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# Assessment of Sumishield® 50WG against Susceptible and Resistant Strains of *Anopheles gambiae* s.l.: Experimental Hut and Field Trials in Senegal

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## Abstract

Malaria control efforts have led to a decline in incidence across Africa; however, the rise in insecticide resistance threatens these gains. This study evaluated the efficacy and residual activity of SumiShield® 50WG on cement and mud surfaces in Senegal. WHO cone bioassays were conducted using both susceptible and resistant strains of *Anopheles gambiae* s.l. The susceptible strain was tested monthly from August 2017 to July 2018, while the resistant strains were assessed five months after treatment. Knockdown was recorded at 30 and 60 minutes, and mortality at 24, 48, 72, and 96 hours. Trials were conducted in experimental huts and in two villages: Ndioukhane and Bandafassi. Knockdown rates at 30 and 60 minutes were low across all strains, surface types (cement and mud), and sites. In Bandafassi, 24-hour mortality exceeded the WHO threshold of 80%, except in month 4 on the mud surface, where it dropped to 65%. In Ndioukhane and at the experimental station, 24-hour mortality remained above 80% on both surface types from 7 days to 5 months post-treatment. At the experimental station, 48-hour mortality for all resistant strains also exceeded the 80% threshold on both surfaces. In Ndioukhane, 24-hour mortality consistently remained above the WHO threshold as well. These results demonstrate that SumiShield® 50WG is an effective insecticide for malaria vector control, showing high residual activity against both susceptible and resistant *An. gambiae* s.l. strains. Its efficacy on both cement and mud surfaces supports its potential as a promising alternative to insecticides compromised by resistance, offering a sustainable option for long-term malaria control.

**Keywords**

*Anopheles gambiae* (s.l.*),* SumiShield® 50WG, Efficacy, Experimental Huts, Ndioukhane, Bandafassi, Senegal

## 1. Introduction

In Senegal, vector control efforts focus on long-lasting insecticide-treated nets (LLINs) and indoor residual spraying (IRS). The IRS campaign began in 2007, spearheaded by the National Malaria Control Programme (NMCP) in collaboration with the President's Malaria Initiative (PMI). Over the years, various insecticides have been deployed, including ICON WP10 from 2007 to 2009, K-OTHRINE WG 250 from 2010 to 2011 [1], FICAM WP 80 from 2011 to 2014 [2] and Actellic 300 CS from 2017 to 2018 [3]. These interventions, combined with rapid diagnostic tests and prompt artemisinin-based combination therapies (ACTs), have substantially reduced malaria morbidity and mortality in Senegal. The number of malaria-related deaths dropped from 555 in 2018 to 260 in 2019 [4]. However, the effectiveness of these strategies is increasingly threatened by emerging insecticide resistance. Pyrethroid resistance is well-documented in Senegal [5] [6], and resistance to other insecticide classes is emerging across the country [4]. This trend poses a growing challenge for the NMCP. Currently WHO-prequalified IRS insecticides fall into four chemical classes: carbamates, organophosphates, pyrethroids and neonicotinoids [7]. Neonicotinoids first introduced in the 1990s for agricultural use and quickly became the most widely used class of pesticides worldwide, targeting a broad spectrum of crop pests [8]. In October 2017, the WHO prequalified a neonicotinoid formulation SumiShield™ 50WG, a water dispersible granules containing 50% clothianidin for adult mosquito control [7]. Manufactured by Sumitomo Chemical, SumiShield™ 50WG is applied at a target dose of 300 mg active ingredient per m$^2$. Clothianidin acts on nicotinic acetylcholine receptors (nAChRs), providing a novel mode of action in vector control that potentially circumvents cross-resistance with other IRS insecticide classes. Neonicotinoids also generally exhibit low toxicity to mammals [9].

In this study, we evaluated the efficacy and residual activity of SumiShield 50WG at 300 mg a.i./m$^2$, against both susceptible and resistant *Anopheles gambiae* s.l. strains on cement and mud substrates. Trials took place in experimental huts and two villages, Ndioukhane and Bandafassi, to assess the potential contribution of SumiShield in enhancing malaria vector control.

## 2. Study Area, Materials and Methods

### 2.1. Study Area

The study was conducted in two locations in Senegal: the village of Ndioukhane and the village of Bandafassi. The experimental work spanned 12 months, from

August 2017 to July 2018. Ndioukhane (14˚42'13.05"N, 16˚50'54.88"W) is situated approximately 12 km from the city of Thiès and 70 km from Dakar, the capital of Senegal. Located in the rural commune of Notto Diobass, the village has a predominantly young population of about 837 inhabitants. It lies within a Sudano-Sahelian zone characterized by a long dry season. Water supply is supported by shallow wells connected to the local water table. Most homes are traditional dwellings with cement walls.

The Experimental station, situated about 400m from the outskirts of Ndioukhane and 500 meters from the nearest market gardens, was built in 2010 by the Laboratoire d'Ecologie Vectorielle et Parasitaire at the University Cheikh Anta Diop (UCAD). It follows the standard experimental hut design used throughout West Africa [10] [11]. The station comprises ten experimental huts arranged on two groups: eight on one side and two on the opposite. Each hut measures 2.64 m in length, 2 m in width, and 2 m in height and is constructed with cement bricks. The distance between two huts is approximately 5.3 m. The walls and floors are either cement or mud (6 and 4 huts, respectively). Roofs are made of corrugated iron, topped with false ceilings of plywood. Each hut features four entry slits to facilitate mosquito entry while preventing their escape. A fully screened veranda trap is located on the fourth wall to capture exophilic mosquitoes (**Figure 1**).

**Figure 1.** Experimental huts at the Experimental station (Senegal) used for the evaluation of SumiShield™ 50WG.

Bandafassi, the second study site, is located about 15 km from the city of Kédougou and 701 km from Dakar, within the Sudano-Guinean savannah zone. The region borders Tambacounda to the west and north, Mali to the east, and Guinea to the south. The local climate is characterized by seven months of dry harmattan winds (October to April), followed by a rainy season that begins in May, peaks in June and July, and lasts until October or November. Annual rainfall averages around 1300 mm, supporting rich vegetation and enabling intense agricultural and livestock activities. The local economy largely depends on cotton farming and animal husbandry, both favored by the area's environmental conditions.

Malaria vectors in this region are primarily of the *An. gambiae* complex, with *An. gambiae*, *An. funestus* and *An. nili* being the most common species [12]. These vectors exhibit marked resistance to pyrethroids, likely due to the widespread and prolonged use of pesticides such as cypermethrin, acetamiprid and lambda-cyhalothrin in horticulture and cotton cultivation [13], as well as the long-standing use of pyrethroid-treated bed nets distributed in the region [14].

## 2.2. Materials and Methods

### 2.2.1. Insecticide Formulation Used

The study evaluated SumiShield® 50WG (Sumitomo Chemical), a wettable granule formulation containing 50% clothianidin and 50% inert ingredients. The product was applied at a target dose of 300 mg a.i./m$^2$. Packaged in 150 g sachets, it was diluted in 10 liters of water to treat 250 m$^2$, corresponding to an application volume of 40 ml/m$^2$.

### 2.2.2. Selection and Treatment of Houses and Huts

The efficacy of SumiShield® 50WG was evaluated between August 2017 to July 2018. At the experimental station, eight huts were treated (three with cement walls and three with mud walls), while two huts (one cement, one mud) served as untreated controls. In the village of Ndioukhane, five cement-walled rooms were included: three were treated and two served as controls. In Bandafassi, seven rooms (four cement and three mud), were treated, while two rooms (one cement, one mud) were used as untreated controls. Insecticide application was carried out using Hudson Xpert® 67422 AD compression sprayers (WHO specification No. WHO/VBC/89.9) in accordance with WHO guidelines [15]. Waste management and disposal WHO-recommended procedures.

### 2.2.3. Mosquito Strains Used

**1) Susceptible strain**

A laboratory-maintained strain of *An. coluzzii* was used, previously employed in several studies [2] [16]. It was originally colonized in 2008 from Essos (3˚53'12"N, 11˚32'32"E), Yaoundé, Cameroon, and has been maintained under standard insectary conditions at 25˚C ± 2˚C and 80% ± 10% relative humidity.

**2) Resistant strains**

Three *An. gambiae* s.l. strains were collected from the field in December 2017 from Pikine (14˚42'33N, 17˚23'59W), Ndioukhane (14˚42'13,05N, 16˚50'54,88W) and Kedougou (12˚33′28″N, 12˚10′27″W). Larvae were reared to adulthood under controlled conditions (25˚C ± 2˚C and 80% ± 10% RH) and maintained with a daily supply of a sugar-water solution.

### 2.2.4. Bioassay Tests

Bioassays were conducted using the susceptible strain *An. coluzzii* at all the three sites, beginning seven days after treatment and continuing monthly until 12 months post-application (August 2017 to July 2018). WHO cone tests were performed according to established protocols [17]. In each treated and untreated hut or room, cones were affixed to all interior walls. Ten unfed female mosquitoes (3 - 5 days old) were introduced into each cone and exposed for 30 minutes. After exposure, mosquitoes were transferred to labeled holding cups stored and maintained in a controlled environment (25˚C ± 2˚C and 80% ± 10% relative humidity). They were provided with a 10% sugar solution throughout the observation period. Knockdown were recorded at 30 and 60 minutes post-exposure, and mortality was assessed at 24, 48, 72 and 96 hours. Additionally, to assess efficacy on resistant strains, the same protocol was used to test field-collected *An. gambiae* s.l. from Pikine, Ndioukhane, and Kedougou five months post-treatment.

#### 2.2.5. Data Analysis

Treatment efficacy was evaluated by calculating knockdown and mortality rates. knockdown rates were expressed as the proportion of mosquitoes knocked down at 30 and 60 minutes post-exposure relative to number tested. Mortality rates were calculated as the percentage of dead mosquitoes at each time point (24, 48, 72 and 96 hours) out of the total exposed. A residual efficacy threshold of 80% was used in line with Who guidelines [17]. When control mortality ranged between 5% and 20%, mortality rates were corrected using Abbott's formula [17]. Statistical analyses and visualizations were performed using R software (version 3.6.1).

## 3. Results

### 3.1. Residual Efficacy of Treatments against the Laboratory Colony of *An. coluzzii*

Bioassay results using the susceptible *An. coluzzii* strain conducted from August 2017 to July 2018 at the three sites (Bandafassi, Ndioukhane and the experimental station), showed that knockdown rates at 60 minutes (KD60mn) were consistently higher than those at 30 minutes (KD30mn) on both cement and mud substrates (**Figure 2**, **Figure 3**). In Bandafassi, where the highest mortality rates were recorded, 24-hour mortality generally exceeded the 80% efficacy threshold, except during month 4 on the mud substrate. Specifically, in cement-walled rooms in the village, SumiShield® demonstrated sustained efficacy throughout the study period, with 24-hour mortality consistently above 80% (**Figure 2**).

At the experimental station, efficacy on cement walls persisted during the first five months, with 24-hour mortality consistently above 80%. However, a gradual decline was observed thereafter, with the lowest rate recorded in month 10 (67.7%). On the mud susstrate, mortality rates after 24 hours remained above 80% from day 7 to month 9 post-treatment, but fluctuated thereafter. The lowest mortality rate after 24-hour mortality on the mud support was recorded at month 10 61.6% (**Figure 2**).

In Ndioukhane, on the cement substrate, sustained efficacy was observed for the first five months, followed by a decline in month 6. Although efficacy briefly rebounded in month 7, the product lost its effectiveness between months 8 and 11. The lowest 24-hour mortality rate was recorded in month 10 post-treatment, at 40.1% (**Figure 3**).

Delayed mortality rates, assessed 96 hours post-exposure, consistently exceeded the 80% efficacy threshold at all three sites throughout the evaluation period. The lowest delayed mortality was recorded on cement walls in Ndioukhane, at 98.1% in month 10 post-treatment (**Figure 2** and **Figure 3**).

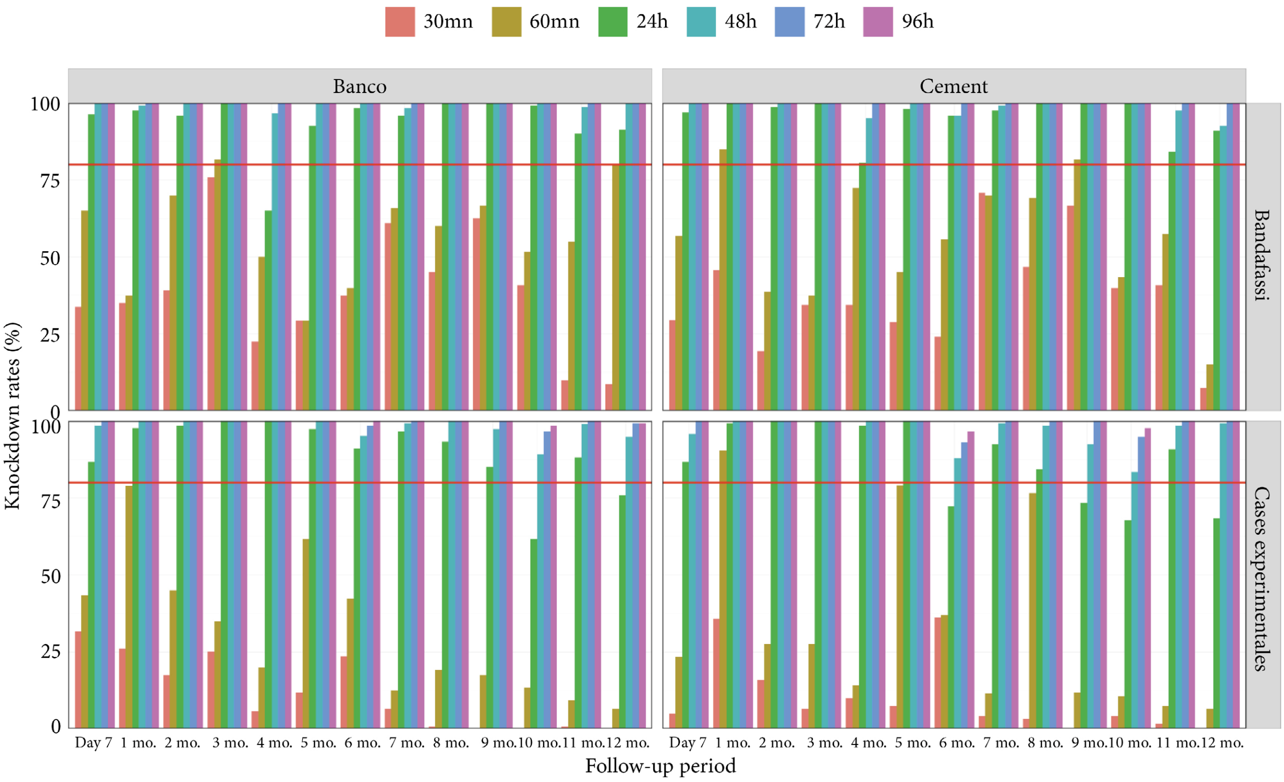


**Figure 2.** Knockdown and mortality rates of the susceptible *An. coluzzii* strain following exposure to SumiShield® on cement and mud surfaces in Bandafassi village and at the experimental station from day 7 to month 12 post-treatment. The red horizontal line indicates the 80% efficacy threshold.

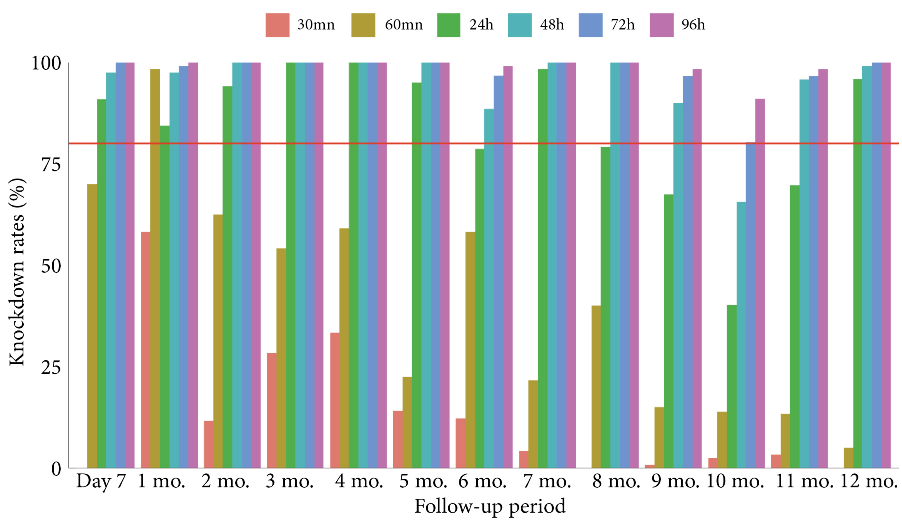


**Figure 3.** Knock-down and mortality rates recorded of the susceptible *An. coluzzii* strain following exposure on cement surfaces in Ndioukhane, from day 7 to 12 months post-treatment. The red horizontal line indicates the 80% efficacy threshold.

### 3.2. Residual Efficacy of Treatments against Resistant Strains

Efficacy tests conducted five months post-treatment in the experimental huts revealed knockdown rates at both 30 minutes (KD30mn) and 60 minutes (KD60mn), with values consistently failing below the 80% threshold (Figure 4). However, 24-hour mortality rates remained high. On mud walls, the Bandafassi strain exhibited

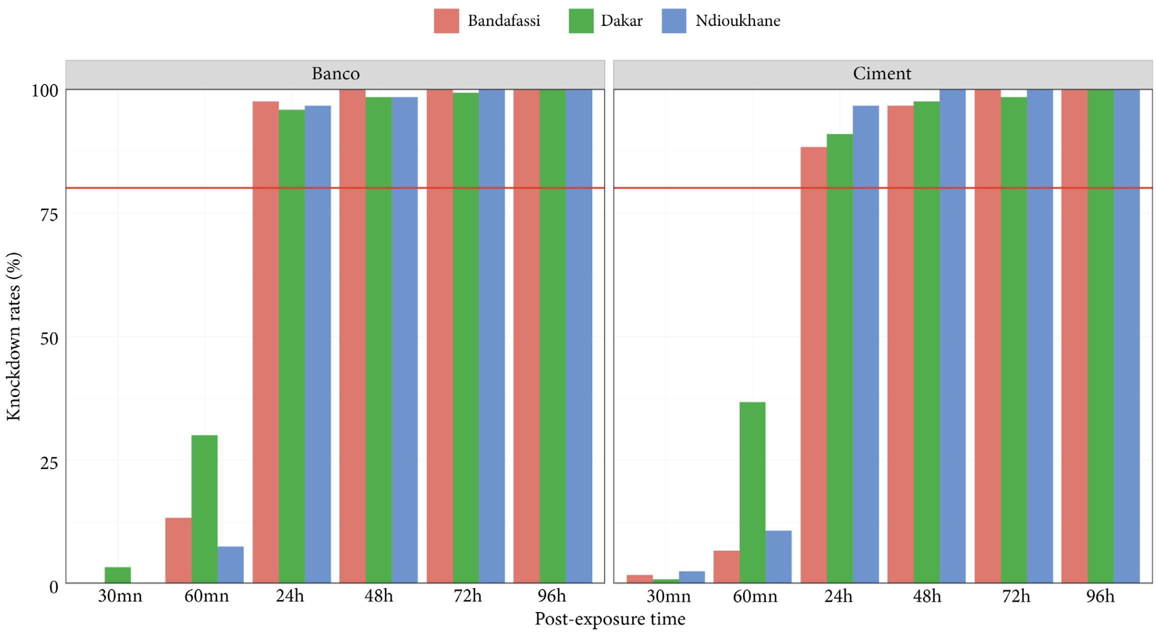


Figure 4. Knockdown and mortality rates of resistant *An. gambiae* s.l. strains from Dakar, Bandafassi, and Ndioukhane following exposure in experimental cement and mud huts, five months after SumiShield® treatment. The red horizontal line indicates the 80% efficacy threshold.

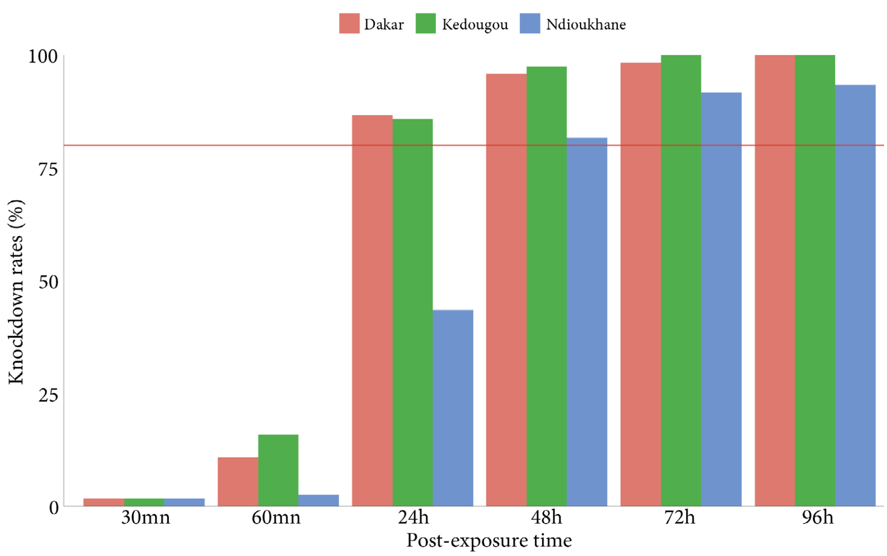


Figure 5. Knockdown and mortality rates of resistant *An. gambiae* s.l. strains from Dakar, Kédougou, and Ndioukhane following exposure in the village of Ndioukhane, five months after SumiShield® treatment. The red horizontal line indicates the 80% efficacy threshold for.

the highest 24-hour rate (97.5%), followed by the Ndioukhane strain (96.6%) and the Dakar strain (95.8%). On cement surfaces, the Ndioukhane strain showed a mortality rate of 96.6%, while the Dakar and Bandafassi strains recorded rates of 90.8% and 88.3%, respectively.

Tests conducted with the same strains in the village of Ndioukhane yielded similar trends to those observed in the experimental huts. The lowest 24-hour mortality rate was recorded for the Ndioukhane strain (43.4%), whereas the Dakar and Kédougou strains showed mortality rates of 86.6% and 85.6%, respectively. Despite the variability in initial knockdown rates, all delayed mortality rates at 96 hours post-exposure consistently exceeded the 80 % efficacy threshold (**Figure 5**).

## 4. Discussion

The efficacy and residual activity of SumiShield® 50WG were evaluated on cement and mud surfaces under both semi-natural conditions (experimental huts) and operational settings (villages houses) in Ndioukhane and Bandafassi. Based on the World Health Organization (WHO) efficacy threshold of 80% [17], results at 24 hours post-exposure demonstrated high efficacy of SumiShield® 50WG against the susceptible *An. coluzzii* strain. On cement surfaces, the insecticide remained effective for 12 months in Bandafassi and for 5 months in both the experimental huts and Ndioukhane. On mud surfaces, residual efficacy persisted for 11 months in Bandafassi and 9 months at the experimental station. These findings highlight the strong performance of SumiShield® 50WG on both types of substrates, supporting its potential for indoor residual spraying (IRS) programs. The results from this study are consistent with findings reported in other African regions. Similar persistence of efficacy was observed in Ethiopia, the Democratic Republic of Congo and Benin, with durations of 9 months [18], 9.5 months [19] and 8 months [20], respectively. Moreover, the efficacy of SumiShield® 50WG against pyrethroid-resistant mosquito strains aligns with observations in Benin [20] [21] and India [22], where residual efficacy lasted up to 6 and 9 months post-treatment.

The low knockdown rates observed with SumiShield® 50WG are consistent with its known mode of action, which differs from the rapid knockdown typical of pyrethroids. As reported in previous studies [20], SumiShield® 50WG acts through delayed mortality rather than immediate incapacitation. Its prolonged residual efficacy can be attributed to the slow degradation of clothianidin, ensuring extended vector control over time. These findings corroborate earlier results on the delayed yet sustained insecticidal effects of SumiShield® 50WG [19] [21] [22], further supporting its suitability for IRS campaigns. While WHO guidelines recommend evaluating IRS efficacy based on 24-hour mortality [17], these protocols were initially designed for fast-acting insecticides. In the case of slower-acting compounds such as clothianidin, delayed mortality assessments are critical. In this study delayed mortality rates at 96 hours consistently exceeded 80% threshold for both susceptible and resistant strains, on both cement and mud substrates. Post-exposure behavioral effects, such as reduced lifespan and mortality occurring before the mosquito becomes infectious may further contribute to interrupting malaria transmission. These delayed effects enhance the overall impact of SumiShield® 50WG in reducing vector populations and limiting risk disease spread.

## 5. Conclusion

The observed efficacy of SumiShield® on different substrates, including cement and mud, highlights its potential as a strong candidate to replace insecticides compromised by resistance in *An. gambiae* s.l. populations. Its prolonged residual activity, which extend beyond the malaria transmission season in Senegal, supports its suitability for long-term vector control in the region.

## Author's Contribution

Ousmane Faye conceived the study. Marième Faye and Moussa Diagne carried out the field activities. Ibrahima Dia and Marième Gueye carried out the data analysis. Ibrahima Dia, Marième Gueye, Ousmane Faye and Lassana Konaté, critically revised the article for intellectual content. All authors read and approved the final article.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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