85 – 6.51)**	19.79	(8.01 – 163.36)	1.52 ± 0.32	0.31	16.96
	pirimicarb (pirimor) 50% DP	30	22.6	(12.26 – 111.6)**	380.31	(87.10 - 37980)	1.05 ± 0.28	0.65	5.08
Goffa	carbosulfan (Marshal) 25% EC	30	0.006	(0.0041 - 0.009)	0.031	(0.021 - 0.059)	1.89 + 0.344	3.80	-
	furathiocarb (Deltanate) 200 EC	30	0.00807	(0.0016 - 0.015)	0.027	(0.015 - 0.421)	1.07± 0.25	6.41	-
	endosulfan (Thiodan) 35% EC	30	0.268	(0.186 - 0.364)	1.565	(0.977 - 3.721)	0.73 ±0.12	2.25	-
	dimethoate (Ethiothoate) 25% EC	30	2.072	(1.622 -2.674)	7.732	(5.326 -14.322)	2.24±0.33	4.64	2.36
	deltamethrin (Decis) 2.5%	30	0.168	(0.121 - 0.227)	0.935	(0.577 - 2.262)	1.72± 0.29	5.14	-
	pirimicarb (pirimor) 50% DP	30	4.446	(3.517-5.575)	14.398	(10.544 -23.45)	2.51± 0.345	2.32	-
Werer	carbosulfan (Marshal) 25% EC	30	0.112	(0.075 - 0.149)**	0.486	(0.341 - 0.902)	0.87 ± 0.15	6.00	18.67
	furathiocarb (Deltanate) 200 EC	30	0.10897	(0.063 - 0.153)**	0.595	(0.403 -1.206)	0.75± 0.14	1.22	13.503
	endosulfan (Thiodan) 35% EC	30	0.941	(0.513 -1.336)**	4.94	(3.383 -9.906)	0.77 ± 0.15	2.40	3.51
	dimethoate (Ethiothoate) 25% EC	30	0.877	(0.646 -1.113)*	2.887	(2.158 -4.577)	1.08 ±0.16	2.99	-
	deltamethrin (Decis) 2.5%	30	2.04	(1.49 - 3.29)**	9.63	(5.22 - 32.18)	1.90 ± 0.34	0.901	12.14
	pirimicarb (pirimor) 50% DP	30	19.64	(12.94 – 39.66)**	124.34	(52.22 – 918.08)	1.6 ± 0.33	0.104	4.41

N= number of aphid tested, LC_{50} = median lethal concentration, LC_{90}= the lethal concentration which killed 90% of the test aphid population, 95%CL= the lower and the higher limits at which the LD_{50} and LD_{90} value can fall at 95% probability, SE= standard Error, χ^2=Chie-square, RR (Resistance Ratio) = LC_{50} of the field population / LC_{50} of Goffa population
**The aphid populations were not significantly different (P<0.05) among each other in their susceptibility to carbosulfan

susceptible Goffa population. This indicates that carbosulfan resistance is emerging and needs a frequent monitoring and its use must be limited. If the selection pressure continues it may result in complete failure of the insecticide within a short period of time. Currently, the widely used ULV formulation has a lot of drawbacks, such as poor spray coverage, environmental and applicator contamination due to drift effect. Thus, in order to have good spray coverage and effective control, the use of carbosulfan must be shifted to EC formulations. Besides, the good spray coverage, environmental and applicator safety, the EC formulations could be easily used by small scale farmers with knapsack sprayer.

Deltamethrin and the other synthetic pyrethroids have been used to control bollworms at Arbaminch, Dubti and Werer for longer period and probably, have made selection pressure on the cotton aphid at the same time. As a result, the field rate could not give high mortality and two times higher concentration was required to get more than 96% mortality. Bingzong *et al.* (1987) reported that resistance of cotton aphid in China to be as high as 519.7-flod to fenvalerate (pyrethroid). Also, high level of resistance has been reported in China to deltamethrin, cyhalotrin and dimethoate (Jianguo *et al.* 1987, Jinliang *et al.* 1987). Gubran, *et al.* (1992) recorded a high level of 82, 127 and 167-fold resistance to deltamethrin in three Sudanese cotton aphid biotypes (SI, SIII and SV, respectively) than the susceptible English strain. Herron *et al.* (2001) reported deltamethrin-Forte resistance in Australia, with a resistance levels ranging from moderate to high. Very recent study made in Pakistan showed that, *A. gossypii* was found to be resistant to seven pyrethroids viz. cypermethrine, alphcypermethrine, zetacypermethrine, cyfluthrin, fenpropathrin, bifenthrin, and lamda-cyhalotrin. On the contrary, it has shown consistently lower resistance to deltamethrin than other pyrethroids (Ahmad *et al.* 2003). Therefore, the use of pyrethroids for bollworm and whitefly management must be restricted to late season as their hazardous effect to the natural enemies and the development of resistance by cotton aphid in major cotton growing areas of Ethiopia may be the forthcoming major problems.

In Ethiopia, endosulfan is under use since the early 1970's for control of bollworms and resistance was not mentioned. Similarly, endosulfan resistance in cotton aphid in Australia was negligible or not detected in Queens land population associated with control failure (Herron *et al.* 2001). In contrast, In the Sudan Gubran *et al.* (1992) reported up to 369-fold level of aphid resistance to endosulfan. Geremew (2005) reported the complicated situations of pesticide use in Ethiopia and detected the presence of endosulfan resistant African bollworm; *Helicoverpa armigera* strains in Arbaminch populations and indicated the suspicion of incipient resistance to endosulfan in other bollworm populations. Generally, in Ethiopia the resistance level obtained from cotton aphid populations for endosulfan is very low and it has the potential to be used in cotton pest management if its use is restricted to the early season of cotton crop development.

In Ethiopia the use of dimethoate for the control of cotton aphid was discontinued 20 years ago because it failed to control cotton aphid (IAR 1990). However, results of this study showed that, optimum mortality percentage was obtained with field rate and its LC_{50} value was relatively low especially on the Werer populations. This might be due to lifted selection pressure of dimethoate from Middle Awash area and the dilution of resistance genes with the susceptible immigrant aphids. On the contrary, the Goffa population, which has no history of dimethoate selection, has recorded higher LC_{50} value (2.072µl/ml) than the Werer population (0.877µl/ml) (Table 2). However, the possible reason should be sorted out. Therefore, the Werer population was used as the susceptible check for the calculation of RR for dimethoate. But, as compared to carbosulfan and furathiocarb, the LC_{50} values obtained from dimethoate were very high and indicate the presence of resistance by cotton aphid. Similarly, Kerns and Gaylor (1992) reported low level of resistance to dimethoate in USA. On the contrary, Gubran *et al.* (1992) reported dimethoate resistance up to 112x on the three Sudanese cotton aphid populations which is very high compared to the current finding, i.e. RR of 3.62 on Dubti population. Therefore, dimethoate could not be used in Ethiopia for cotton aphid control.

During this study, pirimicarb exhibited very low toxicity to all test aphid populations at field rate (5µl/ml) and 100% mortality was obtained only at 32-times higher rate (160 µl/ml) (Table 3). This level of response of pirimicarb to field aphid

Table 3. Concentrations of insecticides used for Slide dip experiments, Melka Werer Ethiopia 2005

No.	Concentrations	Carbosulfan µl/ml H_2O	Furathiocarb µl/ml H_2O	Dimethoate µl/ml H_2O	Endosulfan µl/ml H_2O	Deltamethrin µl/ml H_2O	Pirimicarb µl/ml H_2O
1	32xn	-	-	-	-	-	**160***
2	16xn	-	-	-	-	-	**80***
3	8xn	-	-	-	-	-	**40***
4	4xn	-	-	-	-	-	**20***
5	2xn	-	-	-	-	**3***	**10***
6	**n****	**8.8**	**10**	**7.5***	**12.252***	**1.52***	5
7	n/2	4.4	5	**3.75***	**6.126***	**0.76***	2.5
8	n/4	2.2	2.5	**1.8752***	**3.0632***	**0.376***	1.25
9	n/8	**1.1***	**1.25***	**0.9736***	**1.5316***	**0.188***	0.6252
10	n/16	**0.55***	**0.6252***	**0.4688***	**0.7656***	**-**	
11	n/32	**0.275***	**0.3126***	-	-	-	-
12	n/64	**0.1375***	**0.1563***	-	-	-	-
13	n/128	**0.06875***	**0.07815***	-	-	-	-

* Concentrations used for probit analysis (LC_{50} determination), ** n = field rate of the insecticides
- = not used or considered, X = times

populations clearly indicates unfitness of the insecticide to control cotton aphid, as it is not economical to increase the dose 32-times. This might result hazardous effect on the applicators, beneficial insects and the environment in general. Studies made overseas by different investigators showed presence of resistance to pirimicarb. Gubran *et al.* (1992) detected a high level of resistance to pirimicarb (RR 66.6, 71.6 and 87.4, in the Sudanese aphid strains SI, SIII and SV, respectively). Similarly, extreme pirimicarb resistance was recorded in Queensland and Western Australia (Herron *et al.* 2001). In Ethiopia, pirimicarb was not used for cotton aphid management, but the heavy use of carbosulfan and furathiocarb might have posed selection pressure to the carbamate groups and this could be the main reason for cross- resistance as a whole in major cotton growing areas like Arbaminch, Dubti and Werer (Ermias 2006).

Most of the cotton farms in Ethiopia, use the same group and few numbers of insecticides for cotton pest management. Thus, the situation of resistance level with cotton aphids for most insecticides was same across the wide geographical cotton growing regions. Therefore, in the future Insect Resistance Management Strategies must be developed and combined with IPM. Resistance monitoring works must be done regularly to anticipate resistance management options needed.

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