Pak. J. Agri. Sci., Vol. 54(3), 567-578; 2017
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/17.5994
http://www.pakjas.com.pk

COMPARATIVE EFFICACY OF PYRETHROIDS ON *Aedes aegypti*, *Aedes albopictus* AND *Culex quinquefasciatus* COLLECTED FROM DIFFERENT ECOLOGICAL ZONES OF PUNJAB, PAKISTAN

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Chemical control is widely adopted method in mosquito control that emphasizes on the management of the adult and larval populations using various insecticides. Present study was carried out in the year 2015 to use chemicals which were currently being utilized in mosquito control program against prevalent mosquito species (*Culex* and *Aedes* spp.) collected from different ecological zones of Punjab (Pakistan) (i.e. Faisalabad, Lahore and Rawalpindi) formed as a result of dengue prevalence to evaluate their efficacy by performing adult bioassay using standard WHO protocols. Results revealed that among three pyrethroids used as adulticides, alpha-cypermethrin 10% SC showed greater residual efficacy and percent mortality on various substrates/surfaces like cement, mud, plaster, wood and filter paper followed by lambda-cyhalothrin 10% CS and deltamethrin 5WP in a period of 20 weeks. Response of these chemicals was greater on filter paper and cement and less on wood and mud. Data collected on these parameters was subjected to SPSS and Minitab software for drawing inferences.
Keywords: *Aedes aegypti, Aedes albopictus, Culex quinquefasciatus*, pyrethroids, bioassay

INTRODUCTION

To control mosquitoes, several adulticides are applied as insecticide residual sprays (IRS), space sprayings, treated/impregnated materials (nets) (Vontas *et al*., 2012). Pyrethroids are the most important group of insecticides with main usage in household and public health insecticide products (Yap *et al*., 2000). Pyrethroids as adulticides are currently the single group of insecticides advocated for the impregnation of mosquito nets and residual sprays because of their high insecticidal strength and quick knock down effect along with their low mammalian toxicity and a comparative safety for human contact and domestic handling (Karunaratne *et al*., 2013; Hirata *et al*., 2014).

Among all the control methods, indoor residual spraying (IRS) is one of the important method of vector control (Moosa-Kazemi *et al*., 2007) including spraying of insecticides on the walls of a home or community building (Kolaczinski *et al*., 2007). IRS consist of spraying on indoor surfaces like walls of room, warehouses, stables and shed with the insecticide that keep their efficiency in transmission period and kill or repel vectors (Moosa-Kazemi *et al*., 2007). IRS is helpful against the mosquito species that are hidden indoors which are termed as endophilic mosquitoes (Najera and Zaim, 2001); so that these can rest on the treated surface for an adequate amount of time to catch a lethal dose (Pates and Curtis, 2005). Indoor resting is quite frequent at higher elevation where there is a difference between indoor and outdoor temperatures (Pates and Curtis, 2005; Manguin, 2008; Tchuinkam *et al.*, 2010). IRS is found to be more effective when outdoor temperature is low because mosquitoes spend most of the time indoors on treated surfaces (Paaijmans and Thomas, 2011). The threshold of bio-efficacy is 80% mortality or 95% knock-down in the exposed mosquitoes (WHO, 2013a).

Residual efficacy of insecticides deposited on the wall is determined by cone bioassay but the quantification of insecticides cannot be determined by this method (Silver, 2008). The present World Health Organization (WHO) suggestion is to place filter papers on the walls earlier to spraying (WHO, 2006a). Dose, surface form and age of spray deposits determine the persistency of insecticides in the form of mortality (Giga and Jane, 1991). Effectiveness and residual life span of different compounds including pyrethroids depends upon the surfaces onto which they are applied (Rohani *et al*., 1997). Thus the present work was of significant importance as it focused on the knowledge of common mosquito species from different ecological zones of Punjab (Pakistan) formed as a result of dengue prevalence along with evaluation of efficacy of various adulticides currently being used in dengue control programs.

MATERIALS AND METHODS

Collection of mosquitoes was done from different ecological zones of the Punjab that were formed as a result of dengue prevalence i.e. Lahore (31°32′59″N to 74°20′37″E), Rawalpindi (33° 36′ 0″ N, 73° 2′ 0″ E) and Faisalabad

(31°25′4.8″N 73°4′44.4″E) during the year 2014-15. The field collected samples were screened into *Culex quinquefasciatus*, *Aedes aegypti* and *Aedes albopictus* by running specimen through taxonomic key (Rueda, 2004). Population from respective localities were maintained and reared in Dengue Vector Research Laboratory, Department of Entomology, University of Agriculture Faisalabad Pakistan under laboratory conditions for bioassay. The population was reared at 27±2°C with a relative humidity of 65±5% at L/D 12:12 hour photoperiod. Adults were kept in culture cages provided with 10% sugar solution. Larvae were fed on fish meal while pupae collected daily were transferred to the adult cages. The female mosquitoes were fed on blood of live white rats twice a week (Shaalan *et al*., 2006). Three substrates i.e. cement, plaster and mud were prepared in 25 cm diameter petri dishes. Two surfaces i.e. wood and filter papers were cut in a situation that bioassay cone can be fitted to carry out test. Four blocks of each type of substrate/surface were prepared, three for treated and one for control for each treatment. The substrates/surfaces were treated with recommended doses of deltamethrin 5WP (at the rate of 25mg a.i./m²), lambda-cyhalothrin 10 CS (at the rate of 25mg a.i./m²) and alpha-cypermethrin 10% SC (at the rate of 30mg a.i./m^2) with the help of Hudson® X-Pert compression sprayer to achieve required rate (Vatandoost *et al.*, 2009). The plastic cones were fitted on the surface of each substrate/surface using a rubber band. Ten non-blood-fed adult female mosquitoes aged 2–5 days were introduced into each cone at the vertical position. The mosquitoes were exposed for 30 minutes to the treated substrates/surfaces in three replicates and a control (WHO, 2006b). After exposure time, the adults were transferred to the separate cages provided with 10% sugar solution and the mortality was recorded after 24 hours. This bioassay was conducted on weekly basis up to 20th week to evaluate the performance of chemicals on respective substrates/surfaces. *Culex quinquefasciatus* population was collected from all the three districts, however, regarding *Aedes* species, population collected from Lahore and Faisalabad district was of *Aedes aegypti* while from Rawalpindi district it was *Aedes albopictus.* The threshold bio-efficacy was 80% mortality on the treated substrate/surface (WHO, 2013a). Data so collected was analyzed using 2 factors CRD.

RESULTS

The overall results indicates that the three chemicals i.e. deltamethrin 5WP, lambda-cyhalothrin 10% SC and alpha-cypermethrin 10% CS showed a significant difference in causing the mortalities of *C. quinquefasciatus*, *A. aegypti* and *A. albopictus* in terms of both residual efficacy (80% mortality) and percent mortality up to 20th week but in the early weeks of the study, response of all the chemicals to all the substrates/surfaces was quite similar between the species in terms of mortality as shown in Table 2 and Table 4 where data is shown month wise. After 2-3 months and onward significant difference was recorded in terms of mortality (Table 2, 4). Fig. 1-3 shows percent mortality of *C. quinquefasciatus* from Faisalabad against deltamethrin 5WP, lambda-cyhalothrin 10% CS and alpha-cypermethrin 10SC while Fig. 4-6 shows percent mortality of *C. quinquefasciatus* from Lahore and Fig. 7-9 from Rawalpindi respectively. Fig. 10-12 shows percent mortality of *A. aegypti* from Faisalabad against deltamethrin 5WP, lambda-cyhalothrin 10% CS and alpha-cypermethrin 10SC while Fig. 13-15 shows percent mortality of *A. aegypti* from Lahore and Fig. 16-18 shows percent mortality of *A. albopictus* from Rawalpindi respectively.

Table 1. Analysis of variance (mean square) for percent mortality of *Culex quinquefasciatus* from district Faisalabad, Lahore and Rawalpindi after 24 hours, 5th week, 9th week, 13th week, 17th week and 20th week against all the three chemicals and five substrates/surfaces.

Source of variation	d.f	Mean squares					
		24 hrs	W5	W9	W13	W17	W20
				Faisalabad			
Chemical (C)	2	45.000	351.667*	365.000**	1805.000**	1361.670**	1166.670**
Substrate (S)	4	33.333	220.833*	326.667**	906.670**	2056.670**	1864.170**
C x S	8	22.083	49.583	75.417	34.170	124.170	54.170
Error	45	29.444	81.111	68.889	110.560	110.000	210.560
				Lahore			
Chemical (C)	2	11.667	101.667	281.667	606.670*	1935.000**	1286.670**
Substrate (S)	4	4.167	130.833	714.167**	2216.670**	2031.670**	1406.670**
C x S	8	5.417	68.333	56.667	31.670	70.420	105.420
Error	45	8.333	71.667	95.556	162.780	158.330	243.890
				Rawalpindi			
Chemical (C)	2	5.000	195.000*	406.667*	1205.000**	931.670**	1211.670**
Substrate (S)	4	15.000**	23.333	294.167*	839.170**	1610.830**	1272.500**
C x S	8	5.000	15.833	37.917	96.670	73.330	76.250
Error	45	3.889	59.444	113.889	106.670	136.110	227.780

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 2. Comparison of means with standard error for chemicals x substrates interaction of *Culex quinquefasciatus* from district Faisalabad, Lahore and Rawalpindi after 24 hours, 5th week, 9th week, 13th week, 17th week and 20th week.

Chemical	Substrate	Weeks					
		24 hrs	W5	W9	W13	W17	W20
				Faisalabad			
Deltamethrin		96.00±1.52A	83.50±2.84B	74.50±2.66B	60.00±2.90C	46.50±3.10B	41.50±3.65B
Lamda-cyhalothrin		97.50±1.23A	91.00±1.61A	79.50±1.98AB	69.50±3.20B	54.50±3.94B	46.50±4.12AB
Alpha-cypermethrin		99.00±0.69A	90.50±1.53A	83.00±1.47A	79.00±2.16A	63.00±3.49A	56.50±3.93A
	Cement	99.17±0.83A	92.50±2.18AB	83.33±1.88A	75.00±3.37AB	58.33±4.58AB	50.83±5.57AB
	Mud	98.33±1.67A	86.67±2.25AB	73.33±2.84B	56.67±3.76C	35.00±3.79C	30.00±4.26C
	Plaster	95.00±1.95A	90.00±2.75AB	81.67±2.41AB	72.50±3.72AB	60.00±2.75AB	51.67±3.86AB
	Wood	96.67±1.88A	81.67±4.05B	73.33±3.33B	65.00±4.17BC	50.00±3.48B	44.17±3.79BC
	Filter paper	98.33±1.12A	90.83±1.49A	83.33±2.25A	78.33±3.22A	70.00±3.26A	64.17±3.79A
				Lahore			
Deltamethrin		98.50±0.82A	86.00±1.69A	75.00±2.67A	60.50±3.80B	40.50±3.59B	34.50±3.20B
Lamda-cyhalothrin		100.00±0.00A	88.00±1.72A	81.50±2.21A	65.50±3.80AB	48.00±3.52B	41.50±4.25AB
Alpha-cypermethrin		99.00±0.69A	90.50±2.35A	81.50±2.84A	71.50±3.79A	60.00±4.04A	50.50±4.20A
	Cement	100.00±0.00A	90.83±2.29A	85.00±2.30A	75.00±3.14A	51.67±4.23B	45.00±4.85A
	Mud	99.17±0.83A	85.00±2.61A	70.00±3.02C	46.67±3.33C	31.67±3.66C	26.67±3.55B
	Plaster	99.17±0.83A	86.67±2.84A	81.67±2.71AB	70.00±3.48AB	54.17±4.68AB	43.33±5.55AB
	Wood	99.17±0.83A	85.83±1.93A	72.50±3.51BC	57.50±5.09BC	43.33±4.32BC	39.17±4.34AB
	Filter Paper	98.33±1.12A	92.50±2.50A	87.50±2.50A	80.00±2.75A	66.67±3.96A	56.67±4.82A
				Rawalpindi			
Deltamethrin		99.00±0.69A	87.00±1.64B	76.50±3.19B	63.50±3.50B	50.00±2.99B	42.00±3.88B
Lamda-cyhalothrin		100.00±0.00A	91.50±1.67AB	81.50±2.09AB	70.50±2.76B	55.00±3.66AB	48.50±4.12AB
Alpha-cypermethrin		99.50±0.50A	93.00±1.47A	85.50±1.70A	79.00±1.91A	63.50±3.50A	57.50±3.15A
	Cement	100.00±0.00A	91.67±2.41A	81.67±2.41AB	74.17±3.13A	60.83±3.58AB	52.50±4.63A
	Mud	97.50±1.31B	88.33±2.07A	74.17±4.17B	57.50±4.29B	37.50±3.72C	32.50±4.46B
	Plaster	100.00±0.00A	91.67±2.07A	83.33±2.25AB	73.33±3.96A	60.00±3.26AB	53.33±4.97A
	Wood	100.00±0.00A	90.00±2.13A	79.17±3.98AB	70.00±3.69A	54.17±3.79B	48.33±4.05AB
	Filter Paper	100.00±0.00A	90.83±2.29A	87.50±1.79A	80.00±1.74A	68.33±3.66A	60.00±4.26A

Means sharing similar letter within a cell (within lines) are statistically non-significant (P>0.05).

Table 3. Analysis of variance (mean square) for percent mortality of *A. aegypti* and *A. albopictus* from district Faisalabad, Lahore and Rawalpindi after 24 hours, 5th week, 9th week, 13th week, 17th week and 20th week against all the three chemicals and five substrates/surfaces.

Source of variation	d.f	Mean squares					
		24 hrs	W5	W9	W13	W17	W20
				Faisalabad			
Chemical (C)	2	46.667	11.667	261.667	461.670*	1211.670**	921.670**
Substrate (S)	4	23.333	243.333*	239.167	1110.000**	1802.500**	2014.170**
C x S	8	38.333	103.333	86.667	82.500	113.750	52.920
Error	45	26.667	92.222	95.556	105.560	95.000	203.330
				Lahore			
Chemical (C)	2	5.000	151.667	231.667*	801.670**	1601.670**	846.670*
Substrate (S)	4	10.000	172.500*	589.167**	2135.000**	2518.330**	2837.500**
C x S	8	11.250	91.250	50.417	122.500	68.330	55.000
Error	45	13.333	57.222	59.444	83.890	143.330	212.220
				Rawalpindi			
Chemical (C)	2	6.667	186.667	231.667	801.670**	761.670*	501.670*
Substrate (S)	4	27.500	169.167*	290.000	2043.330**	2929.170**	2812.500**
C x S	8	58.750*	74.167	83.750	105.830	167.920	103.750
Error	45	22.778	63.333	145.000	150.000	157.220	158.890

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 4. Comparison of means with standard error for chemicals x substrates interaction of *A. aegypti* and *A. albopictus* from district Faisalabad, Lahore and Rawalpindi after 24 hours, 5th week, 9th week, 13th week, 17th week and 20th week.

Chemical	Substrate	Weeks					
		24 hrs	W5	W9	W13	W17	W20
				Faisalabad			
Deltamethrin		97.00±1.79A	90.00±2.51A	80.00±2.81A	67.50±3.62B	54.00±2.94B	48.00±3.81B
Lamda-cyhalothrin		99.00±1.00A	91.50±2.09A	80.50±2.11A	73.50±2.54AB	63.00±3.49A	53.50±4.12AB
Alpha-cypermethrin		100.00±0.00A	90.50±2.23A	86.50±1.82A	77.00±2.52A	69.50±3.44A	61.50±3.86A
	Cement	100.00±0.00A	97.50±1.31A	85.00±3.14A	80.00±2.13A	69.17±4.52A	60.83±4.52AB
	Mud	100.00±0.00A	87.50±2.79AB	77.50±2.79A	60.00±3.02C	45.00±2.89B	35.00±3.99C
	Plaster	98.33±1.67A	91.67±2.41AB	85.00±2.89A	76.67±3.55AB	67.50±3.05A	59.17±4.68AB
	Wood	96.67±2.56A	85.83±3.58B	77.50±3.29A	65.00±3.99BC	54.17±3.58B	48.33±4.41BC
	Filter paper	98.33±1.67A	90.83±3.13AB	86.67±2.25A	81.67±2.41A	75.00±2.61A	68.33±2.97A
				Lahore			
Deltamethrin		99.00±0.69A	85.00±1.85A	82.00±1.72AB	65.00±3.12B	48.00±3.29B	42.00±3.81B
Lamda-cyhalothrin		98.50±1.09A	89.50±1.98A	80.50±2.46B	67.50±4.22B	53.50±4.25B	48.00±4.33AB
Alpha-cypermethrin		99.50±0.50A	90.00±1.78A	87.00±2.31A	77.00±2.72A	65.50±4.00A	55.00±4.78A
	Cement	99.17±0.83A	91.67±2.07A	87.50±1.79A	76.67±2.56A	62.50±4.46A	53.33±4.49AB
	Mud	100.00±0.00A	84.17±1.93B	71.67±3.22B	48.33±3.86C	34.17±2.88C	27.50±3.29C
	Plaster	99.17±0.83A	85.00±1.95B	85.83±1.49A	76.67±1.88A	62.50±3.29A	52.50±5.09AB
	Wood	97.50±1.79A	87.50±2.50AB	81.67±2.41A	65.83±4.17B	48.33±4.74B	40.00±3.69BC
	Filter Paper	99.17±0.83A	92.50±3.05A	89.17±2.29A	81.67±2.41A	70.83±3.98A	68.33±4.23A
				Rawalpindi			
Deltamethrin		97.50±1.43A	88.00±2.00A	79.00±2.28A	67.00±4.05B	54.00±4.26B	46.50±4.18B
Lamda-cyhalothrin		97.50±1.23A	92.00±1.56A	84.00±3.03A	71.50±4.18AB	57.50±4.64AB	52.00±4.08AB
Alpha-cypermethrin		98.50±0.82A	94.00±2.10A	85.50±2.76A	79.50±2.76A	66.00±3.66A	56.50±4.06A
	Cement	97.50±1.79A	95.83±1.49A	85.83±3.98A	80.83±3.36A	70.83±4.52A	60.83±4.17AB
	Mud	98.33±1.12A	88.33±2.41B	78.33±3.22A	55.00±4.52B	35.00±3.59C	28.33±3.66C
	Plaster	95.83±2.29A	88.33±2.97B	86.67±2.84A	80.83±2.60A	61.67±3.45AB	54.17±3.13AB
	Wood	97.50±1.31A	89.17±2.88B	76.67±3.96A	62.50±5.09B	54.17±4.52B	46.67±4.14B
	Filter Paper	100.00±0.00A	95.00±1.95A	86.67±2.84A	84.17±2.29A	74.17±3.13A	68.33±3.22A

Means sharing similar letter within a cell (within lines) are statistically non-significant (P>0.05).

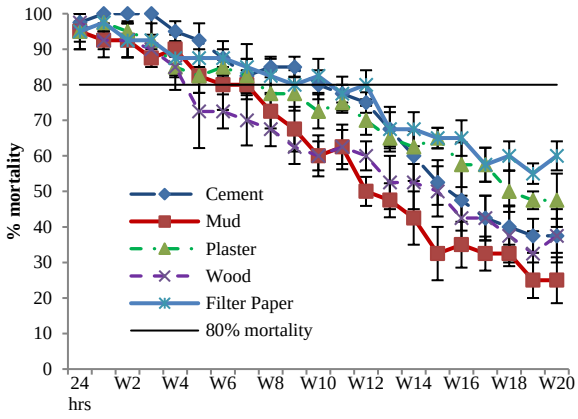

Figure 1. Effect of Deltamethrin 5WP on percent mortality of *C. quinquefasciatus* population from Faisalabad

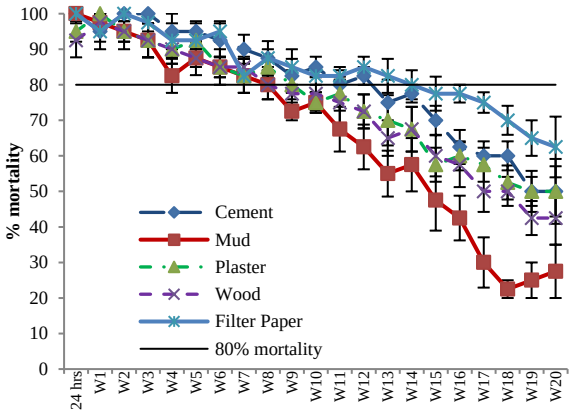

Figure 2. Effect of Lamda-cyhalothrin 10% CS on percent mortality of *C. quinquefasciatus* population from Faisalabad

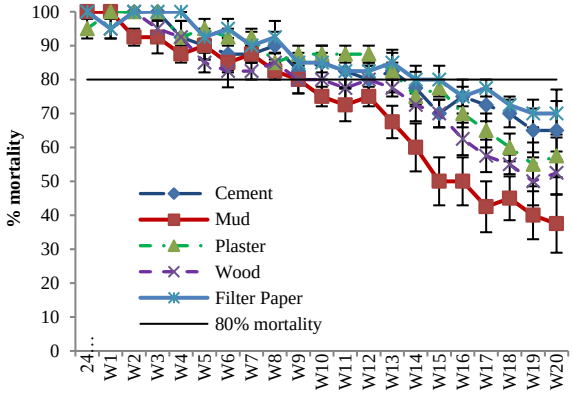

Figure 3. Effect of Alpha-cypermethrin 10% SC on percent mortality of *C. quinquefasciatus* population from Faisalabad

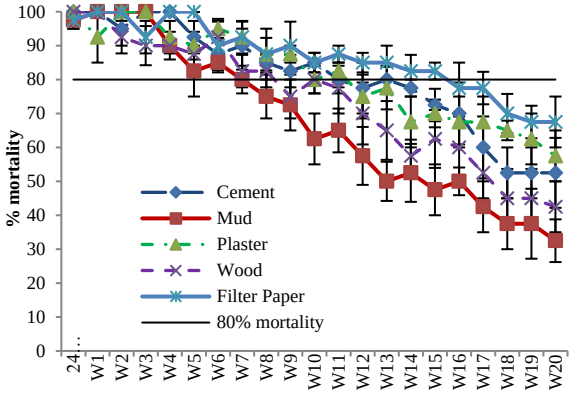

Figure 6. Effect of Alpha-cypermethrin 10% SC on percent mortality of *C. quinquefasciatus* population from Lahore

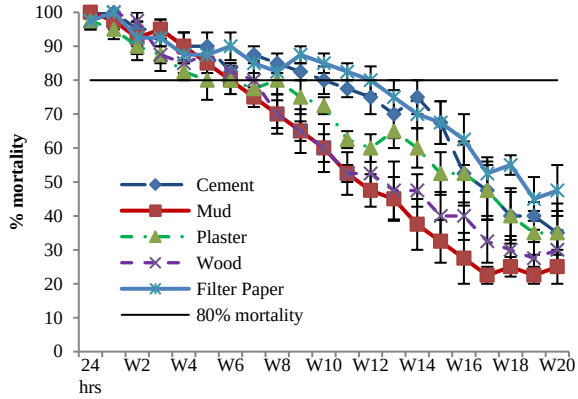

Figure 4. Effect of Deltamethrin 5WP on percent mortality of *C. quinquefasciatus* population from Lahore

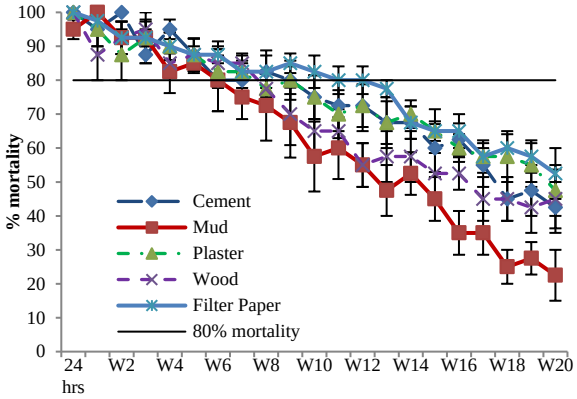

Figure 7. Effect of Deltamethrin 5WP on percent mortality of *C. quinquefasciatus* population from Rawalpindi

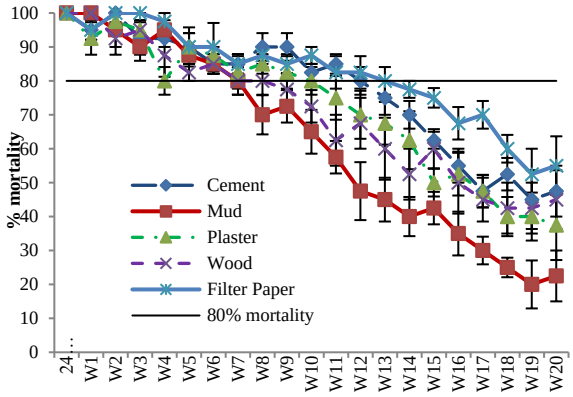

Figure 5. Effect of Lamda-cyhalothrin 10% CS on percent mortality of *C. quinquefasciatus* population from Lahore

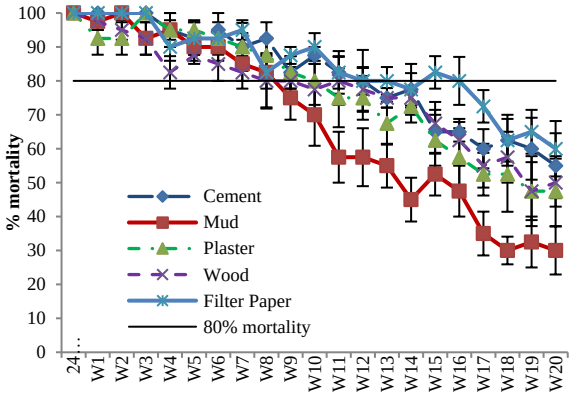

Figure 8. Effect of Lamda-cyhalothrin 10% CS on percent mortality of *C. quinquefasciatus* population from Rawalpindi

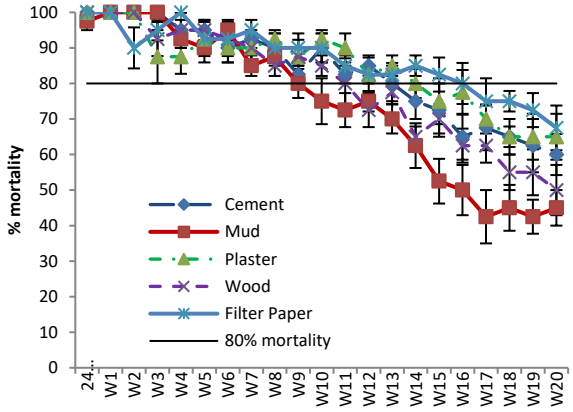

Figure 9. Effect of Alpha-cypermethrin 10% SC on percent mortality of *C. quinquefasciatus* population from Rawalpindi

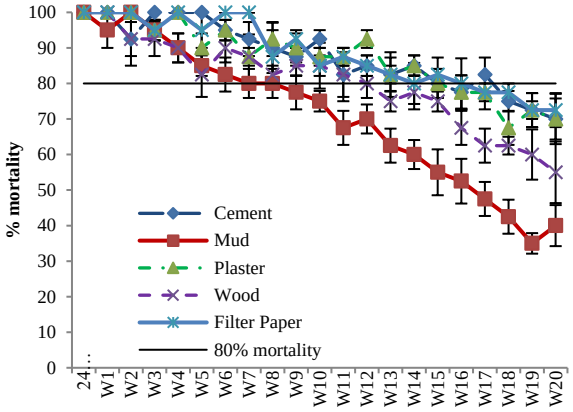

Figure 12. Effect of Alpha-cypermethrin 10% SC on percent mortality of *A. aegypti* population from Faisalabad

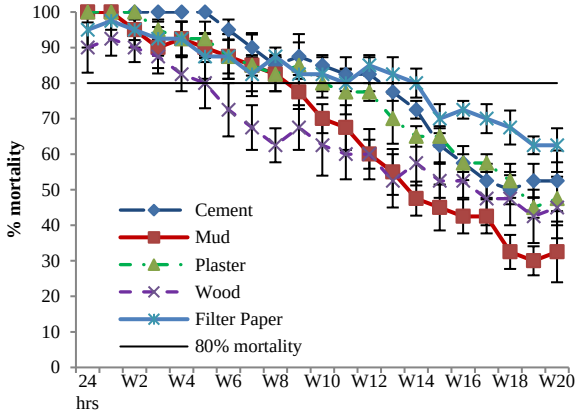

Figure 10. Effect of Deltamethrin 5WP on percent mortality of *A. aegypti* population from Faisalabad.

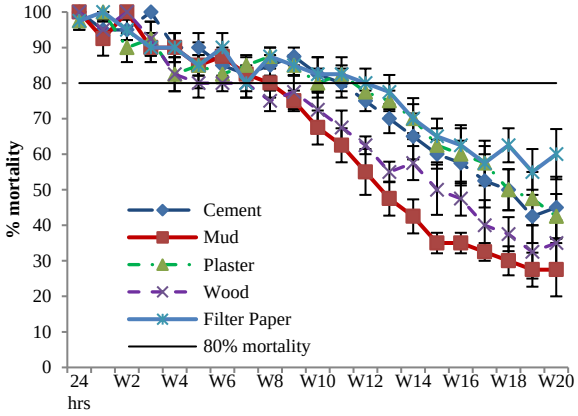

Figure 13. Effect of Deltamethrin 5WP on percent mortality of *A. aegypti* population from Lahore.

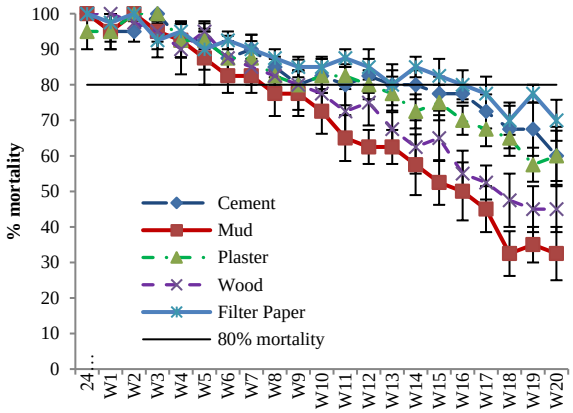

Figure 11. Effect of Lamda-cyhalothrin 10% CS on percent mortality of *A. aegypti* population from Faisalabad.

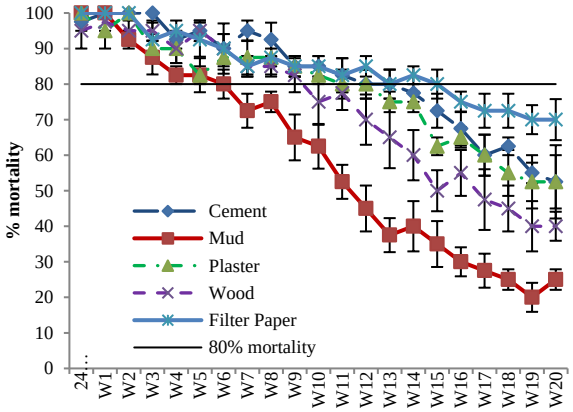

Figure 14. Effect of Lamda-cyhalothrin 10% CS on percent mortality of *A. aegypti* population from Lahore.

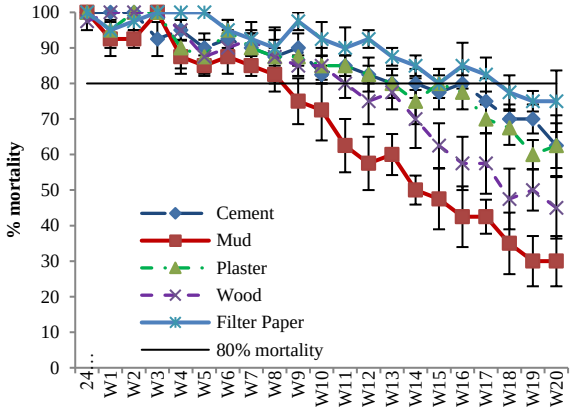

Figure 15. Effect of Alpha-cypermethrin 10% SC on percent mortality of *A. aegypti* population from Lahore

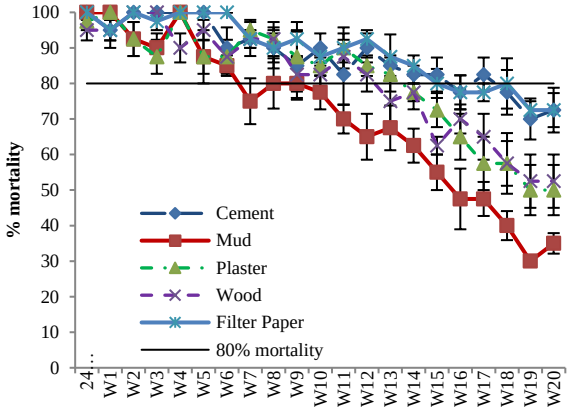

Figure 18. Effect of Alpha-cypermethrin 10% SC on percent mortality of *A. albopictus* population from Rawalpindi

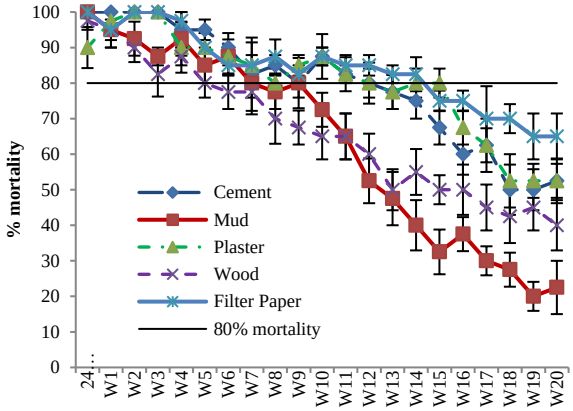

Figure 16. Effect of Deltamethrin 5WP on percent mortality of *A. albopictus* population from Rawalpindi

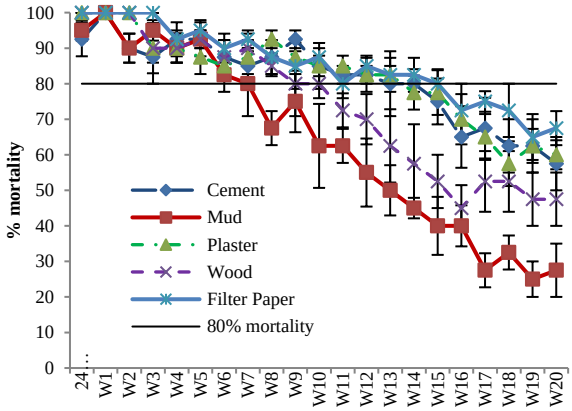

Figure 17. Effect of Lamda-cyhalothrin 10% CS on percent mortality of *A.* albopictus population from Rawalpindi

Response of the chemicals varied i.e., deltamethrin 5WP showed least residual efficacy (approximately 2 months for *A. aegypti* and *A. albopictus* and 1 month for *C. quinquefasciatus*) and percent mortality at 20th week as compared to lambda-cyhalothrin 10% SC (residual efficacy approximately 2.5-3.5 months for *A. aegypti* and *A. albopictus* and 1.5-2.5 months for *C. quinquefasciatus*) on tested surfaces/substrates as shown in Fig. 1-18. Alpha-cypermethrin 10% CS showed highest residual efficacy (approximately 3.5-4.5 months for *A. aegypti* and *A. albopictus* and 2.5-3 months for *C. quinquefasciatus*) and percent mortality at 20th week than the other two chemicals tested (Fig. 1-18). *A. aegypti* and *A. albopictus* showed more susceptibility in terms of percent mortality as compared to *C. quinquefasciatus*. Population of *C. quinquefasciatus* and *A. aegypti* from Lahore was found less responsive to the chemicals tested as compared to the population from Faisalabad and Rawalpindi. Filter paper showed highest efficacy and mud showed least among the substrates/surfaces tested. Response of these substrates/surfaces to the applied chemicals was same and non-significant differences were recorded between substrates/surfaces and chemicals interactions.

DISCUSSION

These results are close to that of WHO which states that deltamethrin wettable powder (WP) and water dispersible granules (WG) and lambda-cyhalothrin 10% CS has the residual activity estimated between two and six months (WHO, 2009; WHO, 2013b). Findings of Paredes-Esquivel *et al.* (2016) are also similar to our results that showed mortality of *A. aegypti* was greater than 80% for 8 weeks when deltamethrin was applied to painted wood, unpainted wood and brick. The residual activity of deltamethrin reported by Rozilawati *et al.* (2005) on wood-brick houses against *A.*

aegypti and *A. albopictus* was found to be of six weeks which is also close to our results. However, these results are somewhat dissimilar to that of Raeisi *et al.* (2008) and Mohammad *et al.* (2011) in which they reported the effectiveness of deltamethrin against *Anopheles* and *Culex* species up to 4 months.

The effectiveness of alpha-cypermethrin WP and WG was reported up to 4 months on cement and mud wall against *An. stephensi* by Faraj *et al*. (2013) and Ratovonjato *et al.* (2014) which match with our results on cement but dissimilar to that of mud in which relatively less effectiveness was found in our results. Alpha-cypermethrin WG, WP and SC formulation used in IRS showed efficacy up to four months against *An. stephensi* and *An. culicifacies* as reported by Rowland *et al.* (2000); Grieco *et al*. (2007) and Thanispong *et al*. (2009) which are similar to our results. Alpha-cypermethrin WG-SB formulation showed residual efficacy (>80% mortality) for 13–15 weeks against *An. stephensi* as reported by Uragayala *et al.* (2015) which is very close to our results on different substrates used against *A. aegypti* and *A. albopictus*.

Moreover, the residual efficacy of alpha-cypermethrin reported by Mahmood and Reisen (1981) and Boewono (2005) against *An. aconitus* is similar to that of our results against *C. quinquefasciatus* which is approximately of 3 months but dissimilar to that of *A. aegypti* and *A. albopictus* which is about 4 months. The results of IRS trials conducted in Philippines with alpha-cypermethrin WP showed 100% mortality up to seven months on all treated surfaces except on cement (90%) reported by WHO (1998) are dissimilar to our results. Wood surfaces treated with alpha-cypermethrin showed higher bio-efficacy than cement surfaces reported by Tseng *et al*. (2008) are also dissimilar to our results in which our findings showed that cement surfaces have higher bio-efficacy than wood surfaces.

The results of Matthews *et al.* (2009), Raghavendra *et al.* (2011), Agossa *et al.* (2014) and WHOPES (2015) revealed that the residual efficacy of lambda-cyhalothrin is up to two-four months on different surfaces against malarial vectors which is similar to our results against *A. aegypti* and *A. albopictus.* The results of WHOPES supervised trial of lambda-cyhalothrin in Benin showed the persistence of effectiveness up to two months which is slightly less than our results whereas the results of the trial in India reported persistence up to four-six months which is significantly higher than our results (WHOPES, 2007). N'Guessan *et al.* (2010) reported loss of activity in lambda-cyhalothrin treated cement-sand walls within a few months against *C. quinquefasciatus* which is similar to our results about *C. quinquefasciatus*. The shorter residual life of lambda-cyhalothrin (i.e. less than 6 months) on cement surface was described earlier by Corbel *et al.* (2007) which might be due to pyrethroid resistant mosquitoes that may reduce the duration of protection to a month or less, despite surface residues persisting for much longer.

Effectiveness of lambda-cyhalothrin lasted up to four, five and three months, respectively, on wood, bamboo and brick walls in bioassay carried out against *An. dirus* (WHOPES, 2007). Effectiveness of lamda-cyhalothrin on cement surface was reported up to 6 months by Corbel *et al.* (2007) and Rowland *et al*. (2013) and approximately 100% mortality of *An. gambiae* was observed on sprayed surfaces up to seven months by Curtis *et al.* (1998). Results of all of these researchers are significantly different as their results indicates higher residual efficacy of lamda-cyhalothrin as compared to our findings.

Darriet (1991) reported that alpha-cypermethrin and lambda-cyhalothrin showed equal toxicity against free-living *Anophelines* but according to Dorta *et al*. (1993); Sulaiman *et al*. (1996) and Hougard *et al*. (2003) bioassay tests indicated that alpha-cypermethrin was more persistent than lambda-cyhalothrin on mud, wood, cement and thatch surfaces which endorsed our results. Lambda-cyhalothrin impregnated papers were found to be more effective as compared to deltamethrin impregnated papers against females of *A. albopictus* in laboratory conditions (Sulaiman *et al.*, 1991) which is similar to our results that indicates that lamda-cyhalothrin is more effective than deltamethrin.

The results of Vatandoost *et al*. (2009) and Mushtaq *et al.* (2015) are in accordance with our findings in which they reported that filter paper surface yielded long residual activity of deltamethrin and mud yielded least when compared with plaster, wood and cement after five months of post IRS application against *An. stephensi* and *A. aegypti*. The current WHO recommendation is to place filter papers on the walls prior to spraying (WHO, 2006a) which also supports our results that filter paper have best residual activity of chemicals applied to it. The residual efficacy of lamda-cyhalothrin and deltamethrin reported by Etang *et al.* (2011) is about 4-7 months on different surfaces which is significantly higher than our results but their results endorsed our findings in terms of effectiveness of surfaces in which mud and wood surfaces showed less effectiveness than concrete/cement.

The less residual activity on mud surface by deltamethrin as compared to other surfaces is similar to the findings of Clark and Rangel (1998) in which they observed that deltamethrin gave mortalities of more than 80% for ≥1 month against *An. darling*. The shorter residual activity of lambda-cyhalothrin CS on mud surfaces as compared to cement surfaces against *An. gambiae* was also reported by Tchicaya *et al.* (2014) which is similar to our results in which mud showed less residual activity as compared to cement. The fast rate of decay of lambda-cyhalothrin on mud surfaces as compared to cement against *C. quiniquefasciatus* was also stated by Rowland *et al*. (2013) that endorse our findings.

The less persistence of the applied chemicals on the mud as compared to other was also reported earlier by Okumu *et al*. (2012) which stated that insecticidal activity on mud walls decayed over two months which is concurrent to our results.

This was earlier described by Mpofu *et al.* (1988) in which they stated that insecticides degrade much faster on porous surfaces. Also, this phenomenon was reported by Hadaway and Barlow (1963) in which they stated that mud surfaces generally absorb some of the applied insecticide and certain types of mud may also break down insecticides chemically. The difference in the effectiveness and residual life span of different pyrethroids in our results is due to the surface onto which these are sprayed as described earlier by Rohani *et al*. (1997).

The results of Ansari *et al.* (1997) showed mortality of *An. culicifacies* more on mud (12 weeks) as compared to cement (10 weeks) and that of Raeisi *et al.* (2010) also showed the residual activity of mud (2.5 months) greater than cement (1 month) when treated with deltamethrin against *An. stephensi*. These results showed mud has longer persistence as compared to cement which is dissimilar to our findings.

Alpha-cypermethrin and lamda-cyhalothrin showed less effectiveness against *C. quinquefasciatus* as compared to *Aedes notoscriptus* as reported by Pettit *et al.* (2010) which is almost similar to our results suggesting higher efficacy of these chemicals against *Aedes* species and low efficacy against *C. quinquefasciatus*. This less responsive behavior of *C. quinquefasciatus* against generally used pyrethroids resulting in low mortality in our findings is in accordance with the work of Yap *et al*. (1995); WHO (1996); Sathantriphop *et al.* (2006); Pridgeon *et al.* (2008); Kumar *et al*. (2011); Ekloh *et al*. (2013) and Naseri-Karimi *et al*. (2015).

***Conclusion*:** Alpha-cypermethrin 10% SC showed greater residual efficacy and percent mortality on different substrates/surfaces like cement, mud, plaster, wood and filter paper followed by lambda-cyhalothrin 10% CS and deltamethrin 5WP in a period of 20 weeks study. Response of these chemicals was seen greater on filter paper and cement and less on wood and mud.

***Acknowledgement*:** The authors are grateful to Higher Education Commission, Islamabad for providing financial assistance.

REFERENCES

Agossa, F.R., R. Aikpon, R. Azonde´kon, R. Govoetchan, G.G. Padonnou, O. Oussoua, F. Oke´-Agbo and M.C. Akogbe´to. 2014. Efficacy of various insecticides recommended for indoor residual spraying: pirimiphos methyl, potential alternative to bendiocarb for pyrethroid resistance management in Benin, West Africa. Trans. R. Soc. Trop. Med. Hyg. 108:84-91.

Ansari, M.A., P.K. Mittal, R.K. Razdan and C.P. Batra. 1997. Residual efficacy of deltamethrin 2.5 WP (K-Othrine) sprayed on different types of surfaces against malaria vector *Anopheles culicifacies*. Southeast Asian J. Trop. Med. Public Health. 28:606-609.

Boewono, D.T. 2005. Review on the efficacy of insecticides and bio-insecticides (Pathogen and IGR) against vector disease evaluations conducted by VRCRU–(2001-2002). J. Ekol. Keseh. 4:218-226.

Clark, G.G. and Y.N. Rangel. 1998. Mosquito vector control and biology in Latin America-An Eighth symposium. J. Am. Mosq. Control Assoc. 14:219-233.

Corbel, V., R. N'Guessan, C. Brengues, F. Chandre and L. Djogbenou. 2007. Multiple insecticide resistance mechanisms in *Anopheles gambiae* and *Culex quinquefasciatus* from Benin, West Africa. Acta Tropica. 101:207-216.

Curtis, C.F., C.A. Maxwell, R. Finch and K.J. Njunwa. 1998. Comparison of use of a pyrethroid either for house spraying or bed-net treatment against malaria vectors. Trop. Med. Int. Health. 3:619-631.

Darriet, F. 1991. Evaluation sur le terrain de l'efficacité de trois pyrethrinoides dans le cadre de la lutte contre les vecteurs du paludisme. Parassitologia. 33:111-119.

Dorta, M.V., V. Vasuki and A. Rajavel. 1993. Evaluation of organophosphorus and synthetic pyrethroid insecticides against six vector mosquito species. Revista de Saúde Pública. 27:391-397.

Ekloh, W., G. Oppong, M.B. Adinortey, J.B. Stiles-Ocran and D. Hayford. 2013. Susceptibility of *Culex quinquefasciatus* populations to deltamethrin in the Sefwi area of the western region of Ghana. Eur. J. Exp. Biol. 3:72-79.

Etang, J., P. Nwane, J.A. Mbida, M. Piameu, B. Manga, D. Souop and P. Awono-Ambene. 2011. Variations of insecticide residual bio-efficacy on different types of walls: results from a community-based trial in South Cameroon. Malar. J. 10:333. doi:10.1186/1475-2875-10-333.

Faraj, C., E.B. Adlaoui, S. Ouahabi, M. Elkohli, M. Elrhazi and L. Laqraa. 2013. Field evaluation of alpha-cypermethrin in indoor residual spraying for leishmaniasis control in an endemic area, Northern Morocco. Parasit. Vectors. 6:354. doi:10.1186/1756-3305-6-354.

Giga, D.P. and C.S.R. Jane. 1991. Relative toxicity and persistence of pyrethroid deposits on different surfaces for the control of *Prostephanus truncates* and *Sitophilus zeamais*. J. Stored Prod. Res. 27:153-160.

Grieco, J.P., N.L. Achee, T. Chareonviriyaphap, W. Suwonkerd, K. Chauhan and M.R. Sardelis. 2007. A new classification system for the actions of IRS chemicals traditionally used for malaria control. PLoS ONE. 2:e716. doi:10.1371/journal.pone.0000716.

Hadaway, A.B. and F. Barlow. 1963. The residual action of two organophosphorus compounds and a carbamate on dried muds. Bull. World Health Organ. 28:69-76.

Hirata, K., O. Komagata, K. Itokawa, A. Yamamoto, T. Tomita and S. Kasai. 2014. A single crossing-over event in voltage-sensitive Na+ channel genes may cause critical failure of dengue mosquito control by insecticides. PLoS Negl. Trop. Dis. 8:3085. doi:10.1371/journal.pntd.0003085.

Hougard, J., S. Duchon, F. Darriet, M. Zaim, C. Rogier and P. Guillet. 2003. Comparative performances under laboratory conditions of seven pyrethroid insecticides used for impregnation of mosquito nets. Bull. World Health Organ. 81:324-333.

Karunaratne, S.H.P.P., T.C. Weeraratne, M.D.B. Perera and S.N. Surendran. 2013. Insecticide resistance and efficacy of space spraying and larviciding in the control of dengue vectors *Aedes aegypti* and *Aedes albopictus* in Sri Lanka. Pestic. Biochem. Physiol. 107:98-105.

Kolaczinski, K., J. Kolaczinski, A. Kilian and S. Meek. 2007. Extension of indoor residual spraying for malaria control into high transmission setting in Africa. Trans. R. Soc. Trop. Med. Hyg. 101:852-853.

Kumar, K., A.K. Sharma, S. Kumar, S. Patel, M. Sarkar and L.S. Chauhan. 2011. Multiple insecticide resistance/susceptibility status of *Culex quinquefasciatus*, principal vector of bancroftian filariasis from filaria endemic areas of Northern India. Asian Pac. J. Trop. Med. 4:426-429.

Mahmood, F. and W.K. Reisen. 1981. Duration of the gonotrophic cycles of *Anopheles culicifacies* giles and *Anopheles stephensi* list on, with observations on reproductive activity and survivorship during winter in Punjab province, Pakistan. Mosquito News. 41:41-50.

Manguin, S. 2008. Biodiversity of Malaria in the World; English completely updated Ed. Montrouge; Esther [Esher]. John Libbey Eurotext: Surrey; 2008.

Matthews, G.A., H.M. Dobson, P.B. Nkot, T.L. Wiles and M. Birchmore. 2009. Preliminary examination of integrated vector management in a tropical rain forest area of Cameroon. Trans. R. Soc. Trop. Med. Hyg.103:1098-1104.

Mohammad, A., S. Mansoreh, K. Mehdi, V. Hasan, A.M. Reza and A. Kamran. 2011. Persistence and residue activity of deltamethrin on indoor residual spraying surfaces against malaria vectors in Southeastern Iran. Asian Pac. J. Trop. Biomed. 1:271-275.

Moosa-Kazemi, S.H., H. Vatandoost, A. Raeisi and K. Akbarzadeh. 2007. Deltamethrin impregnated bed nets in a malaria control program in Chabahar, Southeast Baluchistan, I.R. Iran. Iran. J. Arthrop. Borne Dis.1:43-51.

Mpofu, S.M., P. Taylor and J. Govere. 1988. An evaluation of the residual life span of DDT in malaria control. J. Am. Mosq. Control Assoc. 4:529-535.

Mushtaq, S., M.U. Mukhtar, A. Arslan, A.B. Zaki, M. Hammad and A. Bhatti. 2015. Probing the residual effects of Deltamethrin on different surfaces against malaria and dengue vector in Pakistan by designing laboratory model. J. Ent. Zool. Stud. 3:440-443.

N'Guessan, R., P. Boko, A. Odjo, J. Chabi, M. Akogbeto and M. Rowland. 2010. Control of pyrethroid and DDT-resistant *Anopheles gambiae* by application of indoor residual spraying or mosquito nets treated with a long-lasting organophosphate insecticide, chlorpyrifos-methyl. Malar. J. 9:44. doi:10.1186/1475-2875-9-44.

Naseri-Karimi, N., H. Vatandoost, M. Bagheri and A.R. Chavshin. 2015. Susceptibility status of *Culex pipiens* against deltamethrin and DDT, Urmia County, West Azerbaijan Province, Northwestern Iran. Asian Pac. J. Trop. Dis. 5:77-79.

Nejera, J.A. and M. Zaim. 2001. Malaria vector control: Insecticides for indoor residual spraying. WHO Dengue Bull. 25:126-128.

Okumu, F.O., B. Chipwaza, E.P. Madumla, E. Mbeyela, G. Lingamba, J. Moore, A.J. Ntamatungro, D.R. Kavishe and S.J. Moore. 2012. Implications of bio-efficacy and persistence of insecticides when indoor residual spraying and long-lasting insecticidal nets are combined for malaria prevention. Malar. J. 11:378. doi:10.1186/1475-2875-11-378.

Paaijmans, K.P. and M.B. Thomas. 2011. The influence of mosquito resting behavior and associated microclimate for malaria risk. Malar. J. 10:183. doi:10.1186/1475-2875-10-183.

Paredes-Esquivel, C., A. Lenhart, R. del Río, M.M. Lezaa, M. Estrugo, E. Chalco, W. Casanova and M.A. Miranda. 2015. The impact of indoor residual spraying of deltamethrin on dengue vector populations in the Peruvian Amazon. Acta Tropica. 154:139-144.

Pates, H. and C. Curtis. 2005. Mosquito behavior and vector control. Ann. Rev. Entomol. 50:53-70.

Pettit, W.J., P.I. Whelan, J. McDonnell and S.P. Jacups. 2010. Efficacy of alpha-cypermethrin and lambda-cyhalothrin applications to prevent *Aedes* breeding in tires. J. Am. Mosq. Control Assoc. 26:387-397.

Pridgeon, J.W., R.M. Pereira, J.J. Becnel, S.A. Allan, G.G. Clark and K.J. Linthicum. 2008. Susceptibility of *Aedes aegypti*, *Culex quinquefasciatus* Say, and *Anopheles quadrimaculatus* Say to 19 pesticides with different modes of action. J. Med. Entomol. 45:82-87.

Raeisi, A., A. Shahbazi, M. Ranjbar, A. Shoghli, H. Vatandoost and L. Faraji. 2008. National strategy plan for malaria control (I.R. Iran, 2004-2008). Tehran: Ministry of Health and Medical Education of Iran Publication. pp.72.

Raeisi, A., M.R. Abai, K. Akbarzadeh, M. Nateghpour, M. Sartipi, A. Hassanzehi, N. Shahbakhsh, L. Faraji, F. Nikpour and M. Mashayekhi. 2010. Residual effects of Deltamethrin WG 25% as a new formulation on different

surfaces against *Anopheles stephensi*, in Southeastern Iran. Iranian J. Arthropod-Borne Dis. 4:60-65.

Raghavendra, K., S.K. Ghosh, A. Eapen, S.N. Tiwari, T.S. Satyanarayan, J. Ravindran, U. Sreehari and A.P. Dash. 2011. Field evaluation of lambda-cyhalothrin (ICON 10 CS) indoor residual spraying against *Anopheles culicifacies* in India. J. Vect. Born. Dis. 48:18-26.

Ratovonjato, J., M. Randrianarivelojosia, M.E. Rakotondrainibe, V. Raharimanga, L. Andrianaivolambo and G. LeGoff. 2014. Entomological and parasitological impacts of indoor residual spraying with DDT, alpha-cypermethrin and deltamethrin in the western foothill area of Madagascar. Malar. J. 13:21. doi:10.1186/1475-2875-13-21.

Rohani, A., M.Z. Zaridah, I. Vythilingam, W.A. Nazni and H.L. Lee. 1997. Residual effect of etofenprox (Trebon®) against *Anopheline* and *Culicine* mosquito on different wall surfaces. Vector. J. 3:25-34.

Rowland, M., P. Boko, A. Odjo, A. Asidi, M. Akogbeto and R. N'Guessan. 2013. A new long-lasting indoor residual formulation of the organophosphate insecticide pirimiphos methyl for prolonged control of pyrethroid-resistant mosquitoes: an experimental hut trial in Benin. PLoS One. 8:e69516. doi: 10.1371/journal.pone.0069516.

Rowland, M., P. Mahmood, J. Iqbal, I. Carneiro and D. Chavasse. 2000. Indoor residual spraying with alpha-cypermethrin controls malaria in Pakistan: A community-randomized trial. Trop. Med. Int. Health. 5:472-481.

Rozilawati, H., H.L. Lee, M.S. Mohd, N.I. Mohd and S. Rosman. 2005. Filed bioefficacy of deltamethrin residual spraying against dengue vectors. Trop. Biomed. 22:143-148.

Rueda, L.M. 2004. Pictorial keys for the identification of mosquitoes (Diptera: Culcidae) associated with dengue virus transmission. Zootaxa. 589:1-60.

Sathantriphop, S., P. Paeporn and K. Supaphathom. 2006. Detection of insecticides resistance status in *Culex quinquefasciatus* and *Aedes aegypti* to four major groups of insecticides. Trop. Biomed. 23:97-101.

Shaalan, E.A., D.V. Canyon, B. Bowden, M.W.F. Younes, H. Abdel-Wahab and A.H. Mansour. 2006. Efficacy of botanical extracts from *Callitris glaucophylla*, against *Aedes aegypti* and *Culex annulirostris* mosquitoes. Trop. Biomed. 23:180-185.

Silver, J.B. 2008. Mosquito Ecology: Field Sampling Methods. 3rd Edition. New York: Springer.

Sulaiman, S., B. Omar, J. Jeffery and V. Busparani. 1991. Evaluation of pyrethroids lambda-cyhalothrin, deltamethrin and permethrin against *Aedes albopictus* in the laboratory. J. Am. Mosq. Control Assoc. 7:322-323.

Sulaiman, S., Z.A. Pawanchee, I. Ghauth, A. Wahab, B. Vadiveloo, J. Jeffery and A.F. Mansor. 1996. The residual effects of alpha-cypermethrin and permethrin against the dengue vector *Aedes albopictus* (Skuse) in wooden huts in Malaysia. J. Vect. Ecol. 21:85-88.

Tchicaya, E.S., C. Nsanzabana, T.A. Smith, J. Donzé, M.L. de Hipsl, Y. Tano, P. Müller, O.J.T. Briët, J. Utzinger and B.G. Koudou. 2014. Micro-encapsulated pirimiphos-methyl shows high insecticidal efficacy and long residual activity against pyrethroid-resistant malaria vectors in central Côte d'Ivoire. Malar. J. 13:332. doi:10.1186/1475-2875-13-332.

Tchuinkam, T., F. Simard, E. Lele-Defo, B. Tene-Fossog, A. Tateng-Ngouateu, C. Antonio-Nkondjio, M. Mpoame, J.C. Toto, T. Njine, D. Fontenille and H.P. Awono-Ambene. 2010. Bionomics of *Anopheline* species and malaria transmission dynamics along an altitudinal transect in Western Cameroon. BMC Infect. Dis. 10:119. doi: 10.1186/1471-2334-10-119.

Thanispong, K., N.L. Achee, M.J. Bangs, J.P. Grieco, W. Suwonkerd and A. Prabaripai. 2009. Irritancy and repellency behavioral responses of three strains of *Aedes aegypti* exposed to DDT and alpha-cypermethrin. J. Med. Entomol. 46:1407-1414.

Tseng, L.F., W.C. Chang, M.C. Ferreira, C.H. Wu, H.S. Rampão and J.C. Lien. 2008. Rapid control of malaria by means of indoor residual spraying of alpha-cypermethrin in the Democratic Republic of São Tomé and Príncipe. Am. J. Trop. Med. Hyg. 78:248-250.

Uragayala, S., R. Kamaraju, S. Tiwari, S.K. Ghosh and N. Valecha. 2015. Small-scale evaluation of the efficacy and residual activity of alpha-cypermethrin WG (250 g AI/kg) for indoor spraying in comparison with alpha-cypermethrin WP (50 g AI/kg) in India. Malar. J. 14:223. doi: 10.1186/s12936-015-0739-7.

Vatandoost, H., M. Abai, M. Abbasi, M. Shaeghi, M. Abtahi and F. Rafie. 2009. Designing of a laboratory model for evaluation of the residual effects of deltamethrin (K-othrine WP 5%) on different surfaces against malaria vector, *Anopheles stephensi* (Diptera: Culicidae). J. Vector Born Dis. 46:261-267.

Vontas, J., E. Kioulos, N. Pavlidi, E. Morou, A. della Torre and H. Ranson. 2012. Insecticide resistance in the major dengue vectors *Aedes albopictus* and *Aedes aegypti*. Pestic. Biochem. Physiol. 104:126-131.

WHO. 1996. Report of the WHO informal consultation on the evaluation and testing of insecticides. CTD/WHOPES/IC/96. Control of Tropical Diseases Division. WHO Report, Geneva, Switzerland.

WHO. 1998. Report of the second WHOPES working group meeting, 22-23 June 1998. Review of Alpha-Cypermethrin 10% SC and 5% WP, Cyfluthrin 5% EW and 10% WP. Geneva: World Health Organization, 1998; WHO/CTD/WHOPES/98.10.

WHO. 2006a. Guidelines for testing mosquito adulticides for indoor residual spraying and treatment of mosquito nets.

Control of neglected tropical diseases WHOPES, pp. 21; WHO/CDS/NTD/WHOPES/GCDPP/2006.3.

WHO. 2006b. Guidelines for testing mosquito adulticides for indoor residual spraying and treatment of mosquito nets. Control of neglected tropical diseases who pesticide evaluation scheme, pp. 11; WHO/CDS/NTD/WHOPES/GCDPP/2006.3.

WHO. 2009. World Health Organization: recommended insecticides for indoor residual spraying against malaria vectors. Available online at http://www.who.int/whopes/quality/en/

WHO. 2013a. Test procedures for insecticide resistance monitoring in malaria vector mosquitoes. 2013: World Health Organization, Geneva, Switzerland.

WHO. 2013b. World Health Organization recommended insecticides for indoor residual spraying against malaria vectors. 2013. Geneva, Switzerland. Available online at http://www.who.int/whopes/Insecticides_IRS_Malaria_25_Oct_2013.pdf?ua=1.

WHOPES. 2007. Report of the tenth WHOPES working group meeting: Review of: Spinosad 0.5% GR and 12 SC, Lambda-cyhalothrin 10% CS, K-O Tab 1-2-3 and Interceptor. Geneva: World Health Organization; 2007, 22-36; WHO/CDS/NTD/WHOPES/2007.1.

WHOPES. 2015. WHO recommended insecticides for indoor residual spraying against malaria vectors. Available online at http://www.who.int/whopes/insectides_IRS_2_Mar_2015.pdf?ua=1. 2015.

Yap, H.H., C.Y. Lee, N.L. Chong, B. Rohaizat and H.T. Tan. 1995. Laboratory bioassays of Malaysian standard mosquito mat formulation against *Aedes aegypti* (L) and *Culex quinquefasciatus* Say using two test methods. J. Biosci. 6:86-93.

Yap, H.H., Y.W. Lee and J. Zairi. 2000. Chemical control of mosquitoes. In: F.S.P. Ng and H.S. Yong (eds.), Mosquitoes and Mosquito-Borne Diseases: Biology, Surveillance, Control, Personal and Public Protection Measures. Academy of Sciences Malaysia, Kuala Lumpur, Malaysia; pp.197-210.