

## Performance evaluation of chemical insecticides used for indoor residual spraying against *Anopheles arabiensis* in Ethiopia

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### Abstract

**Introduction:** Monitoring of the residual efficacy of insecticides is essential to determine the periods that they remain effective in interrupting malaria transmission and schedule when to re-spray. There is a critical need to establish evidence-based information for the insecticide (s) that would be used for IRS in Ethiopia.

**Objectives:** (1) To assess the Indoor Residual Spray quality on different wall surfaces, (2) To determine the residual efficacy of Bendiocarb 80% WP, Propoxur 50% WP and Actellic 300 CS sprayed on different wall surfaces against *An. arabiensis*, (3) To estimate the decay rate of Bendiocarb 80% WP, Propoxur 50 % WP and Actellic 300 CS sprayed on different wall surfaces, and (4) To evaluate the community acceptability of the Indoor Residual Spray.

**Materials and Methods:** The study employed both cross-sectional (assessment of quality of spray) and longitudinal monitoring of the residual efficacy of chemical insecticides on different wall surfaces of sprayed houses in purposively selected villages. In Wondo Genet 48 test houses and 4 control houses were selected for the study. Similarly, 36 test houses and 3 control houses were used for the Mirab Abaya study. Each insecticide treatment was carried out in 12 houses for each wall type on the condition that all wall types were present in each study village. This means that an insecticide was sprayed in 48 and 36 houses respectively where the wall types were rough, smooth, cement and painted. The concentration of the insecticides was assessed by High Performance Liquid Chromatography.

**Results:** The first, second, third and fourth rounds test results summarized as follows. The overall mosquito mortality exposed to wall surfaces sprayed with Propoxur 50% WP ranged from 82.5% - 100% and 91% - 100% for Wondo Genet and Mirab Abaya sites, respectively. The overall mosquito mortality exposed to wall surfaces sprayed with Bendiocarb 80% WP ranged from 85.4% - 100% and 91.1% - 100% for Wondo Genet and Mirab Abaya sites, respectively. The overall mosquito mortality exposed to wall surfaces sprayed with Actellic 300 CS ranged from 96.9% -100% and 94.8% - 100% for Wondo Genet and Mirab Abaya sites, respectively. .. At round five of the assessment, mosquito mortality from Actellic 300 CS sprayed wall surfaces was 84.4% and 87% for Mirab Abaya and Wondo sites, respectively. During the six round residual efficacies monitoring mosquito mortality was found to drop to 52.2% and 48.3% for the two sites, respectively, which is below the required WHO cutoff (point  $\geq$  80%). The effect of Bendiocarb 80% WP on mosquitoes' mortality was found below the WHO cutoff value during the fifth and sixth round monitoring (51.5% for Mirab Abaya site in the sixth round, and 70.9% then 41.25% for Wondo Genet sites in the fifth and sixth round monitoring, respectively) with exception in the fifth round for Mirab Abaya sites (84.1%). The performance of Propoxur 50% WP was below the required WHO value for both sites in the fifth and sixth round monitoring (78.2% and 77.4% in the fifth round, and 50.3% and 41.4% in the sixth round for Mirab Abaya and Wondo Genet sites, respectively). The performance of the Propoxur 50% WP, Bendiocarb 80% WP and Actellic 300 CS on rough, smooth, cement and painted wall surfaces was similar up to the third-round monitoring. Differences in performance were observed at fourth and fifth round monitoring. With regard to acceptability of Indoor Residual Spray, 90.5% of the respondents in Wondo Genet site agreed to allow house spraying in the future and . (100% of the respondents in Mirab Abaya site agreed to allow IRS for malaria and other vector borne diseases protection.

**Conclusion:** The performances of Actellic 300 CS and Bendiocarb 80% WP were better in smooth, cement and painted wall surfaces than the rough wall surface types which is found within the WHO recommendation limit. For drawing further conclusions similar studies are recommended in other sites by different partners in a collaborative and coordinated manner.

**Key words:** Malaria, insecticides, indoor residual spraying, performance, *Anopheles arabiensis*, Ethiopia

### Introduction

In Ethiopia, malaria is among the top public health significant diseases. Almost three-fourths of the total landmass and above half of the total population are at

malaria risk (Terefe et al. 2015). According to National Malaria Control Program recent report indicates that about 2,174,707 malaria cases and 662 deaths occur annually (Federal Ministry of Health 2010).

Generally, indoor residual spraying (IRS) is one of the key elements of malaria vector control and has been in use since the 1950s. IRS is the application of a long-lasting, residual insecticide to potential malaria vector resting surfaces such as internal walls, eaves and ceilings of all houses or structures (including domestic animal shelters) where such vectors might come into contact with the insecticide. IRS and long-lasting insecticidal nets (LLINs) are pillars in malaria prevention and control strategy in Ethiopia and are being used on a large scale. Since 2005, there has been a large-scale application of chemical-based malaria vector control in Ethiopia including indoor residual spray and long-lasting insecticidal nets (FMOH Report 20103). However, appearance and widespread of resistance in malaria vectors has become a potential threat to eliminating malaria from the country in the upcoming decade. There are local evidences showing the widespread of insecticide resistance to various chemicals used for IRS (Yewhalaw et al. 2010; Asale et al. 2014; AIRS 2014).

Monitoring of the residual efficacy of insecticides is essential to determine the periods that they remain effective in interrupting malaria transmission and schedule when to re-spray (WHO 2012). The efficacy of IRS could be influenced by different factors such as mosquito susceptibility to insecticide, mosquito behavior (endophilic and endophagic), type of sprayable surfaces, quality of IRS, residual efficacy of an insecticide and community acceptance (WHO/CDS\_NTD/WHOPES/ GCDPP/2006.1; Das 2007). In addition, other factors have been reported to contribute to the residual efficacy of an insecticide, such as: the type of insecticide; formulation; applied dose; physical and chemical properties of the sprayed surfaces; and weather conditions (Verrone 1962; de Arias et al. 2003, 2004). The insecticide should be sufficiently stable to maintain biological efficacy on treated surfaces over time in order to minimize the number of spraying cycles required to cover the targeted malaria transmission seasons (WHO/CDS/NTD/WHOPES/GCDPP/2006.3). An insecticide for IRS is considered to have adequate residual efficacy when mortality of the exposed mosquitoes is  $\geq 80\%$  24 hours post-exposure (WHO/CDS\_NTD/WHOPES/ GCDPP/2006.1).

*Anopheles arabiensis* is the most important malaria vector in Ethiopia (White et al. 1980). It is found in all malaria endemic administrative regions of the country (O'Connor 1967). Other malaria vectors in the country include *An. pharoensis*, *An. funestus*, and *An. nili* (Gebre-Mariam 1988; Nigatu et al. (1995) recorded the association of DDT resistance with inversion polymorphism in *Anopheles arabiensis* from Ethiopia. Abose et al. (1998) also reported DDT resistance in the primary malaria vector (*An. arabiensis*) in Arbaminch

and Gambella, of southern and southwestern Ethiopia. Similarly, Balkew et al. (2003) reported different resistance levels to Permethrin and Propoxur against the same vector in eastern Ethiopia. Presently, unpublished reports also indicate that the country's primary malaria vector has developed different levels of resistance to all classes of insecticides that are being used for vector control. This calls for generation of quality data on insecticides currently in use and new ones to be registered for use in the future.

Careful planning, monitoring, and evaluation processes are more important than ever to maximize the benefits of the limited resources. Accordingly, the Federal Ministry of Health, together with EPHI and other partners, has planned to conduct different surveys (Mosquito behavior and its dynamics, Decay rate study, Susceptibility study, LLINs longevity study) to assist policymakers, health care providers, and partners to have a source of important information that can be used in decision making in the areas of malaria prevention and control. Therefore, there is a critical need to establish evidence-based information for the insecticide (s) that would be used for IRS. The information generated from this study will be useful in planning the introduction of new insecticides, replacement of resistant insecticides and making decisions to procure insecticides to be used for IRS.

## Materials and Methods

**Study area:** The study was carried out in two sites namely Wondo Genet and Mirab Abaya areas. Wondo Genet is found in Oromia Regional State, located on the western escarpment of the central rift valley of Ethiopia, about 270 km south of the capital city, Addis Ababa. Mirab Abaya Woreda is located about 520 km south of Addis Ababa in Gamo Gofa Zone, SNNP Regional States. The two sites are malaria endemic and selected as sentinel sites for monitoring performance of insecticides and anti-malarial drugs designed to represent the different eco-epidemiological settings in the country.

**Study design:** The study employed both cross-sectional (assessment of quality of spray) and longitudinal residual efficacy study in purposively selected villages. Up to two villages with a relatively easy access and characterized by higher malaria transmission were selected from each district. House selection were based on the availability of different wall types such as mud (rough mud, smooth mud, dung, cement or painted), and brick. In Wondo Genet 48 test houses and 4 as control houses were selected for the study. Similarly, 36 test houses and 3 control houses were used for the Mirab Abaya study. Each insecticide was sprayed in 12 houses of each wall type on the condition that all wall types were present in each study village. This means that an insecticide was sprayed in 48 houses where the wall types were rough, smooth, cement and painted.

**Setting the application of insecticides:** The IRS was conducted by well trained personnel. They were recruited from the local community trained and supervised by study team from EPHI and NMCP/FMOH. Preparations were undertaken in households prior to the spraying which include: removal of movable household utensils; covering of non-movable contents with plastic sheets; and removal of wall coverings and curtains. Household occupants were instructed to stay outdoors during and for at least 2 hours of post spray.

**Conducting application of insecticides:** Bendiocarb 80% WP, Propoxur 50 % WP and Actellic 300 CS were sprayed on all wall surfaces at the recommended doses. Bendiocarb 80% WP was sprayed at a rate of 0.4 g active ingredient (a.i.) / square meter (sq. m), Propoxur 50 % WP at 2 g a.i./sq. m and Actellic acid 300 CS at 1 g of a.i./sq. m (FMOH 2012). Spraying was done by using a Hudson® X-pert compression sprayer (Hudson Manufacturing Company) with a flat nozzle as recommended for IRS following the national spraying operation guidelines (FMOH 2012) and WHO recommendations (WHO 1989). A distance of 45 cm from the nozzle tip to the surface to be sprayed was maintained during spraying. At this distance, the width of the swathe at the point of impact was 75 cm. A 5 cm overlap was maintained between the swathes to make sure that no wall surface was left unsprayed.

**Assessment of spray quality:** To assess the quality of spraying, three Whatman® filter paper No. 1 (size 10 cm x 10 cm) leveled properly were placed on the walls of each surface type (one at low, one at middle and one at upper part) of each wall surface type in each house, before spraying, and removed after complete drying. The papers were wrapped in aluminum foils and subjected to analysis for required insecticide concentration. The chemical analysis results were combined for each substrate to provide the average concentration of insecticide (in mg/m). Insecticide concentration in the Whatman® filter paper was analyzed using High Performance Liquid Chromatography (HPLC).

**Cone wall bioassay test:** Assessment of the bio-efficacy and residual performance of insecticides sprayed on wall surfaces was a longitudinal study aimed at collecting information on monthly basis for six or more month's period. Bio-efficacy and decay rate monitoring of the insecticides on wall surfaces were measured using standard WHO cone tests (WHO/CDS/NTD/WHOPES/GCDPP/2006.3) in houses on different wall surfaces and each surface was replicated four times and one unsprayed house served as control. To assess the quality of spraying, cone testes were carried out 1 – 2 days after spraying. Thereafter, performance of the residual efficacy of

each insecticide on treated wall surfaces was monitored on monthly bases post IRS for 6 consecutive rounds.

On a single wall surface three cones were fixed using fine steel pins at the lower, middle and upper parts of the wall. Cones were not fixed on areas 60 cm above the ground and 60 cm below the roof. Three to five days-old unfed females of *An. arabiensis* of insectary colony were used. Ten mosquitoes were gently transferred into each cone and exposed for 30 minutes. At the end of exposure time, the mosquitoes were transferred back into insecticide free holding paper cup for 24 h holding period and were provided with 10% sugar solution. Paper cups were kept in wooden box or carton which was covered by damp towel to create favorable temperature ( $27 \pm 2$  °C) and humidity ( $70 \pm 10$ ). Bioassays were terminated when the mortality was below 80% in two consecutive bioassays. Mortality counts were taken 24 h post exposure. Mosquitoes were classified as dead if they are immobile or unable to stand or fly in a coordinated way. When average mortality of the controls was between 5% and 20%, test mortality was corrected using Abbot's formula. But if control mortality was above 20%, the results were discarded and the tests were repeated.

**Acceptability of the IRS by the community:** Data were collected from households that were selected at the beginning and end of the study using well-structured questionnaire. Together with the insecticides' impact on the target vector species, data for factors that can limit acceptability of the IRS such as the visible insecticide stains on the walls, an unpleasant odor, skin and nasal irritation were collected. Ease of application (mixing and spraying) by the operators and impacts on other household insects including nuisances were also recorded.

## Results

**Results from High Performance Liquid Chromatography (HPLC):** The quality of spraying was assessed by chemical analysis from three Whatman® filter papers that were stuck on the walls of each surface type (one at lower, one at middle and one at upper part) in each selected house for the study. Chemical analysis using HPLC showed that the concentration of Bendiocarb 80% WP, Propoxur 50 % WP and Actellic acid 300 CS sprayed on all wall surfaces was found above the WHO recommended except for Propoxur in Wondo Genet found close to the borderline limit (Table 1). The chemical analysis from Whatman® filter paper was determined by type of wall surfaces. The results of the analysis showed that the concentration of active ingredient per type of wall surface was again found above the WHO recommended dose for each insecticide except for Propoxur in Wondo near to the lower border limit (Table 2).

**Table 1: Active content of insecticides determined by High Performance Liquid Chromatography (HPLC) from samples of Whatman® filter paper collected from different location on wall surfaces**

| Insecticide Type  | Study site  | Location of Wall surface | Sample count | Active Ingredient, gm/m <sup>2</sup> |               | WHO recommended dose (gm/m <sup>2</sup> ) |
|-------------------|-------------|--------------------------|--------------|--------------------------------------|---------------|-------------------------------------------|
|                   |             |                          |              | Average per location                 | Total average |                                           |
| Propoxur 50% WP   | Arbaminch   | Upper                    | 12           | 2.852                                | 2.7434        | 2                                         |
|                   |             | Middle                   | 12           | 2.429                                |               |                                           |
|                   |             | Lower                    | 12           | 2.968                                |               |                                           |
|                   | Wondo Genet | Upper                    | 12           | 1.749                                | 1.558         |                                           |
|                   |             | Middle                   | 12           | 1.515                                |               |                                           |
|                   |             | Lower                    | 12           | 1.4092                               |               |                                           |
| Bendiocarb 80% WP | Arbaminch   | Upper                    | 12           | 0.7542                               | 0.8497        | 0.4                                       |
|                   |             | Middle                   | 12           | 0.9636                               |               |                                           |
|                   |             | Lower                    | 12           | 0.8401                               |               |                                           |
|                   | Wondo Genet | Upper                    | 12           | 0.855                                | 0.8681        |                                           |
|                   |             | Middle                   | 12           | 0.8967                               |               |                                           |
|                   |             | Lower                    | 12           | 0.8525                               |               |                                           |
| Actellic 300 CS   | Arbaminch   | Upper                    | 12           | 2.0758                               | 2.2712        | 1                                         |
|                   |             | Middle                   | 12           | 1.965                                |               |                                           |
|                   |             | Lower                    | 12           | 2.774                                |               |                                           |

**Table 2: Active content of insecticides determined by High Performance Liquid Chromatography (HPLC) from samples of Whatman® filter paper collected from different types of wall surfaces**

| Insecticide Type  | Study site  | Type of Wall surface | Sample count | Active Ingredient, gm/m <sup>2</sup> |                          |
|-------------------|-------------|----------------------|--------------|--------------------------------------|--------------------------|
|                   |             |                      |              | Sum                                  | Average per wall surface |
| Propoxur 50% WP   | Arbaminch   | Unpainted            | 15           | 60.56                                | 4.0373                   |
|                   |             | Painted              | 21           | 35.46                                | 1.773                    |
|                   | Wondo Genet | Unpainted            | 6            | 9.80                                 | 1.6333                   |
|                   |             | Painted              | 6            | 5.26                                 | 0.8766                   |
|                   |             | Rough                | 15           | 28.55                                | 1.9033                   |
|                   |             | Cement               | 9            | 12.47                                | 1.3856                   |
| Bendiocarb 80% WP | Arbaminch   | Unpainted            | 9            | 7.04                                 | 0.88                     |
|                   |             | Painted              | 18           | 18.48                                | 1.0267                   |
|                   |             | Rough                | 9            | 4.22                                 | 0.4689                   |
|                   |             | Smooth               | 15           | 6.86                                 | 0.4573                   |
|                   | Wondo Genet | Painted              | 6            | 2.65                                 | 0.4417                   |
|                   |             | Rough                | 6            | 6.50                                 | 1.0833                   |
|                   |             | Cement               | 9            | 15.24                                | 1.6933                   |
|                   |             | Unpainted            | 12           | 17.52                                | 1.46                     |
| Actellic 300 CS   | Arbaminch   | Painted              | 24           | 64.26                                | 2.6775                   |

**Results of wall cone bioassay tests:** The following results were recorded based on WHO's wall-cone assay procedure for Propoxur 50% WP, Bendiocarb 80% WP and Actellic 300 CS for total six rounds after initial spray. Field results for KD after 30 minutes were not considered due to inconsistent records. Results for mortality rate 24 hours after application of each insecticide are summarized in the following manners.

**Results of wall cone bioassay from Wondo site, Oromia Regional State:** Mean mortality rates of *An. arabiensis* exposed to Propoxur 50% WP sprayed rough mud wall surfaces was 100%, 95%, 99%, 70%, 81% and 21.7% in the first, second, third, fourth, fifth and sixth rounds, respectively. Similar pattern was observed for cement wall surfaces with 100%, 92.5%, 100%, 60% and 57.5% mortality rates in the first, second, third, fourth and fifth round tests, respectively. For smooth and painted wall surfaces 100% mortality rates were recorded till the fourth round of the study. The mosquito mortality rate on the smooth surfaces fall to 80% and 33.3% in the fifth and sixth round monitoring, respectively. While in the sixth-round

monitoring, results for painted surfaces were found to be 41.4%. The overall mosquito mortality rates in the first, second, third, fourth, fifth and sixth were found to be 100%, 97%, 98.8%, 82.5%, 77.4% and 41.4%, respectively. The performance of Bendiocarb 80% WP in the first, second, third, fourth, fifth and sixth round monitoring on rough wall surface was 100%, 99.2%, 100%, 86.7%, 75% and 30% respectively. For smooth wall surface, a mortality rate of 100% was recorded for the first three rounds while mortality rates of 73.3%, 55% and 43.3% were recorded on the fourth, fifth and sixth round monitoring, respectively. The performance of Bendiocarb 80% WP on painted surface was similar to that of the smooth surface in the first three rounds. Whereas, mortality rates on Bendiocarb 80% WP sprayed cement surface was 100%, 87.5%, 96.7%, 90%, 54.4% and 36.7% in the first, second, third, fourth, fifth and sixth round, respectively. The mosquito mortality rate on bendiocarb 80% WP sprayed painted wall bioassay results declined to 47.5% in the sixth round from the 91.7% in the fourth

round of the study. Over all 100%, 97%, 97.1%, 85%, 71% and 41.25% mortality rates were documented in the first, second, third, fourth, fifth and sixth round of the study, respectively.

The results for Actellic 300 CS showed 100% mosquito mortality on smooth wall type in the first four rounds. The mortality rate dropped to 96.7% and 56.7% in the fifth and sixth rounds, respectively. For painted wall surface 100% mosquito mortality was registered in the first three rounds while 95.5%, 95% and 41% were recorded in the fourth, fifth and sixth rounds, respectively. On the rough wall surface 100% mosquito mortality was obtained on the first two rounds, while mortality rates decreased to 95%, 92.5%, 84.4% and 45% in the third, fourth, fifth and sixth round, respectively. This pattern was mostly similar for cement wall surface type. Overall mosquito mortality rate on Actellic 300CS sprayed wall surface was 100%, 98.3%, 98.1%, 96.9%, 87% and 48.3% in the first, second, third, fourth, fifth and sixth round, respectively.

**Results from Mirab Abaya, SNNP Region:** Mosquito mortality rate on Propoxur 50% WP sprayed smooth and painted wall surface was 100% in the first three rounds. The mosquito mortality rate declined to 95.8%, 71.7 and 56.7% in the fourth, fifth and sixth rounds of the study, respectively on smooth wall surfaces. In the painted wall surface, mosquito mortality declined to 94.2%, 84.2% and 50% in the fourth, fifth and sixth rounds of the study, respectively. Similar performance was observed for rough wall surface with 100% mosquito mortality on first and third rounds, and 98.3% and 82.2% on the second and fourth rounds, respectively. Mosquito mortality rate during the sixth round was 42.2%. Overall, 100%, 99.4%, 98.1%, 91.5%, 78.2% and 50.3% mortality rates were recorded in the first, second, third, fourth, fifth and six rounds, respectively. Due to the problem

of availability of cement wall surfaces, this type of test was not conducted in this study site.

The results for Bendiocarb 80% WP showed 100% mosquito mortality on both rough and smooth wall surfaces in the first two rounds. Mosquito mortality rate (87.7%) declined in the third and fourth on both rough and smooth surfaces. Moreover, mortality rate declined to 73.3% and 35% for rough surfaces, and 84.4% and 52% for smooth surfaces, in the fifth and sixth round, respectively. For painted wall surface, 100% mosquito mortality was recorded for the first-round while 98.3%, 95.8% and 100% were recorded in second, third and fourth round, respectively. For the fifth and sixth rounds 94.4% and 52% mortality rates were recorded, respectively. Over all, 100%, 99.4%, 90.8%, 91.1%, 84.1% and 51.5% mortality rates were recorded in the first, second, third and fourth round tests after spray. The results for Actellic 300 CS showed 100% mortality on rough, smooth and painted wall surfaces in the first two rounds. Mosquito mortality declined during third, fourth, fifth and sixth rounds for smooth and painted surfaces. The performance Actellic 300 CS was high on smooth and painted surfaces compared to the rough surfaces. Over all, 100% mosquito mortality was recorded for the first and second round tests, while 98.7%, 94.8%, 84.4% and 52.2% mortality rates were registered for the third, fourth, fifth and sixth round, respectively.

**Efficacy of the three IRS insecticides:** The performance of the three IRS insecticides in the two study sites is presented in figures 1 and 2. Figure 1 shows that Propoxur 50% WP and Bendiocarb 80% WP did not meet the WHO cutoff value, i.e.,  $\geq 80\%$  (WHO 2006.1; WHO 2016), after the fourth-round wall bioassay tests in Wondo sites. Actellic 300 CS performed well up to the fifth month.

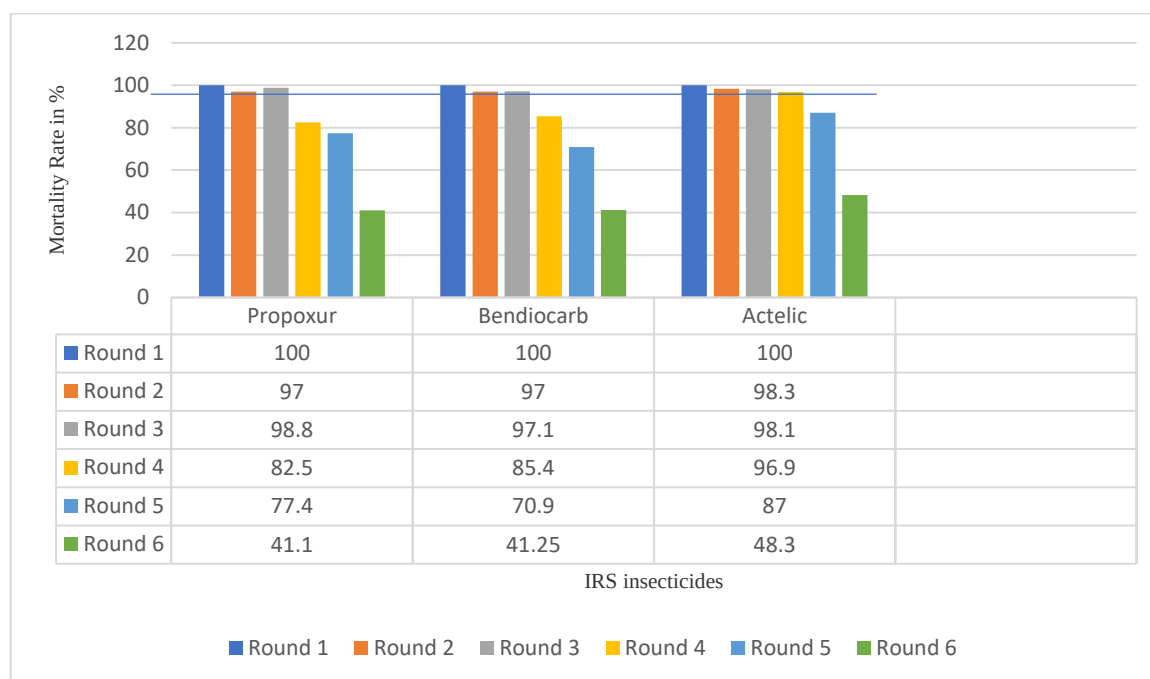


**Figure 1: Result of Propoxur 50% WP, Bendiocarb 80% WP and Actellic 300 CS wall bioassay test (Round 1-6) Wondo Genet site, Oromia Region, Ethiopia**

Figure 2 shows that Propoxur 50% WP did not meet the WHO cutoff value after the four months in Mirab

Abaya site. Whereas, Bendiocarb 80% WP and Actellic 300 CS fulfill the criteria up to fifth month.

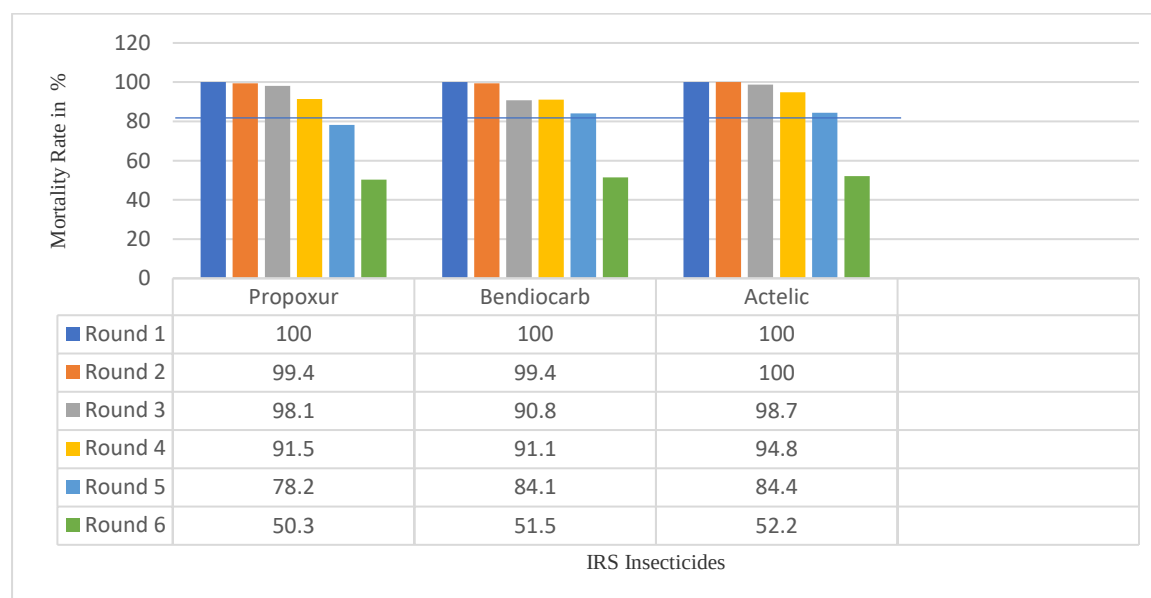


**Figure 2: Result of Propoxur 50% WP, Bendiocarb 80% WP and Actellic 300 CS wall bioassay test (Round 1-6) Mirab Abaya site, SNNPR, Ethiopia**

**The performance of three insecticides sprayed on different wall surfaces:** The decay rates of Propoxur 50% WP on rough, smooth, cement and painted wall surfaces were the same up to the third month in all sites. An interesting observation was that this insecticide performed well up to the fifth round on

painted wall surfaces in all sites (above the required cutoff value) while the results from other wall surfaces were not sufficient to draw valid conclusion (effectively performed up to third rounds). Moreover, its performance was good on smooth wall surface up to the fourth round in both sites (Figures 3 and 4).

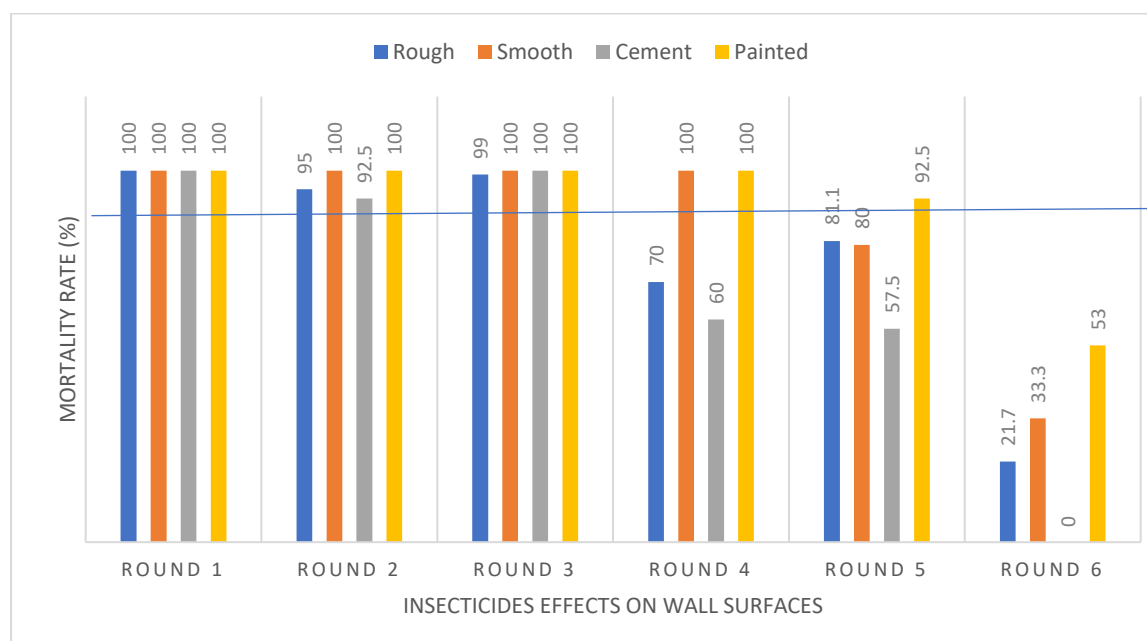


**Figure 3: The decay rate effects of Propoxur 50% WP on rough, smooth, cement and painted wall surfaces, Wondo Genet site, Oromia Region, Ethiopia**

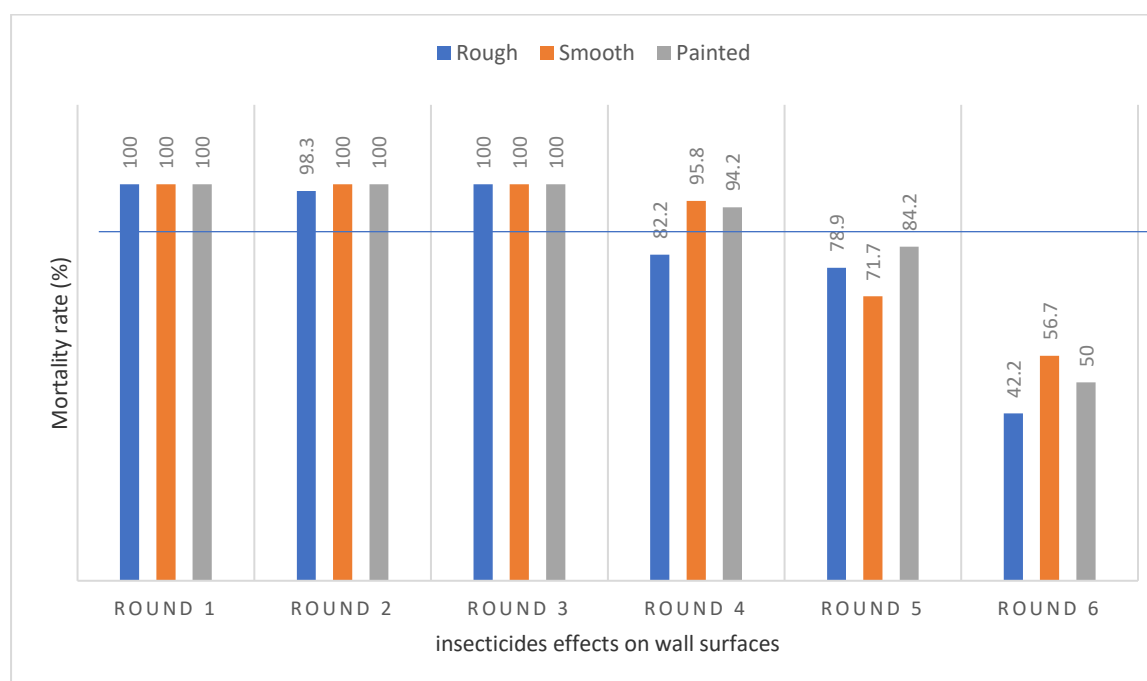


**Figure 4: The decay rate effects of Propoxur 50% WP on rough, smooth and painted wall surfaces, Mirab Abaya site, SNNPR, Ethiopia**

The performance of Bendiocarb 80% WP on rough, smooth, cement and painted wall surfaces up to the third round was similar to the performance of Propoxur 50% WP, no differences in performance was observed on different wall surfaces in both sites. It

was also found that this insecticide worked up to the fourth round on all wall surfaces. It also worked up to the fifth round on painted wall surface. The performance was low after the fourth round on rough, smooth and cement wall surfaces (Figures 5 and 6).

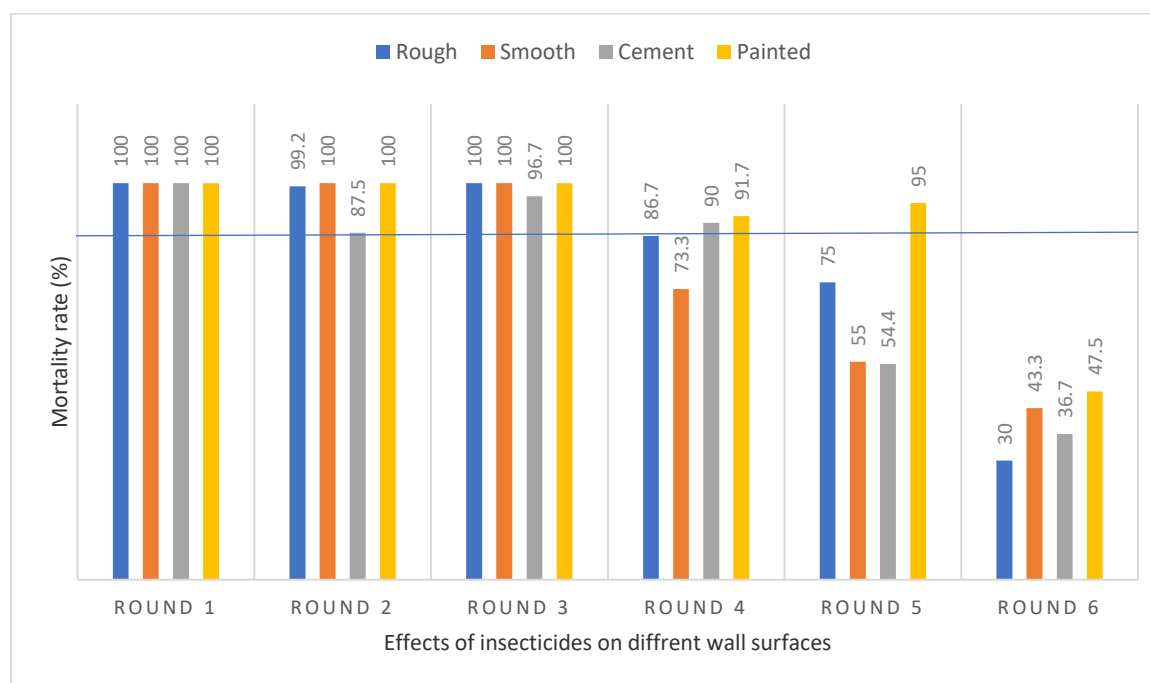


**Figure 5:** The decay rate effects of Bendiocarb 80% WP on rough, smooth, cement and painted wall surfaces, Wondo Genet site, Oromia Region, Ethiopia

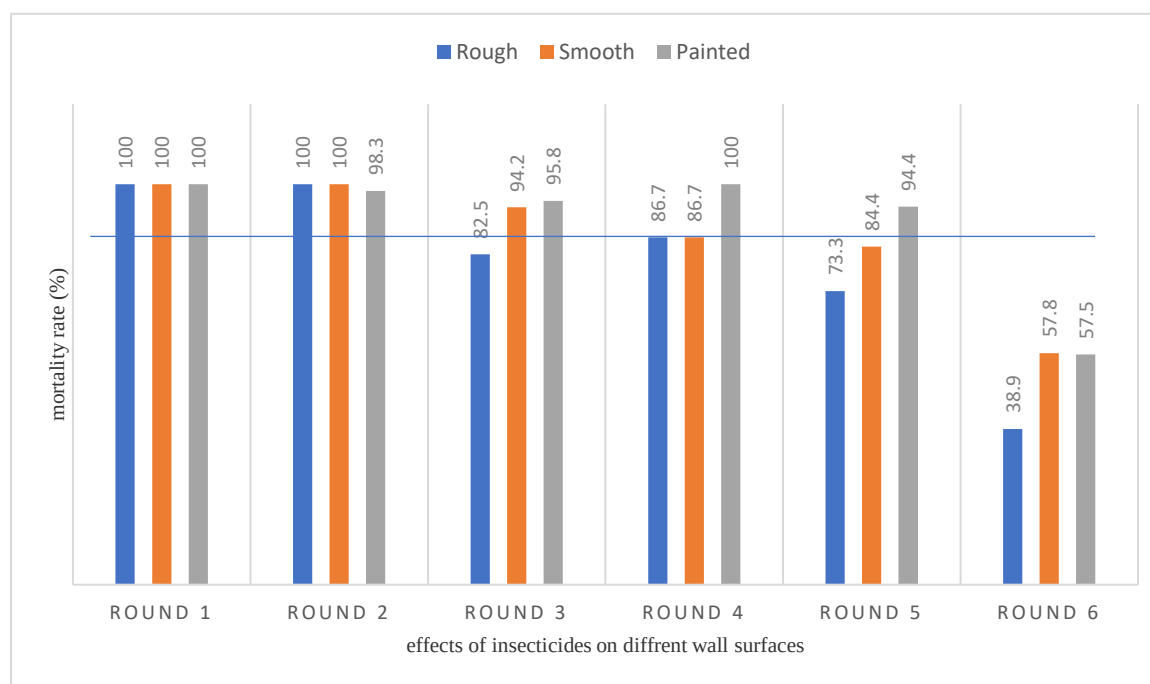


**Figure 6:** The decay rate effect of Bendiocarb 80% WP on rough, smooth and painted wall surfaces, Mirab Abaya site, SNNPR, Ethiopia

The performance Actellic 300 CS on rough, smooth, cement and painted wall surfaces was found to be above the WHO required cutoff value up to the fifth

round. However, performance declined at the fourth round on rough wall types in Mirab Abaya site (Figures 7 and 8).

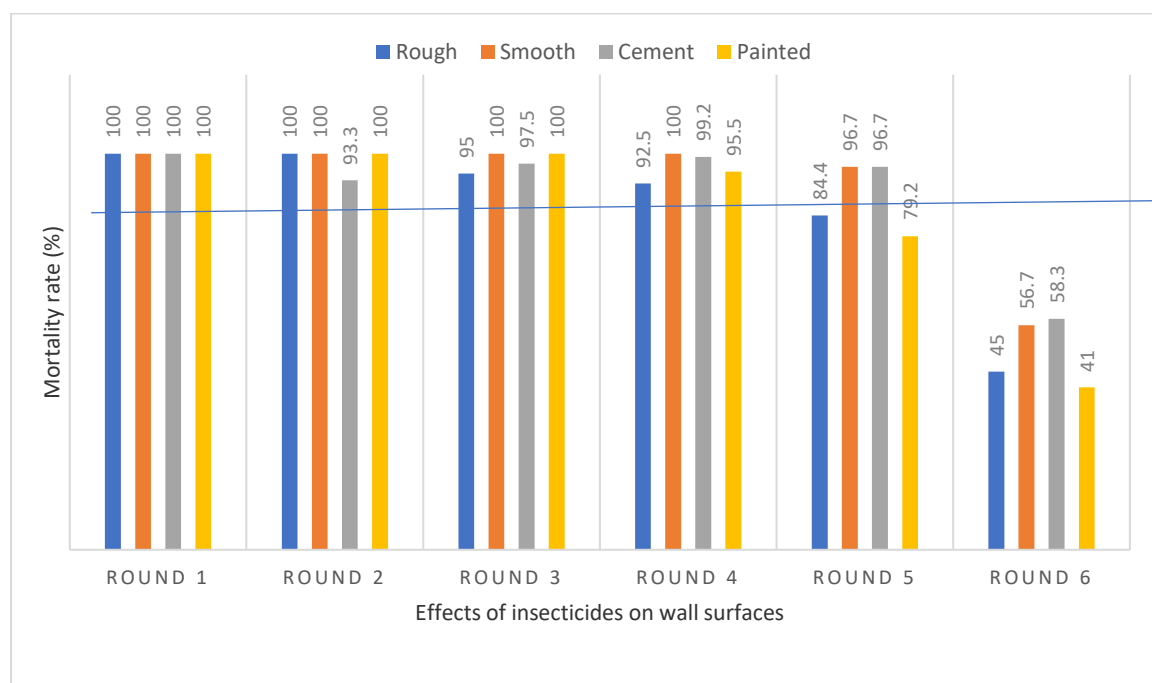


**Figure 7:** The decay rate effect of Actellic 300 CS on rough, smooth, cement and painted wall surfaces, Wondo Genet site, Oromia Region, Ethiopia

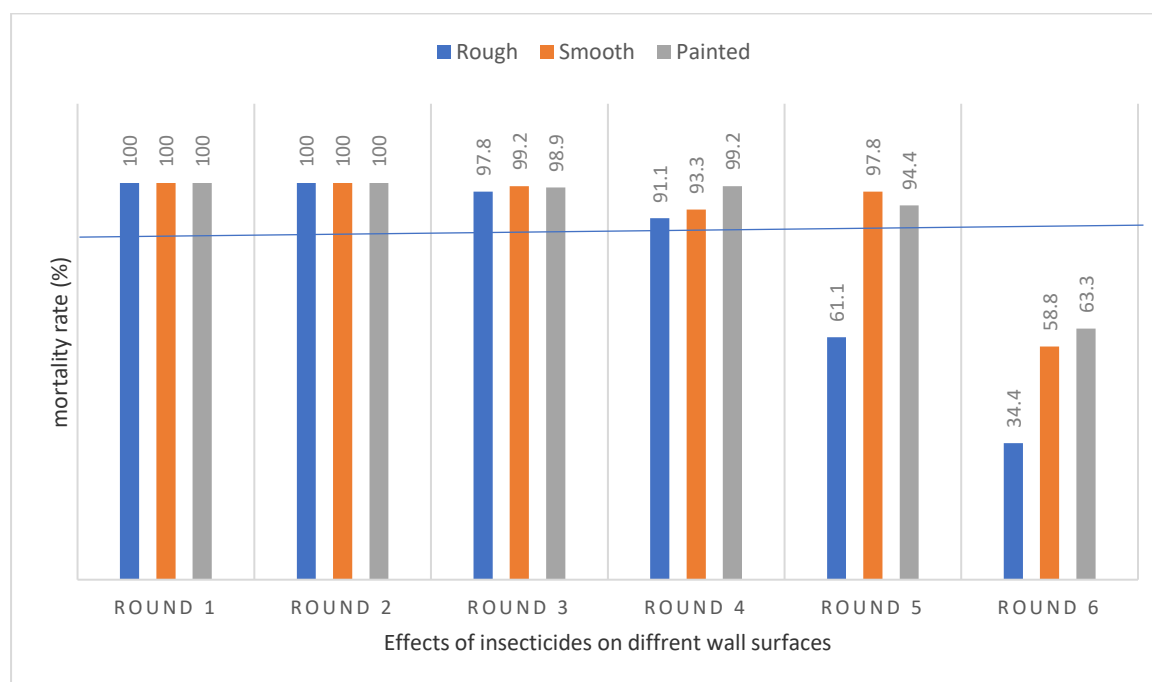


**Figure 8:** The decay rate effect of Actellic 300 CS on rough, smooth, and painted wall surfaces, Mirab Abaya site, SNNPR, Ethiopia

**Acceptability of indoor residual spraying:** Summary results on the acceptability of indoor residual spraying

at the beginning of the study for both Wondo Genet and Mirab Abaya sites was presented in Table 3.

**Table 3: Summary results on the acceptability of indoor residual spraying at the beginning of the study**

| Questions asked                                                                            | Wondo Genet site | Mirab Abaya (Mole village) |
|--------------------------------------------------------------------------------------------|------------------|----------------------------|
| If they know how malaria is transmitted? Those who responded it is transmitted by insect.  | 90.5%            | 88.6% (31/35)              |
| If they protect themselves and family against this disease? Those who responded yes        | 85.7%            | 77.1%                      |
| Allowed spraying in all rooms of their houses                                              | 97.6%            | 91.4%                      |
| If the insecticides leave stains on walls? Those who responded yes                         | 45.2%            | 48.6%                      |
| Those perceived that the sprayed insecticides would have effects on mosquitoes and bedbugs | 90.5%            | 91.4%                      |
| Those who agree to use insecticide spray in the future                                     | 90.5%            | 100%                       |

**Wondo Genet site:** Ninety-one percent (38/42) of respondents mentioned that malaria is transmitted by insects and 85.7% (36/42) of them protected themselves and family against the disease. Of the total respondents, 97.6% of them allowed spraying in all rooms of their houses. Regarding the question asked if the insecticides stained the walls, 45.2% responded yes and 47.6% said no. The majority (90.5%) of the respondents perceived that the sprayed insecticides had effects on mosquitoes and bedbugs. Generally, 90.5% of them agreed to allow insecticide spraying in the future.

**Mirab Abaya (Mole village):** About eighty-nine (31/35) respondents mentioned that malaria is transmitted by insects and 77.1% of them protected themselves and family against this disease. Of the total respondents, 91.4% of them accepted house spraying operation. Forty nine percent of the respondents mentioned that insecticides sprayed left stains on walls. The majority (91.4%) of the respondents perceived that the sprayed insecticides would have effects on mosquitoes and bedbugs. All (100%) agreed to use insecticide residual spraying in the future for malaria and other vector borne diseases protection.

**Results on the acceptability of indoor residual spraying at the end of the study period:** The general pattern of response on acceptability of IRS at the end of the study period was similar to the beginning. Generally, over 95% of the respondents perceived that the insecticides sprayed on walls of houses would have effects on mosquitoes and bedbugs. Similar proportions (95%) agreed to use insecticide residual spraying in the future in both sites.

## Discussion

The concentration of the insecticide assessed by conducting High Performance Liquid Chromatography (HPLC) on different wall types (smooth, rough, painted, unpainted, cemented) as well as the different heights of each wall surface type (low, middle and upper part) in each selected house showed that the three insecticides sprayed fulfilled the WHO recommended doses. Previous study conducted on the effect of pH and wall type on the residual life of the carbamates bendiocarb and propoxur in experimental huts of Ethiopia has the limitation that no attempt was made to quantify the amount of insecticide deposited on the wall during the spray through the use of filter papers and chromatography or other methods (Yemane et al. 2016). This study is the kind that tried to quantify the amount of insecticide deposited on

different wall surfaces during the spray in the community houses.

The round one, two, three and four round residual efficacy monitoring results in both Wondo Genet and Mirab Abaya sites indicated that the performance of all the three insecticides were good. The overall mosquito mortality rate due to Propoxur 50% WP ranged from 82.5% - 100% and 91% - 100% for Wondo Genet and Mirab Abaya sites, respectively. The overall mosquito mortality rate due to Bendiocarb 80% WP ranged from 85.4% - 100% and 91.1% - 100% for Wondo Genet and Mirab Abaya sites, respectively. The overall mosquito mortality rate due to Actellic 300 CS ranged from 96.9% -100% and 94.8% - 100% for Wondo Genet and Mirab Abaya sites, respectively. Relatively the performance of Actellic 300 CS was better than the other two insecticides after four months of the first spray. At round five of the assessment, mortality rate due to Actellic 300 CS was 84.4% and 87% for Mirab Abaya and Wondo sites, respectively. During the sixth round of monitoring mosquito mortality rates dropped to 52.2% and 48.3% for Mirab Abaya and Wondo, respectively, which is below the required WHO cutoff point  $\geq 80\%$  (WHO 2016). The performance of Bendiocarb 80% WP was below WHO cutoff value in the fifth and sixth rounds of the study (51.5% for Mirab Abaya sites in the sixth round, and 70.9% and 41.2 5% for Wondo sites in the fifth and sixth rounds, respectively) with exception in the fifth round for Mirab Abaya sites (84.1%). The performance of Propoxur 50% WP was below the required WHO cutoff value for both sites in the fifth and sixth round assessments (78.2% and 77.4% in the fifth round, and 50.3% and 41.4% in the sixth round for Mirab Abaya and Wondo sites, respectively). Previous study conducted in Ethiopia shows that the mortality rate of mosquitoes exposed to painted, dung plastered and mud plastered wall surfaces with bendiocarb and propoxur remained above 80% for six consecutive months in experimental huts (PMI Africa IRS 2016).

The performances of Actellic 300 CS and Bendiocarb 80% WP were better in smooth, cement and painted wall surfaces than the rough wall surface types. The acceptability of indoor residual spraying in the two sites was high. In general, 90.5% of the respondents agreed to use insecticide residual spraying in the future in Wondo Genet site. Whereas, all of them (100%) agreed to use insecticide residual spraying for malaria

and other vector borne diseases protection in Mirab Abaya site. For drawing valid conclusions similar studies are recommended in other sites by different partners in collaborative and coordinated manner.

This investigation has the following limitations. Primarily the study omits the KD results due to inconsistent recordings in the field. On the other hand, literatures show that this type of recording is important for pyrethroid formulated insecticides. But this study focuses on non-pyrethroid insecticides which do have formulations under organophosphates and carbamates classes (Yemane et al. 2016). Secondly, some of the houses enrolled at the beginning of the study were skipped during the process of the follow up investigations due to various reasons.

### Conclusions and Recommendations

This study provides evidence on the performance of three IRS insecticides in different wall surfaces of two study sites in Ethiopia. The first, second, third and fourth round test results of wall bioassay in both Wondo Genet and Mirab Abaya sites indicated that the decay rates of all the three insecticides were good. Propoxur 50% WP and Bendiocarb 80% WP did not meet the WHO cutoff value, i.e.,  $\geq 80\%$ , after the fourth-round wall bioassay tests in Wondo sites. Actellic 300 CS achieved well up to the fifth month. Propoxur 50% WP did not meet the WHO cutoff value after the four months in Mirab Abaya site. Whereas, Bendiocarb 80% WP and Actellic 300 CS fulfill the criteria up to fifth month. The performance of Bendiocarb 80% WP was found good up to the fourth-round monitoring on different wall surfaces. It worked up to the fifth round on painted wall type. Yet, its performance was not in the acceptable range after the fourth round on rough, smooth and cement wall surfaces. The performance of Actellic 300 CS on rough, smooth, cement and painted wall surfaces was found above the WHO required cutoff value up to the fifth round. However, its performance declined at the fourth round on rough wall types in Mirab Abaya sites. It appeared that the performances of Actellic 300 CS and Bendiocarb 80% WP were found better in the smooth, cement and painted wall surfaces types than on rough wall surface types. Generally, from this study drawing conclusions may not be enough on IRS insecticides utilization and choices in Ethiopia to make decisions. Future assessment studies are relevant in another geographical areas that consider local parameters such different house structures to draw conclusion and recommendations.

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