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Evaluation of the effectiveness of a targeted community-based IRS approach for malaria elimination in an area of low malaria transmission of the central-western Senegal

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ABSTRACT

The implementation of effective malaria control strategies in the central-western Senegal, such as Indoor Residual Spraying (IRS), long-lasting insecticide-treated nets (LLIN), Seasonal malaria chemoprophylaxis (SMC) and appropriate management of malaria cases, has led to the decline of malaria transmission in the region. However, residual malaria transmission still occurring in some localities, known as hotspots villages, making challenging the achievement of the malaria elimination goal. A pilot study was undertaken between 2013 and 2014 to test the feasibility of a community-based IRS approach for malaria elimination in four targeted health districts of the Central Western Senegal.

The residual efficacy of the Actellic® 300CS formulation on the sprayed surface was monitored using WHO cone test.

Overall, 615 walls were tested over the two successive years, respectively 240 and 375 in 2013 and 2014 IRS campaigns. The residual efficacy of the IRS with Actellic®300 CS was longer in the second year due to the improvement of community agents spraying skill the second year thanks to the refreshing training and a better supervision by professional agent of the National Hygiene Service. The analysis of the Incidence Rate Ratio under the Poisson model shows no significant difference of IRS effectiveness according to the building type.

In conclusion, the quality of training of community agents and good supervision of IRS activities play a key role in the quality and the residual efficacy of IRS campaigns. A good planning and implementation of IRS campaign ensure a high quality and a good effectiveness of spraying with the Actellic®300 CS formulation.

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1. Introduction

Malaria control has been and still of greatest concern throughout the sub-Saharan Africa. To control the disease, countries with ongoing malaria transmission across the continent rely principally on insecticide-based vector control strategies, mainly insecticide-treated nets (ITNs) and Indoor Residual Spray (IRS) (Ridley, 2002; Carnevale and Mouchet, 2001). The two measures account for almost 60% of global investment against Malaria worldwide (Roll Back Malaria Partnership, 2008; WHO, 2013). In Senegal, the malaria control programme is in line with the WHO recommendations, relying on artemisinin-based combination therapy (ACT), rapid diagnostic test (RDT), mass distribution of Long Lasting-Insecticide-treated Nets (LLINs), Indoor Residual Spray in sentinel health districts (http://senegal.usaid.gov/news/releases/2008/08_03_03, n.d.), home management of malaria cases, and the implementation of routine monitoring and evaluation of all the above activities. The combined effects of these strategies have led to the decrease of the disease incidence from 1,500,000 cases in 2006 to 174,339 in 2009. In the meantime, the proportional malaria-related deaths have also decreased from 18.17% to 4.4% (ENPS-II, 2009). In 2012, the proportional malaria morbidity and mortality decreased further, estimated respectively estimated to 5% and 8% (PNLP, 2013). Encouraged by such a result, especially in Central-western Senegal, the Senegalese National Malaria Control Programme (NMCP) has changed his target toward malaria elimination in eligible areas (PNLP, 2016). This pilot study was undertaken between 2013 and 2014 to test the feasibility of a community-based IRS approach for malaria elimination in four targeted health districts of the Central Western Senegal.

We report here the results of the monitoring and evaluation of the residual efficacy of two community-based IRS campaigns with the Actelic®300CS employing a local staff, as part of a cluster randomized trial to test the feasibility of a targeted vector control programme in malaria transmission hotspots in the Central- western of Senegal.

2. Methodology

2.1. Study area

The study was conducted in four Senegalese health districts (Mbour, Bambey, Niakhar and Fatick), located in the central Senegal rural areas. The climate of the study area is of the Sudan-Sahelian type with a single rainy season lasting from July to October. The monthly mean temperature ranges from 24 °C (December–January) to 30 °C (May–June) (SAGNA, 2005). The main agricultural crops in the study area are millet and groundnuts. The study localities and their characteristics are widely reported elsewhere (Sy et al., 2018). Hotspots villages, defined as localities which have reported at least 6 autochthonous malaria cases

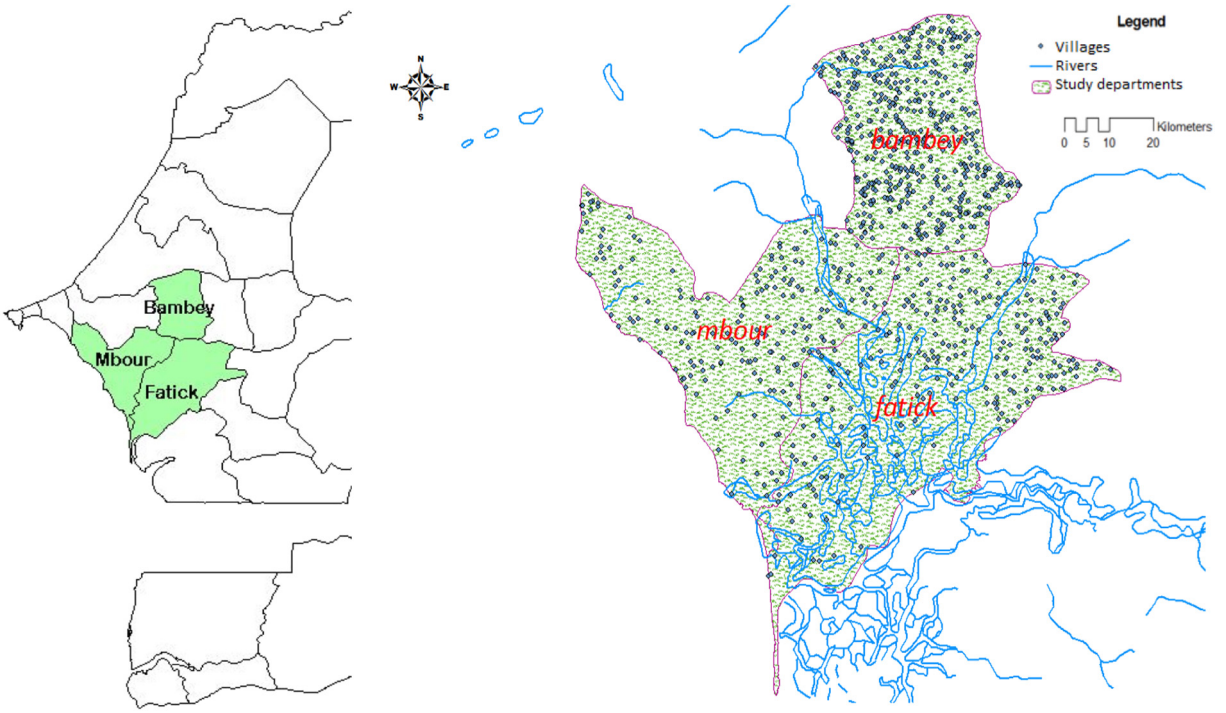

Fig. 1. Study area.

during the previous transmission season (Bousema et al., 2012), were treated by trained sprayers hired locally from the communities within each of the IRS sentinel villages.

2.2. Training of sprayers

Training/refreshing of locally hired spray operators took place a month before the starting of each IRS campaign and last at least 1 or 2 weeks based on the previous experience of sprayers. Theoretical and practical training sessions were animated by the staff of the National Hygiene Service, who are highly trained and experimented technicians involved on a routine basis in the implementation of IRS for pest control at throughout the country (Fig. 1).

2.3. IRS spray campaigns

During the two IRS campaigns a total of 401 hotspots villages, respectively 79 in 2013 and 322 in 2014, were sprayed. For each year, a total of 151 community workers composed of sprayers, sprayers team leaders, laundresses, supervisors, stock managers and field coordinators were hired locally then trained to carry out IRS interventions.

2.4. Type of sprayed structures tested

Table 1 reports the number of the structures tested per building type in each of the study sites for the two campaigns. Overall, 615 walls were tested over the two successive years, respectively 240 and 375 in 2013 and 2014 IRS campaigns. The number and type of structure varied between study villages and IRS campaigns. Indeed, Toucar Nganeme was the sole locality where all the three building types (Cement/Zinc, Mud/Zinc and Mud/Grass) were found during the 2013 spray campaign. While during the following year, all the three structures were found both in Toucar Nganeme and Sessene. Noteworthy, in addition being the main type of structure found in all sentinel sites during the two campaigns, habitation made of Cement wall and Zinc roof were the sole type of construction found in the locality of Mbour-Djilakh during the two spray campaigns. Conversely to the latter village, structures made of Cement/Zinc and Mud/Grass were the unique construction types encountered in Bary Ndolndol (District of Bambey) and Bicole Centre (District of Fatick) during the 2013 IRS campaign. Noteworthy, in 2014, the locality of Bary Ndolndol of the district of Bambey has been replaced by the village of Sessene due to a change in the epidemiological status of the first village the previous year, which was no longer a hotspot village. While in the meantime, the same structures were kept for IRS monitoring in Bicole Centre in Fatick (Table 1).

2.5. Residual efficacy of IRS

The residual efficacy of the Actellic®300CS (1 g/m^2) formulation prepared following the manufacturer's instruction, was monitored on the sprayed surface using WHO cone tests (WHO, 2006), up to 6 months (at months 1, 2, 4 and 6 post-spraying) in 2013, and up to 9 months (at months 1, 2, 4, 6, and 9 post- spraying) in 2014. In each of the sentinel sites four treated and one untreated (due to closed doors or owner's refusal) rooms were selected randomly for the monitoring of the residual efficacy of IRS. Bioassays were carried out on three randomly selected walls of each of the 4 treated rooms and on all of the four walls of the unique untreated room, chosen as a control in comparison to test rooms. A single cone was randomly fixed on surface of each of the wall of the treated and the control rooms approximately 50 cm above the floor. Tests were carried out with unfed 2 to 5-days-old female of a susceptible laboratory-reared *An. coluzzii* strain and local *An. gambiae* s.l. populations, mainly of *An. arabiensis* as reported previously (Sy et al., 2018), collected from breeding sites within and around study sites and reared to adulthood. Approximately ten individuals were gently introduced into each cone for 30 min. After the exposure period, mosquitoes were gently removed from each cone and placed into an individual cardboard cup labelled with corresponding information of each cone per room. The immediate mortality was assessed 20 min post-exposure, then cups were stored under standard rearing conditions at a

Table 1
Number of the structures tested by building type, study sites and spray campaign.

Campaigns	District - villages	Cement/Zinc	Mud/Zinc	Mud/Grass	Total
2013	Bambey-Bary Ndolndol	48	0	12	60
	Fatick-Bicole Centre	36	0	24	60
	Mbour-Djilakh	60	0	0	60
	Niakhar-Toucar Nganem	36	12	12	60
	Total 2013	***180***	***12***	***48***	***240***
2014	Bambey-Sessene	30	30	15	75
	Fatick-Bicole Centre	45	0	30	75
	Mbour-Djilakh	75	0	0	75
	Niakhar-Toucar Nganem	45	15	15	75
	Fatick-Nonane (NHS)	15	0	60	75
	Total 2014	***210***	***45***	***120***	***375***

NHS = sprays perform by professional of the National Hygiene Service.

temperature of 27 ± 2 °C and a relative humidity of 80 ± 10% and mosquitoes were provided with 10% sugar solution for the 24 hour observation period to assess delayed mortality.

The test results were read 24 hour post-exposure and the dead and live mosquitoes were counted and recorded in both the tests and the control groups. The tests were validated according the mortality rate in the control group: i) the test was validated when the mortality in the control group is <5%, ii) It was unvalidated and repeated when the mortality in the control group exceeds 20%. For mortality in the control between 5 and 20%, the mortality in the test group was corrected using the Abbot's formula (Abbott, 1925).

The residual activity of a sprayed surface was considered as good as long as the induced mortality rate in the test group was higher than the threshold of 70%. The monitoring was pursued until the observed mortality rate in the test group dropped below the threshold for two consecutive months (WHO, 2013).

3. Data analysis

The residual efficacy of insecticides on wall surfaces was compared between the different building types and between villages for the same building type. Pairwise comparisons were performed between the three main structures (Cement/Zinc; Mud/Zinc and Mud/Grass) encountered in the study; then between Cement/Zinc and Mud/Grass in the absence of the Mud/Zinc type of building. The overall residual efficacy of IRS was then assessed at the village level over the time and between villages.

In 2014, the villages of Nonane, chosen as a treated control, was sprayed by professional agents from the National Hygiene Service, while others were sprayed by amateurs from the local community, the residual efficacy of IRS to assess the effect of sprayers' skill on the effectiveness of spraying.

Statistical analysis was done using the Poisson regression model to compare 24 hour post-exposure mortality rates of the different test groups, thus clustering at the test level. To determine if there was any difference in the spraying remanence over the time between different building types or villages, test for putative interactions were performed between relevant variables and time. Time intervals from the beginning of the spraying was calculated as the date of test minus the date of spraying and modelled as a linear variable.

Data from the 2013 and the 2014 campaigns were analysed separately since there was an improvement of the spraying implementation in the latter year which is likely to impact the results.

4. Results

4.1. The residual efficacy of IRS according to the building type

The residual efficacy of IRS was monitored for all the three building types in Toucar Nganem both in 2013 and 2014, and the village of Sessene in 2014. While in the three remaining villages, the residual efficacy of IRS was monitored only for two construction types (cement/zinc and mud/straw). The analysis of the Incidence Rate Ratio under the Poisson model shows that with the 95% confidence there was statistically non-significant effect of building type on the residual efficacy of sprayings whatever the building combination and the IRS campaign considered (Table 2). However, the lag time after spraying had a significant effect on IRS efficacy decreasing over the time (Table 2).

Table 2
The effect of the building type on the residual efficacy of the IRS in 2013 and 2014.

	2013				2014			
	IRR[a]	95% CI	*p*-Value	p-Value for interaction	IRR[a]	95% CI	p-Value	p-Value for interaction
Comparison of all building types								
Time post-spraying	0.89	0.83: 0.95	<0.001		0.94	0.91: 0.97	<0.001	
Mud/zinc vs cement/zinc	0.90	0.73: 1.11	0.336		1.00	0.87: 1.15	0.994	
Mud/grass vs. cement/zinc	1.01	0.79: 1.29	0.955		0.91	0.79: 1.05	0.187	
Interaction: effect of time within wall type								
Mud/zinc	1.05	0.97: 1.14	0.226		0.99	0.95: 1.04	0.709	
Mud/grass	1.00	0.91: 1.10	0.965	**0.344**	1.04	0.99: 1.09	0.086	**0.078**
Comparison of cement/zinc and mud/grass								
Time post-spraying	0.86	0.80: 0.93	<0.001		0.93	0.91: 0.95	<0.001	
Mud/grass vs. cement/zinc	0.71	0.48: 1.06	0.091		0.87	0.76: 0.99	0.035	
Interaction: effect of time within wall type								
Mud/grass	0.99	0.86: 1.13	0.840	**0.840**	1.05	1.01: 1.09	0.010	**0.010**

IRR = Incidence Rate Ratio.
[a] Adjusted for village.

Table 3
The effect of village on the residual efficacy of the IRS for same building type during the 2014 IRS campaign.

	IRR	95% CI	p-Value	p-Value for interaction
Comparison of villages within cement/zinc building type				
Time since spraying	***0.98***	***0.97:1.00***	***0.029***	
Djilakh vs *Bicole*	***1.17***	***1.05:1.31***	***0.005***	
Sessene vs Bicole	1.15	0.96:1.37	0.125	
Toucar Nganem vs Bicole	1.03	0.91:1.17	0.616	
Interaction: effect of time within wall type				
Djilakh	0.94	0.91:0.97	<0.001	
Sessene	0.95	0.89:1.00	0.072	
Toucar Nganem	0.96	0.93:1.00	0.072	<**0.001**
Comparison of villages within Mud/Grass building type				
Time since spraying	0.61	0.45:0.84	0.002	
Sessene vs Bicole	6.25	0.09:419.45	0.393	
Toucar Nganem vs *Bicole*	***0.05***	***0.00:0.68***	***0.026***	
Interaction: effect of time within wall type				
Sessene	0.94	0.49:1.77	0.84	
Toucar Nganem	1.55	0.96:2.50	0.073	**0.1418**
Comparison of villages within mud/zinc building type				
Time since spraying	0.94	0.91:0.98	0.001	
Toucar Nganem vs Sessene	0.99	0.79:1.24	0.932	
Interaction: effect of time within wall type				
Toucar Nganem	0.96	0.90:1.03	0.246	**0.246**

IRR = Incidence Rate Ratio.

4.2. The village effect on the residual efficacy of the IRS within each building type in 2014

Excepted for the structures made of Cement/Zinc and Mud/Grass building type, only the lag time post-spraying has displayed a significant effect on the IRS residual efficacy (Table 3). However, for the Cement/Zinc structures, comparison between villages revealed a significant village effect only between the villages of Djilakh vs Bicole. Likewise, for the Mud/Grass building type, the IRS residual efficacy was significantly different for the localities of Toucar Nganem vs Bicole. In fact, although the mosquitoes' mortality rate was lower in Bicole during the first month post-spraying, the sprayed walls in the village of Bicole kept their residual efficacy longer than those in the other villages. For the other type of construction, the time post-spraying was the sole parameter having a significant effect on the difference of the persistence residual efficacy of IRS (Table 3).

4.3. The effect of sprayers qualification on the residual efficacy of the IRS in 2014

Whatever the building type, the quality of sprays was affected by the level of qualification of the sprayers team and within the locally hired agent between the two campaigns (Figs. 2 and 3). Indeed, the professional team formed by the agent of the National Hygiene service performed a better spraying operation than the local community agents. However, the community agents spraying skill has improved during the second IRS campaign in 2014 (Figs. 2 and 3).

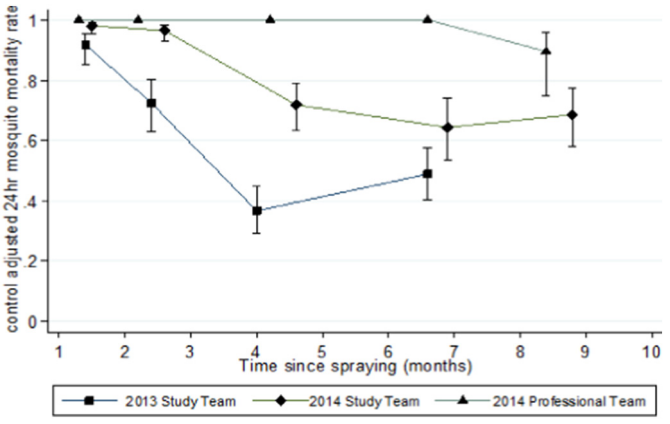

Fig. 2. Spray quality of professional vs local agents over the time for Cement-Zinc building type (Tests carried out with female of a susceptible laboratory-reared *An. coluzzii* strain).

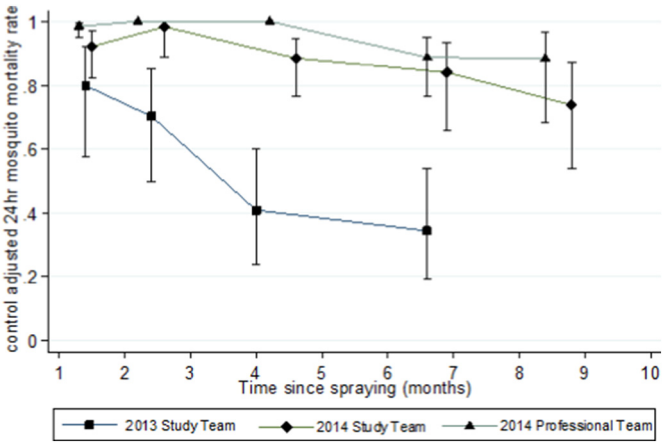

Fig. 3. Spray quality of professional vs local agents over the time for Mud-Straw building type (Tests carried out with female of a susceptible laboratory-reared *An. coluzzii* strain).

5. Discussion

In the context of a nationwide decrease of malaria incidence in Senegal thanks to the scale-up of effective anti-malaria interventions, the country malaria strategic plan has been updated (PNLP, 2016). Indeed, due to the persistence of malaria mainly in hotspot area, the control method such as IRS becomes more targeted to identified hotspots. Therefore, several pilot studies, including this, have been undertaken to test the feasibility of malaria elimination in hotspots villages in the Central West Senegal with targeted IRS using the pirimiphos-methyl micro-encapsulated formulation (Actellic®300CS).

Overall, the spray quality and persistence were affected by the structure wall nature and sprayers skills showing a spatial and temporal variation over the study area, months post-spraying and between the two years of IRS campaigns. Indeed, the main observation was that the community agent displayed weaker competencies for the implementation of the spraying operation than the professional of the National Hygiene Service agents highly skilled on such an activity they perform on routine base. However, an improvement has been noticed in community agent over the years.

One of the limitations in the implement of the first IRS campaign in 2013 was insufficiency in the training process of community workers and supervisors due to the lack of time before the transmission season. The community agents training has been improved during the refreshment training in the beginning of the 2014 IRS campaign. Moreover, several constraints have been noticed during the implementation of the 2013 IRS campaign, including the delay of the start of the project due to a late shipping of insecticide and spraying materials as well as the rapid shortage of the insecticide only after 15 days from the official lunch of the campaign. The above issues are likely to have led to the low performance of spraying operations yielding a lower coverage rate than planned as well as the observed low residual efficacy. In fact, increasing the targeted communities' awareness and the quality of the training of spray operators are key points for reaching high IRS quality and a better effectiveness of interventions against malaria transmission in an IRS campaign (Louis et al., 1992).

Therefore, the training of field agents have been reinforced and the local agents have been supported by the highly experienced agent of the National Hygiene Service resulting to an increased the quality of sprayers' supervision and good spraying quality. In addition, the planning of training and the shipment of sufficient insecticide and IRS material have been improved leading to an overall improvement of the residual efficacy of IRS with the Actellic®300 CS lasting for 7 to 9 months.

The correct implementation of IRS with correct treatment concertation of the Actellic®300 CS held an effective protective effect against malaria vectors as previously shown in Benin, Ethiopia, Gambia, India, Senegal, South Africa, Tanzania, Vietnam and Zambia where the residual efficacy of spraying with 1 g ma/m^2 of the active ingredient lasted up 9 months (WHO/HQ, 2013; Rowland et al., 2013; Darriet et al., 2002). Moreover, two formulations of the pirimiphos-methyl, including the 300 CS [encapsulated] used here, have been already tested in experimental huts located in the region of Thies in Senegal. Based on the good performance of the 300 CS formulation of the Actelic (>80%) for up to 11 months, it has been retained by the NMCP for use in the national control programme where the targeted vector population were found susceptible to organophosphates (Konate et al., 2013). Therefore, the low persistence observed during the first IRS campaign could be related to poor quality of the application of the insecticide by the undertrained operators. However, other factors such as the porous or compact nature of the treated surfaces could not be excluded (Hadaway and Barlow, 1963a). These hypotheses are reinforced with the improvement of the residual activity of IRS during the second campaign, certainly due to a better application quality as a result of the refreshment training of the local operators and the support from more skilled agents. The support obtained from the National Hygiene Service consisted to providing experimented trainers; who in addition to the training provided have shown to the local communities' agents their responsibility for the success of operations, resulting in better intake of recommendation and compliance with the instructions given to them.

No significant effect of the type of building type has been noticed in the present study. The quality of insecticide intake by treated surface could be influenced by the nature of wall as reported in The Gambia, where spaying with the pirimiphos-methyl CS formulation persisted for at least five months in IRS villages (Tangena et al., 2013). Furthermore, this study showed a faster decrease of IRS residual effect on cement substrates compared to the banco ones, probably related to the paint coated on the walls that may have affected the insecticide intake by cement wall. Whereas, the contrary was reported elsewhere confirming that differential performance of organophosphate and carbamate treatments on different types of surfaces, but with a rapid loss of efficacy on various types of mud, while on less porous surfaces such as wood and cement highest levels of mortality were recorded for several months (Hadaway and Barlow, 1963a). More recently, tests performed on painted cement wall in Ghana and Mozambique, revealed high performance of the Actelic encapsulated formulation (CS) which remained effective on the treated materials for a relatively long period (Fuseini et al., 2011). In Zambia, a small-scale trial using the pirimiphos-methyl 300 CS applied at 1 g ai/m^2 in two districts, showed that the good residual efficacy of treatment inducing over 80% of mortality tested population for 6–8 months on cement surfaces against 6–7 months on the mud surfaces (Chanda et al., 2013; Hadaway and Barlow, 1963b).

6. Conclusion

This study showed that the quality of training and supervision of IRS play a key role in quality and the residual efficacy of IRS campaign. In fact, despite the proven residual effect of the Actellic®300 CS formulation, its persistency has been affected by operators' skills. However, a good planning and implementation of IRS campaign ensure the achievement of the expected residual efficacy of the Actellic®300 CS formulation. Therefore, in the context of the widespread of pyrethroid resistance and low persistence of some formulation of carbamate, the Actellic®300 CS could be used as an alternative chemical for both the management of insecticide resistance and plays thus an important role in the context of vector control for malaria elimination in the hotspots in West Central and other parts of Senegal.

Abbreviations

IRS	Indoor Residual Spraying
SMC	Seasonal Malaria Chemoprevention
ITNs	insecticide-treated nets
ACT	artemisinin-based combination therapy
LLINs	Long Lasting Insecticide-treated Nets
RDT	rapid diagnostic test
NMCP	National Malaria Control Programme
PMI	President's Malaria Initiative
WHO	World Health Organisation
NHS	National Hygiene Service
IRR	Incidence Rate Ratio

Authors' contributions

BC, OS, LK, PM, OG and OF designed the study. OF, OS, LK, BC and OG supervised the study. OS carried out the field collections and performed the experiments with AD, AN. OS, EAN, PM, FT, EB and AD contributed toward data analysis. OS, EAN and PM analysed the data and wrote the manuscript. All authors read, and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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Consent for publication

Not applicable.

Ethics approval and consent to participate

This study was approved by the National Ethics Committee of Senegal.

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